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SYSTEMS AND METHODS FOR HIGH-DYNAMIC RANGE IMAGES

Abstract

A system, method, and computer program product are provided for high-dynamic range images. In use, a first pixel attribute of a first pixel is received and a second pixel attribute of a second pixel is received. Next, a scalar based on the first pixel attribute and the second pixel attribute is identified. Finally, the first pixel and the second pixel are blended, based on the scalar, wherein the first pixel is brighter than the second pixel. Additional systems, methods, and computer program products are also presented.

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Background/Summary

RELATED APPLICATIONS [0001] The present application is a continuation of, and claims priority to, U.S. patent application Ser. No. 18/646,581, entitled “IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME,” filed Apr. 25, 2024, which in turn is a continuation of, and claims priority to U.S. patent application Ser. No. 17/321,166 (DUELP019D), now U.S. Pat. No. 12,003,864, entitled “IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME,” filed May 14, 2021, which in turn is a continuation of, and claims priority to U.S. patent application Ser. No. 16/857,016 (DUELP019C), now U.S. Pat. No. 11,025,831, entitled “IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME,” filed Apr. 23, 2020, which in turn is a continuation of, and claims priority to U.S. patent application Ser. No. 16/519,244 (DUELP019B), now U.S. Pat. No. 10,652,478, entitled “IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME,” filed Jul. 23, 2019, which in turn is a continuation of, and claims priority to U.S. patent application Ser. No. 15/891,251 (DUELP019A), now U.S. Pat. No. 10,382,702, entitled “IMAGE SENSOR

APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME," filed Feb. 7, 2018, which in turn, is a continuation of, and claims priority to U.S. patent application Ser. No. 14/823,993 (DUELP019), now U.S. Pat. No. 9,918,017, entitled "IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME," filed Aug. 11, 2015. The foregoing applications and/or patents are herein incorporated by reference in its entirety for all purposes. [0002] As noted above, the present application is a continuation of U.S. patent application Ser. No. 18/646,581, and claims priority thereto. No new subject matter has been added to the present application. While certain material was previously incorporated by reference in the parent application and is now expressly included in full herein, such express inclusion does not constitute the addition of new subject matter. Accordingly, this application is properly filed as a continuation under 35 U.S.C. § 120. [0003] U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/534,079 (DUELP007), now U.S. Pat. No. 9,137,455, entitled "IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING MULTIPLE EXPOSURES WITH ZERO INTERFRAME TIME," filed Nov. 5, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0004] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/568,045 (DUELP003A), now U.S. Pat. No. 9,406,147, entitled "COLOR BALANCE IN DIGITAL PHOTOGRAPHY," filed on Dec. 11, 2014, which is a continuation of U.S. patent application Ser. No. 13/573,252 (DUELP003), now U.S. Pat. No. 8,976,264, entitled "COLOR BALANCE IN DIGITAL PHOTOGRAPHY," filed Sep. 4, 2012. The foregoing applications and/or patents are herein incorporated by reference in their entirety for all purposes. [0005] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/534,068 (DUELP005), now U.S. Pat. No. 9,167,174, entitled "SYSTEMS AND METHODS FOR HIGH-DYNAMIC RANGE IMAGES," filed on Nov. 5, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0006] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/534,089 (DUELP008), now U.S. Pat. No. 9,167,169, entitled "IMAGE SENSOR APPARATUS AND METHOD FOR SIMULTANEOUSLY CAPTURING MULTIPLE IMAGES," filed Nov. 5, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0007] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/535,274 (DUELP009), now U.S. Pat. No. 9,154,708, entitled "IMAGE SENSOR APPARATUS AND METHOD FOR SIMULTANEOUSLY CAPTURING FLASH AND AMBIENT ILLUMINATED IMAGES," filed Nov. 6, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0008] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/535,279 (DUELP010), now U.S. Pat. No. 9,179,085, entitled "IMAGE SENSOR APPARATUS AND METHOD FOR OBTAINING LOW-NOISE, HIGH-SPEED CAPTURES OF A PHOTOGRAPHIC SCENE" filed Nov. 6, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0009] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/535,282 (DUELP011), now U.S. Pat. No. 9,179,062, entitled "SYSTEMS AND METHODS FOR PERFORMING OPERATIONS ON PIXEL DATA" filed Nov. 6, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0010] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/536,524 (DUELP012), now U.S. Pat. No. 9,160,936, entitled "SYSTEMS AND METHODS FOR GENERATING A HIGH-DYNAMIC RANGE (HDR) PIXEL STREAM," filed Nov. 7, 2014. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0011] Additionally, U.S. patent application Ser. No. 14/823,993 is a continuation-in-part of, and claims priority to U.S. patent application Ser. No. 14/702,549 (DUELP017), now U.S. Pat. No. 9,531,961, entitled "SYSTEMS AND METHODS FOR GENERATING A DIGITAL IMAGE USING SEPARATE COLOR AND INTENSITY DATA," filed May 1, 2015. The foregoing application and/or patent is herein incorporated by reference in its entirety for all purposes. [0012] This application is related to the following which is incorporated herein by reference in its entirety for all purposes: U.S. patent application Ser. No. 13/999,678 (DUELP022), now U.S. Pat. No. 9,807,322, filed Mar. 14, 2014, entitled "SYSTEMS AND METHODS FOR DIGITAL IMAGE SENSOR."

FIELD OF THE INVENTION

[0013] The present invention relates to digital photographic systems, and more particularly to systems and methods for high-dynamic range images.

BACKGROUND

[0014] Traditional digital photography systems are inherently limited by the dynamic range of a capturing image sensor. One solution to such limitation is the use of high dynamic-range (HDR) photography. HDR photography involves capturing multiple exposures of a same scene, where each of the exposures is metered differently, and then merging the multiple captures to create an image with a larger dynamic range.

SUMMARY

[0015] A system, method, and computer program product are provided for high-dynamic range images. In use, a first pixel attribute of a first pixel is received and a second pixel attribute of a second pixel is received. Next, a scalar based on the first pixel attribute and the second pixel attribute is identified. Finally, the first pixel and the second pixel are blended, based on the scalar, wherein the first pixel is brighter than the second pixel. Additional systems, methods, and computer program products are also presented.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** illustrates an exemplary system for outputting a blended brighter and a darker pixel, in accordance with one possible embodiment.

[0017] FIG. **2** illustrates a method for blending a brighter pixel and a darker pixel, in accordance with one embodiment.

[0018] FIG. **3**A illustrates a digital photographic system, in accordance with an embodiment.

[0019] FIG. **3**B illustrates a processor complex within the digital photographic system, according to one embodiment.

[0020] FIG. **3**C illustrates a digital camera, in accordance with an embodiment.

[0021] FIG. **3**D illustrates a wireless mobile device, in accordance with another embodiment.

[0022] FIG. **3**E illustrates a camera module configured to sample an image, according to one embodiment.

[0023] FIG. **3**F illustrates a camera module configured to sample an image, according to another embodiment.

[0024] FIG. **3**G illustrates a camera module in communication with an application processor, in accordance with an embodiment.

[0025] FIG. **4** illustrates a network service system, in accordance with another embodiment.

[0026] FIG. **5** illustrates a system for outputting a HDR pixel, in accordance with another embodiment.

[0027] FIG. **6** illustrates a method for generating a HDR pixel based on combined HDR pixel and an effects function, in accordance with another embodiment.

[0028] FIG. **7** illustrates a system for outputting a HDR pixel, in accordance with another embodiment.
[0029] FIG. **8** illustrates a method for generating a HDR pixel based on combined HDR pixel and an effects function, in accordance with another embodiment.
[0030] FIG. **9** illustrates a method for generating a HDR pixel based on combined HDR pixel and an effects function, in accordance with another embodiment.
[0031] FIG. **10**A illustrates a surface diagram, in accordance with another embodiment.
[0032] FIG. **10**B illustrates a surface diagram, in accordance with another embodiment.
[0033] FIG. **11**A illustrates a surface diagram, in accordance with another embodiment.
[0034] FIG. **11**B illustrates a surface diagram, in accordance with another embodiment.
[0035] FIG. **12** illustrates a levels mapping diagram, in accordance with another embodiment.
[0036] FIG. **13** illustrates a levels mapping diagram, in accordance with another embodiment.
[0037] FIG. **14** illustrates an image synthesis operation, in accordance with another embodiment.
[0038] FIG. **15** illustrates a user interface (UI) system for generating a combined image, in accordance with another embodiment.
[0039] FIG. **16** is a flow diagram of method for generating a combined image, in accordance with another embodiment.
[0040] FIG. **17**A illustrates a user interface (UI) system for adjusting a white point and a black point, in accordance with another embodiment.
[0041] FIG. **17**B illustrates a user interface (UI) system for adjusting a white point, median point, and a black point, in accordance with another embodiment.
[0042] FIG. **18-1** illustrates an exemplary system for obtaining multiple exposures with zero interframe time, in accordance with one possible embodiment.
[0043] FIG. **18-2** illustrates an exemplary method carried out for obtaining multiple exposures with zero interframe time, in accordance with one embodiment.
[0044] FIGS. **18-3**A-**18-3**E illustrate systems for converting optical scene information to an electronic representation of a photographic scene, in accordance with other embodiments.
[0045] FIG. **18-4** illustrates a system for converting analog pixel data to digital pixel data, in accordance with an embodiment.
[0046] FIG. **18-5** illustrates a system for converting analog pixel data of an analog signal to digital pixel data, in accordance with another embodiment.
[0047] FIG. **18-6** illustrates various timing configurations for amplifying analog signals, in accordance with other embodiments.
[0048] FIG. **18-7** illustrates a system for converting in parallel analog pixel data to multiple signals of digital pixel data, in accordance with one embodiment.
[0049] FIG. **18-8** illustrates a message sequence for generating a combined image utilizing a network, according to another embodiment.
[0050] FIG. **19-1** illustrates an exemplary system for simultaneously capturing multiple images.
[0051] FIG. **19-2** illustrates an exemplary method carried out for simultaneously capturing multiple images.
[0052] FIG. **19-3** illustrates a circuit diagram for a photosensitive cell, according to one embodiment.
[0053] FIG. **19-4** illustrates a system for converting analog pixel data of more than one analog signal to digital pixel data, in accordance with another embodiment.
[0054] FIG. **20-1** illustrates an exemplary system for simultaneously capturing flash and ambient illuminated images, in accordance with an embodiment.
[0055] FIG. **20-2** illustrates an exemplary method carried out for simultaneously capturing flash and ambient illuminated images, in accordance with an embodiment.
[0056] FIG. **20-3** illustrates a system for converting analog pixel data of more than one analog signal to digital pixel data, in accordance with another embodiment.

[0057] FIG. **20-4**A illustrates a user interface system for generating a combined image, according to an embodiment.
[0058] FIG. **20-4**B illustrates another user interface system for generating a combined image, according to one embodiment.
[0059] FIG. **20-4**C illustrates user interface (UI) systems displaying combined images with differing levels of strobe exposure, according to an embodiment.
[0060] FIG. **21-1** illustrates an exemplary system for obtaining low-noise, high-speed captures of a photographic scene, in accordance with one embodiment.
[0061] FIG. **21-2** illustrates an exemplary system for obtaining low-noise, high-speed captures of a photographic scene, in accordance with another embodiment.
[0062] FIG. **21-3**A illustrates a circuit diagram for a photosensitive cell, according to one embodiment.
[0063] FIG. **21-3**B illustrates a circuit diagram for another photosensitive cell, according to another embodiment.
[0064] FIG. **21-3**C illustrates a circuit diagram for a plurality of communicatively coupled photosensitive cells, according to yet another embodiment.
[0065] FIG. **21-4** illustrates implementations of different analog storage planes, in accordance with another embodiment.
[0066] FIG. **21-5** illustrates a system for converting analog pixel data of an analog signal to digital pixel data, in accordance with another embodiment.
[0067] FIG. **22-1**A illustrates a first data flow process for generating a blended image based on at least an ambient image and a strobe image, according to one embodiment of the present invention;
[0068] FIG. **22-1**B illustrates a second data flow process for generating a blended image based on at least an ambient image and a strobe image, according to one embodiment of the present invention;
[0069] FIG. **22-1**C illustrates a third data flow process for generating a blended image based on at least an ambient image and a strobe image, according to one embodiment of the present invention;
[0070] FIG. **22-1**D illustrates a fourth data flow process for generating a blended image based on at least an ambient image and a strobe image, according to one embodiment of the present invention;
[0071] FIG. **22-2**A illustrates an image blend operation for blending a strobe image with an ambient image to generate a blended image, according to one embodiment of the present invention;
[0072] FIG. **22-2**B illustrates a blend function for blending pixels associated with a strobe image and an ambient image, according to one embodiment of the present invention;
[0073] FIG. **22-2**C illustrates a blend surface for blending two pixels, according to one embodiment of the present invention;
[0074] FIG. **22-2**D illustrates a blend surface for blending two pixels, according to another embodiment of the present invention;
[0075] FIG. **22-2**E illustrates an image blend operation for blending a strobe image with an ambient image to generate a blended image, according to one embodiment of the present invention;
[0076] FIG. **22-3**A illustrates a patch-level analysis process for generating a patch correction array, according to one embodiment of the present invention;
[0077] FIG. **22-3**B illustrates a frame-level analysis process for generating frame-level characterization data, according to one embodiment of the present invention;
[0078] FIG. **22-4**A illustrates a data flow process for correcting strobe pixel color, according to one embodiment of the present invention;
[0079] FIG. **22-4**B illustrates a chromatic attractor function, according to one embodiment of the present invention;
[0080] FIG. **22-5** is a flow diagram of method steps for generating an adjusted digital photograph, according to one embodiment of the present invention;
[0081] FIG. **22-6**A is a flow diagram of method steps for blending a strobe image with an ambient

image to generate a blended image, according to a first embodiment of the present invention;
[0082] FIG. **22-6**B is a flow diagram of method steps for blending a strobe image with an ambient image to generate a blended image, according to a second embodiment of the present invention;
[0083] FIG. **22-7**A is a flow diagram of method steps for blending a strobe image with an ambient image to generate a blended image, according to a third embodiment of the present invention;
[0084] FIG. **22-7**B is a flow diagram of method steps for blending a strobe image with an ambient image to generate a blended image, according to a fourth embodiment of the present invention;
[0085] FIG. **23-1** illustrates an exemplary method for generating a high dynamic range (HDR) pixel stream, in accordance with an embodiment.
[0086] FIG. **23-2** illustrates a system for generating a HDR pixel stream, in accordance with another embodiment.
[0087] FIG. **23-3** illustrates a system for receiving a pixel stream and outputting a HDR pixel stream, in accordance with another embodiment.
[0088] FIG. **24-1**A illustrates a flow chart of a method for generating an image stack comprising two or more images of a photographic scene, in accordance with one embodiment;
[0089] FIG. **24-1**B illustrates a flow chart of a method for generating an image stack comprising an ambient image and a strobe image of a photographic scene, in accordance with one embodiment;
[0090] FIG. **24-2** illustrates a block diagram of image sensor, according to one embodiment of the present disclosure;
[0091] FIG. **24-3** is a circuit diagram for a photo-sensitive cell within a pixel implemented using complementary-symmetry metal-oxide semiconductor devices, according to one embodiment;
[0092] FIG. **24-4**A is a circuit diagram for a first photo-sensitive cell, according to one embodiment;
[0093] FIG. **24-4**B is a circuit diagram for a second photo-sensitive cell, according to one embodiment;
[0094] FIG. **24-4**C is a circuit diagram for a third photo-sensitive cell, according to one embodiment;
[0095] FIG. **24-4**D depicts exemplary physical layout for a pixel comprising four photo-sensitive cells, according to one embodiment;
[0096] FIG. **24-5**A illustrates exemplary timing for controlling cells within a pixel array to sequentially capture an ambient image and a strobe image illuminated by a strobe unit, according to one embodiment of the present disclosure;
[0097] FIG. **24-5**B illustrates exemplary timing for controlling cells within a pixel array to concurrently capture an ambient image and an image illuminated by a strobe unit, according to one embodiment of the present disclosure;
[0098] FIG. **24-5**C illustrates exemplary timing for controlling cells within a pixel array to concurrently capture two ambient images having different exposures, according to one embodiment of the present disclosure;
[0099] FIG. **24-5**D illustrates exemplary timing for controlling cells within a pixel array to concurrently capture two ambient images having different exposures, according to one embodiment of the present disclosure;
[0100] FIG. **24-5**E illustrates exemplary timing for controlling cells within a pixel array to concurrently capture four ambient images, each having different exposure times, according to one embodiment of the present disclosure; and
[0101] FIG. **24-5**F illustrates exemplary timing for controlling cells within a pixel array to concurrently capture three ambient images having different exposures and subsequently capture a strobe image, according to one embodiment of the present disclosure.
[0102] FIG. **25-1** illustrates an exemplary flow diagram for performing operations on pixel data utilizing a hardwired element, in accordance with one possible embodiment.
[0103] FIG. **25-2** illustrates an exemplary method carried out for performing operations on pixel

data utilizing a hardwired element, in accordance with one embodiment.
[0104] FIG. **25-3** illustrates a camera system in communication with an application processor, in accordance with an embodiment.
[0105] FIG. **25-4** illustrates a camera system for processing one or more points of interest, in accordance with an embodiment.
[0106] FIG. **25-5** illustrates a camera system for adjusting white balance, in accordance with an embodiment.
[0107] FIG. **25-6** illustrates a frequency method for focusing, in accordance with an embodiment.
[0108] FIG. **26-1** illustrates a flow chart of a method **26-100** for generating a digital image, in accordance with one embodiment;
[0109] FIG. **26-2** illustrates an image processing subsystem configured to implement the method **26-100** of FIG. **26-1**, in accordance with one embodiment;
[0110] FIG. **26-3**A illustrates a circuit diagram for a photosensitive cell, in accordance with one possible embodiment;
[0111] FIG. **26-3**B illustrates a circuit diagram for a photosensitive cell, in accordance with another possible embodiment;
[0112] FIG. **26-4**A illustrates a configuration of the camera module, in accordance with one embodiment;
[0113] FIG. **26-4**B illustrates a configuration of the camera module, in accordance with another embodiment;
[0114] FIG. **26-4**C illustrates a configuration of the camera module, in accordance with yet another embodiment;
[0115] FIG. **26-5** illustrates a flow chart of a method for generating a digital image, in accordance with one embodiment;
[0116] FIG. **26-6**A illustrates a viewer application configured to generate a resulting image based two image sets, in accordance with one embodiment;
[0117] FIG. **26-6**B illustrates an exemplary user interface associated with the viewer application **26-910** of FIG. **26-6**A, in accordance with one embodiment;
[0118] FIG. **26-6**C illustrates a system for generating a resulting image from a high dynamic range chrominance image and a high dynamic range luminance image, in accordance with one embodiment.

DETAILED DESCRIPTION

[0119] FIG. **1** illustrates an exemplary system **100** for outputting a blended brighter and a darker pixel, in accordance with one possible embodiment. As an option, the system **100** may be implemented in the context of any of the Figures. Of course, however, the system **100** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0120] As shown, the system **100** includes a first pixel **102** and a second pixel **104**. In one embodiment, the first pixel may be associated with a brighter pixel, and the second pixel may be associated with a darker pixel. In the context of the present description, a brighter pixel includes any pixel that is brighter than a corresponding darker pixel, and a darker pixel includes any pixel that is darker than a corresponding brighter pixel. A brighter pixel may be associated with an image having brighter overall exposure, and a corresponding darker pixel may be associated with an image having a darker overall exposure. In various embodiments, brighter and darker pixels may be computed by combining other corresponding pixels based on intensity, exposure, color attributes, saturation, and/or any other image or pixel parameter.
[0121] In one embodiment, a brighter pixel and a darker pixel may be associated with a brighter pixel attribute and a darker pixel attribute, respectively. In various embodiments, a pixel attribute (e.g. for a brighter pixel attribute, for a darker pixel attribute, etc.) may include an intensity, a saturation, a hue, a color space value (e.g. EGB, Y CbCr, YUV, etc.), a brightness, an RGB color, a

luminance, a chrominance, and/or any other feature which may be associated with a pixel in some manner.

[0122] Additionally, the first pixel **102** and the second pixel **104** are inputs to a blend process **106**. In one embodiment, the blending may be based on one or more features associated with the pixels. For example, blending may include a spatial positioning feature wherein the pixel of the brighter pixel is aligned with a corresponding pixel of the darker pixel. Of course, any other relevant techniques known in the art may be used to align corresponding pixels on more than one image.

[0123] In other embodiments, various techniques to blend may be used, including taking an average of two or more pixel points, summing and normalizing a color attribute associated with each pixel point (e.g. a summation of a red/green/blue component in a RGB color space, etc.), determining a RGB (or any color space) vector length which may then be normalized, using an average pixel point in combination with a brighter pixel or a darker pixel, and/or using any other combination to blend two or more pixel points. In one embodiment, blending may occur independent of any color values or color spaces. In another embodiment, blending may include mixing two or more pixel points. In a specific embodiment, blending may include an OpenGL (or any vector rendering application) Mix operation whereby the operation linearly interpolates between two input values.

[0124] In one embodiment, blending may occur automatically or may be based on user input. For example, in some embodiments, the blending may occur automatically based on one or more set targets, including, for example, a set exposure point, a set focus value, a set temperature (e.g. Kelvin scale, etc.), a predetermined white point value, a predetermined color saturation value, a predetermined normalizing value (e.g. for color space characteristics, etc.), a predetermined levels value, a predetermined curves value, a set black point, a set white point, a set median value point, and/or any other feature of the pixel or image which may be used as a basis for blending. In other embodiments, features associated with the camera may be used as a basis for determining one or more automatic values. For example, a camera may include metadata associated with the pixels, including the ISO value, an exposure value, an aperture value, a histogram distribution, a geo positioning coordinate, an identification of the camera, an identification of the lens, an identification of the user of the camera, the time of day, and/or any other value which may be associated with the camera.

[0125] In one embodiment, the metadata associated with the pixels may be used to set one or more automatic points for automatically blending.

[0126] In one embodiment, such automatic features may be inputted or based, at least in part, on cloud-based input or feedback. For example, a user may develop a set of batch rules or a package of image settings which should be applied to future images. Such settings can be saved to the cloud and/or to any other memory device which can subsequently be accessed by the camera device or module. As an example, a user may use a mobile device for taking and editing photos. Based on such past actions taken (e.g. with respect to editing the pixels or images, etc.), the user may save such actions as a package to be used for future images or pixels received. In other embodiments, the mobile device may recognize and track such actions taken by the user and may prompt the user to save the actions as a package to be applied for future received images or pixels.

[0127] In other embodiments, a package of actions or settings may also be associated with third party users. For example, such packages may be received from an online repository (e.g. associated with users on a photo sharing site, etc.), or may be transferred device-to-device (e.g. Bluetooth, NFC, Wifi, Wifi-direct, etc.). In one embodiment, a package of actions or settings may be device specific. For example, a specific device may be known to overexpose images or tint images and the package of actions or settings may be used to correct a deficiency associated with the device, camera, or lens. In other embodiments, known settings or actions may be improved upon. For example, the user may wish to create a black and white to mimic an Ansel Adams type photograph. A collection of settings or actions may be applied which is based on the specific device receiving the pixels or images (e.g. correct for deficiencies in the device, etc.), feedback from the community on how to achieve the best looking Ansel Adams look (e.g. cloud based feedback, etc.), and/or any other information which may be used to create the Ansel Adams type photograph.

[0128] In a separate embodiment, the blending may occur based on user input. For example, a number of user interface elements may be displayed to the user on a display, including an element for controlling overall color of the image (e.g. sepia, graytone, black and white, etc.), a package of target points to create a feel (e.g. a Polaroid feel package would have higher exposure with greater contrast, an intense feel package which would increase the saturation levels, etc.), one or more selective colors of an image (e.g. only display one or more colors such as red, blue, yellow, etc.), a saturation level, an exposure level, an ISO value, a black point, a white point, a levels value, a curves value, and/or any other point which may be associated with the image or pixel. In various embodiments, a user interface element may be used to control multiple values or points (e.g. one sliding element controls a package of settings, etc.), or may also be used to allow the user to control each and every element associated with the image or pixel.

[0129] Of course, in other embodiments, the blending may occur based on one or more automatic settings and on user input. For example, pixels or images may be blended first using one or more automatic settings, after which the user can then modify specific elements associated with the image. In other embodiments, any combination of automatic or manual settings may be applied to the blending.

[0130] In various embodiments, the blending may include mixing one or more pixels. In other embodiments, the blending may be based on a row of pixels (i.e. blending occurs row by row, etc.), by an entire image of pixels (e.g. all rows and columns of pixels, etc.), and/or in any manner associated with the pixels.

[0131] In one embodiment, the blend between two or more pixels may include applying an alpha blend. Of course, in other embodiments, any process for combining two or more pixels may be used to create a final resulting image.

[0132] As shown, after the blend process, an output **108** includes a blended first pixel and a second pixel. In one embodiment, the output may include a blended brighter and darker pixel. Additionally, the first pixel may be brighter than the second pixel.

[0133] In one embodiment, the blending of a brighter pixel and a darker pixel may result in a high dynamic range (HDR) pixel as an output. In other embodiments, the output may include a brighter pixel blended with a medium pixel to provide a first resulting pixel. The brighter pixel may be characterized by a brighter pixel attribute and the medium pixel may be characterized by a medium pixel attribute. The blend operation between the brighter pixel and the medium pixel may be based on a scalar result from a first mix value function that receives the brighter pixel attribute and the medium pixel attribute. In a further embodiment, the output may include a medium pixel blended with a darker pixel to provide a second resulting pixel. The darker pixel may be characterized by a darker pixel attribute. The blend operation between the medium pixel and the darker pixel may be based on a scalar result from a second mix value function that receives the medium pixel attribute and the darker pixel attribute. Further, in one embodiment, a scalar may be identified based on a mix value function that receives as inputs the first (e.g. brighter, etc.) pixel attribute and the second (e.g. darker, etc.) pixel attribute. The scalar may provide a blending weight between two different pixels (e.g. between brighter and medium, or between medium and darker). Lastly, in one embodiment, a mix value function (e.g. the first mix value function and the second mix value function) may include a flat region, a transition region, and a saturation region corresponding to thresholds associated with the inputs.

[0134] In one embodiment, the output may be based on a mix value surface associated with two or more pixels. For example, in one embodiment, a blending may create an intermediary value which is then used to output a final value associated with two or more pixels. In such an embodiment, the intermediary value (e.g. between two or more pixels, etc.) may be used to compute a value associated with a three-dimensional (3D) surface. The resulting pixel may be associated with the value computed using the intermediary value. Of course, in a variety of embodiments, the output may be associated with any type of functions, and any number of dimensions or inputs.

[0135] FIG. **2** illustrates a method **200** for blending a brighter pixel and a darker pixel, in accordance with one embodiment. As an option, the method **200** may be implemented in the context of any of the Figures. Of course, however, the method **200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0136] As shown, a first pixel attribute of a first pixel is received. See operation **202**. Additionally, a second pixel attribute of a second pixel is received. See operation **204**. In one embodiment, the first pixel attribute may correspond with a brighter pixel attribute, the first pixel may correspond with a brighter pixel, the second pixel attribute may correspond with a darker pixel attribute, and the second pixel may correspond with a darker pixel.

[0137] In one embodiment, a brighter pixel attribute and a darker pixel attribute each may include an intensity. In one embodiment, the intensity may correspond to a first value of a numeric range (e.g. 0.0 to 1.0) for the first pixel, and a second value of the numeric range for the second pixel. In other embodiments, a first (e.g. brighter, etc.) pixel attribute and a second (e.g. darker, etc.) pixel attribute each may include a saturation, a hue, a color space value (e.g. EGB, Y CbCr, Y UV, etc.), a brightness, hue, an RGB color, a luminance, a chrominance, and/or any other feature which may be associated with a pixel in some manner.

[0138] In another embodiment, a medium pixel attribute of a medium pixel that may be darker than a brighter pixel and brighter than a darker pixel, may be received. In another embodiment, a dark exposure parameter and a bright exposure parameter may be estimated, wherein the bright exposure parameter may be used for receiving the first (e.g. brighter, etc.) pixel attribute of the first (e.g. brighter, etc.) pixel, and the second (e.g. dark, etc.) exposure parameter may be used for receiving the second (e.g. darker, etc.) pixel attribute of the darker pixel. Further, in another embodiment, the dark exposure parameter and the bright exposure parameter may be associated with an exposure time. Still yet, in one embodiment, a medium exposure parameter may be estimated, wherein the medium exposure parameter is used for receiving a medium pixel attribute of a medium pixel.

[0139] In an additional embodiment, a medium pixel attribute of a medium pixel may be received, wherein a brighter pixel is associated with a first value, a darker pixel is associated with a second value, and a medium pixel is associated with a third value, the third value being in between the first value and the second value. Additionally, a first resulting pixel may include a first HDR pixel, and a second resulting pixel may include a second HDR pixel, such that the combined pixel may be generated by combining the first HDR pixel and the second HDR pixel based on a predetermined function to generate the combined pixel which may include a third HDR pixel.

[0140] As shown, a scalar is identified based on the first pixel attribute and the second pixel attribute. See operation **206**.

[0141] In various embodiments, the scalar may be identified by generating, selecting, interpolating, and/or any other operation which may result in a scalar. In a further embodiment, the scalar may be identified utilizing one or more polynomials.

[0142] In one embodiment, a first one of the polynomials may have a first order that may be different than a second order of a second one of the polynomials. In another embodiment, a first polynomial of the plurality of polynomials may be a function of the first (e.g. brighter, etc.) pixel attribute and a second polynomial of the plurality of polynomials may be a function of the second (e.g. darker, etc.) pixel attribute. Still yet, in another embodiment, a first one of the polynomials may be a function of a brighter pixel attribute and may have a first order that may be less than a second order of a second one of the polynomials that may be a function of the darker pixel attribute. Additionally, in one embodiment, the first polynomial may be at least one of a higher order, an equal order, or a lower order relative to the second polynomial.

[0143] As shown, blending the first pixel and the second pixel may be based on the scalar, wherein the first pixel is brighter than the second pixel. See operation **208**.

[0144] In another embodiment, a scalar may be identified based on either a polynomial of the form z=(1−(1−(1−x){circumflex over ( )}A){circumflex over ( )}B)*(1−(1−y){circumflex over ( )}C){circumflex over ( )}D) or a polynomial of the form z=(1−(1−x){circumflex over ( )}A){circumflex over ( )}B)*(1−(1−y){circumflex over ( )}C){circumflex over ( )}D), where z corresponds to the scalar, x corresponds to the second (e.g. darker, etc.) pixel attribute, y corresponds to the (e.g. brighter, etc.) first pixel attribute, and A, B, C, D correspond to arbitrary constants.

[0145] In one embodiment, the blending of a first (e.g. brighter, etc.) pixel and a second (e.g. darker, etc.) pixel may result in a high dynamic range (HDR) pixel as an output. In other embodiments, the blending may include identifying a first scalar based on the brighter pixel attribute and the medium pixel attribute, the first scalar being used for blending the brighter pixel and the medium pixel to provide a first resulting pixel. Additionally, in one embodiment, a second scalar based on the medium pixel attribute and the darker pixel attribute, the second scalar being used for blending the medium pixel and the darker pixel to provide a second resulting pixel.

[0146] In one embodiment, a third pixel attribute of a third pixel may be received. Additionally, a second scalar based on the second pixel attribute and the third pixel attribute may be identified. Further, based on the second scalar, the second pixel and the third pixel may be blended. Still yet, a first resulting pixel based on the blending of the first pixel and the second pixel may be generated, and a second resulting pixel based on the blending of the second pixel and the third pixel may be generated.

[0147] Additionally, in various embodiments, the first resulting pixel and the second resulting pixel are combined resulting in a combined pixel. Further, in one embodiment, the combined pixel may be processed based on an input associated with an intensity, a saturation, a hue, a color space value (e.g. RGB, Y CbCr, Y UV, etc.), a brightness, an RGB color, a luminance, a chrominance, and/or any other feature associated with the combined pixel. In a further embodiment, the combined pixel may be processed based on a saturation input or level mapping input.

[0148] In one embodiment, level mapping (or any input) may be performed on at least one pixel subject to the blending. In various embodiments, the level mapping (or any input) may occur in response to user input (e.g. selection of an input and/or a value associated with an input, etc.). Of course, the level mapping (or any input) may occur automatically based on a default value or setting, feedback from a cloud-based source (e.g. cloud source best settings for a photo effect, etc.), feedback from a local device (e.g. based on past photos taken by the user and analyzed the user's system, based on photos taken by others including the user within a set geographic proximity, etc.), and/or any other setting or value associated with an automatic action. In one embodiment, the level mapping may comprise an equalization operation, such as an equalization technique known in the art as contrast limited adaptive histogram equalization (CLAHE).

[0149] In some embodiments, one or more user interfaces and user interface elements may be used to receive a user input. For example, in one embodiment, a first indicia corresponding to at least one brighter point and a second indicia corresponding to at least one brighter point may be displayed, and the user input may be further capable of including manipulation of at least one of the first indicia or the second indicia. Additionally, in one embodiment, third indicia corresponding to at least one medium point may be displayed, and the user input may be further capable of including manipulation of the third indicia.

[0150] In another embodiment, a first one of the polynomials may be a function of a first pixel attribute, and a second one of the polynomials may be a function of a second pixel attribute, and the resulting pixel may be a product of the first and second polynomials. Still yet, in one embodiment, the resulting pixel may be a product of the first and second polynomials in combination with a strength function.

[0151] Additionally, in one embodiment, a strength function and/or coefficient may control a function operating on two or more pixels, including the blending (e.g. mixing, etc.) of the two or more pixels. For example, in various embodiments, the strength function may be used to control the blending of the two or more pixels, including providing no HDR effect (e.g. ev0, etc.), a full HDR effect, or even an amplification of the HDR effect. In this manner, the strength function may control the resulting pixel based on the first and second polynomials.

[0152] In another embodiment, the blending may include at one or more stages in the blending process. For example, in one embodiment, the first polynomial may be based on a single pixel attribute and the second polynomial may be based on a second single pixel attribute, and blending may include taking an average based on the first and second polynomials. In another embodiment, the first polynomial and the second polynomial may be based on an average of many pixel attributes (e.g. multiple exposures, multiple saturations, etc.), and the blending may include taking an average based on the first and second polynomials.

[0153] Of course, in one embodiment, the polynomials may be associated with a surface diagram. For example, in one embodiment, an x value may be associated with a polynomial associated with the first pixel attribute (or a plurality of pixel attributes), and a y value may be associated with a polynomial associated with the second pixel attribute (or a plurality of pixel attributes). Further, in another embodiment, a z value may be associated with a strength function. In one embodiment, a resulting pixel value may be determined by blending the x value and y value based on the z value, as determined by the surface diagram.

[0154] In an alternative embodiment, a resulting pixel value may be selected from a table that embodies the surface diagram. In another embodiment, a first value associated with a first polynomial and a second value associated with a second polynomial may each be used to select a corresponding value from a table, and the two values may be used to interpolate a resulting pixel.

[0155] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.

[0156] FIG. **3**A illustrates a digital photographic system **300**, in accordance with one embodiment. As an option, the digital photographic system **300** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the digital photographic system **300** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0157] As shown, the digital photographic system **300** may include a processor complex **310** coupled to a camera module **330** via an interconnect **334**. In one embodiment, the processor complex **310** is coupled to a strobe unit **336**. The digital photographic system **300** may also include, without limitation, a display unit **312**, a set of input/output devices **314**, non-volatile memory **316**, volatile memory **318**, a wireless unit **340**, and sensor devices **342**, each coupled to the processor complex **310**. In one embodiment, a power management subsystem **320** is configured to generate appropriate power supply voltages for each electrical load element within the digital photographic system **300**. A battery **322** may be configured to supply electrical energy to the power management subsystem **320**. The battery **322** may implement any technically feasible energy storage system, including primary or rechargeable battery technologies. Of course, in other embodiments, additional or fewer features, units, devices, sensors, or subsystems may be included in the system.

[0158] In one embodiment, a strobe unit **336** may be integrated into the digital photographic system **300** and configured to provide strobe illumination **350** during an image sample event performed by the digital photographic system **300**. In another embodiment, a strobe unit **336** may be implemented as an independent device from the digital photographic system **300** and configured to provide strobe illumination **350** during an image sample event performed by the digital

photographic system **300**. The strobe unit **336** may comprise one or more LED devices, a gas-discharge illuminator (e.g. a Xenon strobe device, a Xenon flash lamp, etc.), or any other technically feasible illumination device. In certain embodiments, two or more strobe units are configured to synchronously generate strobe illumination in conjunction with sampling an image. In one embodiment, the strobe unit **336** is controlled through a strobe control signal **338** to either emit the strobe illumination **350** or not emit the strobe illumination **350**. The strobe control signal **338** may be implemented using any technically feasible signal transmission protocol. The strobe control signal **338** may indicate a strobe parameter (e.g. strobe intensity, strobe color, strobe time, etc.), for directing the strobe unit **336** to generate a specified intensity and/or color of the strobe illumination **350**. The strobe control signal **338** may be generated by the processor complex **310**, the camera module **330**, or by any other technically feasible combination thereof. In one embodiment, the strobe control signal **338** is generated by a camera interface unit within the processor complex **310** and transmitted to both the strobe unit **336** and the camera module **330** via the interconnect **334**. In another embodiment, the strobe control signal **338** is generated by the camera module **330** and transmitted to the strobe unit **336** via the interconnect **334**.
[0159] Optical scene information **352**, which may include at least a portion of the strobe illumination **350** reflected from objects in the photographic scene, is focused as an optical image onto an image sensor **332** within the camera module **330**. The image sensor **332** generates an electronic representation of the optical image. The electronic representation comprises spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. The electronic representation is transmitted to the processor complex **310** via the interconnect **334**, which may implement any technically feasible signal transmission protocol.
[0160] In one embodiment, input/output devices **314** may include, without limitation, a capacitive touch input surface, a resistive tablet input surface, one or more buttons, one or more knobs, light-emitting devices, light detecting devices, sound emitting devices, sound detecting devices, or any other technically feasible device for receiving user input and converting the input to electrical signals, or converting electrical signals into a physical signal. In one embodiment, the input/output devices **314** include a capacitive touch input surface coupled to a display unit **312**. A touch entry display system may include the display unit **312** and a capacitive touch input surface, also coupled to processor complex **310**.
[0161] Additionally, in other embodiments, non-volatile (NV) memory **316** is configured to store data when power is interrupted. In one embodiment, the NV memory **316** comprises one or more flash memory devices (e.g. ROM, PCM, FeRAM, FRAM, PRAM, MRAM, NRAM, etc.). The NV memory **316** comprises a non-transitory computer-readable medium, which may be configured to include programming instructions for execution by one or more processing units within the processor complex **310**. The programming instructions may implement, without limitation, an operating system (OS), UI software modules, image processing and storage software modules, one or more input/output devices **314** connected to the processor complex **310**, one or more software modules for sampling an image stack through camera module **330**, one or more software modules for presenting the image stack or one or more synthetic images generated from the image stack through the display unit **312**. As an example, in one embodiment, the programming instructions may also implement one or more software modules for merging images or portions of images within the image stack, aligning at least portions of each image within the image stack, or a combination thereof. In another embodiment, the processor complex **310** may be configured to execute the programming instructions, which may implement one or more software modules operable to create a high dynamic range (HDR) image.
[0162] Still yet, in one embodiment, one or more memory devices comprising the NV memory **316** may be packaged as a module configured to be installed or removed by a user. In one embodiment, volatile memory **318** comprises dynamic random access memory (DRA M) configured to

temporarily store programming instructions, image data such as data associated with an image stack, and the like, accessed during the course of normal operation of the digital photographic system **300**. Of course, the volatile memory may be used in any manner and in association with any other input/output device **314** or sensor device **342** attached to the process complex **310**.

[0163] In one embodiment, sensor devices **342** may include, without limitation, one or more of an accelerometer to detect motion and/or orientation, an electronic gyroscope to detect motion and/or orientation, a magnetic flux detector to detect orientation, a global positioning system (GPS) module to detect geographic position, or any combination thereof. Of course, other sensors, including but not limited to a motion detection sensor, a proximity sensor, an RGB light sensor, a gesture sensor, a 3-D input image sensor, a pressure sensor, and an indoor position sensor, may be integrated as sensor devices. In one embodiment, the sensor devices may be one example of input/output devices **314**.

[0164] Wireless unit **340** may include one or more digital radios configured to send and receive digital data. In particular, the wireless unit **340** may implement wireless standards (e.g. WiFi, Bluetooth, NFC, etc.), and may implement digital cellular telephony standards for data communication (e.g. CDMA, 3G, 4G, LTE, LTE-Advanced, etc.). Of course, any wireless standard or digital cellular telephony standards may be used.

[0165] In one embodiment, the digital photographic system **300** is configured to transmit one or more digital photographs to a network-based (online) or "cloud-based" photographic media service via the wireless unit **340**. The one or more digital photographs may reside within either the NV memory **316** or the volatile memory **318**, or any other memory device associated with the processor complex **310**. In one embodiment, a user may possess credentials to access an online photographic media service and to transmit one or more digital photographs for storage to, retrieval from, and presentation by the online photographic media service. The credentials may be stored or generated within the digital photographic system **300** prior to transmission of the digital photographs. The online photographic media service may comprise a social networking service, photograph sharing service, or any other network-based service that provides storage of digital photographs, processing of digital photographs, transmission of digital photographs, sharing of digital photographs, or any combination thereof. In certain embodiments, one or more digital photographs are generated by the online photographic media service based on image data (e.g. image stack, HDR image stack, image package, etc.) transmitted to servers associated with the online photographic media service. In such embodiments, a user may upload one or more source images from the digital photographic system **300** for processing by the online photographic media service.

[0166] In one embodiment, the digital photographic system **300** comprises at least one instance of a camera module **330**. In another embodiment, the digital photographic system **300** comprises a plurality of camera modules **330**. Such an embodiment may also include at least one strobe unit **336** configured to illuminate a photographic scene, sampled as multiple views by the plurality of camera modules **330**. The plurality of camera modules **330** may be configured to sample a wide angle view (e.g., greater than forty-five degrees of sweep among cameras) to generate a panoramic photograph. In one embodiment, a plurality of camera modules **330** may be configured to sample two or more narrow angle views (e.g., less than forty-five degrees of sweep among cameras) to generate a stereoscopic photograph. In other embodiments, a plurality of camera modules **330** may be configured to generate a 3-D image or to otherwise display a depth perspective (e.g. a z-component, etc.) as shown on the display unit **312** or any other display device.

[0167] In one embodiment, a display unit **312** may be configured to display a two-dimensional array of pixels to form an image for display. The display unit **312** may comprise a liquid-crystal (LCD) display, a light-emitting diode (LED) display, an organic LED display, or any other technically feasible type of display. In certain embodiments, the display unit **312** may be able to display a narrower dynamic range of image intensity values than a complete range of intensity values sampled from a photographic scene, such as within a single HDR image or over a set of two or more images comprising a multiple exposure or HDR image stack. In one embodiment, images comprising an image stack may be merged according to any technically feasible HDR blending technique to generate a synthetic image for display within dynamic range constraints of the display unit **312**. In one embodiment, the limited dynamic range may specify an eight-bit per color channel binary representation of corresponding color intensities. In other embodiments, the limited dynamic range may specify more than eight-bits (e.g., 10 bits, 12 bits, or 14 bits, etc.) per color channel binary representation.

[0168] FIG. **3**B illustrates a processor complex **310** within the digital photographic system **300** of FIG. **3**A, in accordance with one embodiment. As an option, the processor complex **310** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the processor complex **310** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0169] As shown, the processor complex **310** includes a processor subsystem **360** and may include a memory subsystem **362**. In one embodiment, processor complex **310** may comprise a system on a chip (SoC) device that implements processor subsystem **360**, and memory subsystem **362** comprises one or more DRAM devices coupled to the processor subsystem **360**. In another embodiment, the processor complex **310** may comprise a multi-chip module (MCM) encapsulating the SoC device and the one or more DRAM devices comprising the memory subsystem **362**.

[0170] The processor subsystem **360** may include, without limitation, one or more central processing unit (CPU) cores **370**, a memory interface **380**, input/output interfaces unit **384**, and a display interface unit **382**, each coupled to an interconnect **374**. The one or more CPU cores **370** may be configured to execute instructions residing within the memory subsystem **362**, volatile memory **318**, NV memory **316**, or any combination thereof. Each of the one or more CPU cores **370** may be configured to retrieve and store data through interconnect **374** and the memory interface **380**. In one embodiment, each of the one or more CPU cores **370** may include a data cache, and an instruction cache. Additionally, two or more of the CPU cores **370** may share a data cache, an instruction cache, or any combination thereof. In one embodiment, a cache hierarchy is implemented to provide each CPU core **370** with a private cache layer, and a shared cache layer.

[0171] In some embodiments, processor subsystem **360** may include one or more graphics processing unit (GPU) cores **372**. Each GPU core **372** may comprise a plurality of multi-threaded execution units that may be programmed to implement, without limitation, graphics acceleration functions. In various embodiments, the GPU cores **372** may be configured to execute multiple thread programs according to well-known standards (e.g. OpenGL™, WebGL™, OpenCL™, CUDA™, etc.), and/or any other programmable rendering graphic standard. In certain embodiments, at least one GPU core **372** implements at least a portion of a motion estimation function, such as a well-known Harris detector or a well-known Hessian-Laplace detector. Such a motion estimation function may be used at least in part to align images or portions of images within an image stack. For example, in one embodiment, an HDR image may be compiled based on an image stack, where two or more images are first aligned prior to compiling the HDR image.

[0172] As shown, the interconnect **374** is configured to transmit data between and among the memory interface **380**, the display interface unit **382**, the input/output interfaces unit **384**, the CPU cores **370**, and the GPU cores **372**. In various embodiments, the interconnect **374** may implement one or more buses, one or more rings, a cross-bar, a mesh, or any other technically feasible data transmission structure or technique. The memory interface **380** is configured to couple the memory subsystem **362** to the interconnect **374**. The memory interface **380** may also couple NV memory **316**, volatile memory **318**, or any combination thereof to the interconnect **374**. The display interface unit **382** may be configured to couple a display unit **312** to the interconnect **374**. The display interface unit **382** may implement certain frame buffer functions (e.g. frame refresh, etc.). Alternatively, in another embodiment, the display unit **312** may implement certain frame buffer functions (e.g. frame refresh, etc.). The input/output interfaces unit **384** may be configured to

couple various input/output devices to the interconnect **374**.
[0173] In certain embodiments, a camera module **330** is configured to store exposure parameters for sampling each image associated with an image stack. For example, in one embodiment, when directed to sample a photographic scene, the camera module **330** may sample a set of images comprising the image stack according to stored exposure parameters. A software module comprising programming instructions executing within a processor complex **310** may generate and store the exposure parameters prior to directing the camera module **330** to sample the image stack. In other embodiments, the camera module **330** may be used to meter an image or an image stack, and the software module comprising programming instructions executing within a processor complex **310** may generate and store metering parameters prior to directing the camera module **330** to capture the image. Of course, the camera module **330** may be used in any manner in combination with the processor complex **310**.
[0174] In one embodiment, exposure parameters associated with images comprising the image stack may be stored within an exposure parameter data structure that includes exposure parameters for one or more images. In another embodiment, a camera interface unit (not shown in FIG. **3**B) within the processor complex **310** may be configured to read exposure parameters from the exposure parameter data structure and to transmit associated exposure parameters to the camera module **330** in preparation of sampling a photographic scene. After the camera module **330** is configured according to the exposure parameters, the camera interface may direct the camera module **330** to sample the photographic scene; the camera module **330** may then generate a corresponding image stack. The exposure parameter data structure may be stored within the camera interface unit, a memory circuit within the processor complex **310**, volatile memory **318**, NV memory **316**, the camera module **330**, or within any other technically feasible memory circuit. Further, in another embodiment, a software module executing within processor complex **310** may generate and store the exposure parameter data structure.
[0175] FIG. **3**C illustrates a digital camera **302**, in accordance with one embodiment. As an option, the digital camera **302** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the digital camera **302** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0176] In one embodiment, the digital camera **302** may be configured to include a digital photographic system, such as digital photographic system **300** of FIG. **3**A. As shown, the digital camera **302** includes a camera module **330**, which may include optical elements configured to focus optical scene information representing a photographic scene onto an image sensor, which may be configured to convert the optical scene information to an electronic representation of the photographic scene.
[0177] Additionally, the digital camera **302** may include a strobe unit **336**, and may include a shutter release button **315** for triggering a photographic sample event, whereby digital camera **302** samples one or more images comprising the electronic representation. In other embodiments, any other technically feasible shutter release mechanism may trigger the photographic sample event (e.g. such as a timer trigger or remote control trigger, etc.).
[0178] FIG. **3**D illustrates a wireless mobile device **376**, in accordance with one embodiment. As an option, the mobile device **376** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the mobile device **376** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0179] In one embodiment, the mobile device **376** may be configured to include a digital photographic system (e.g. such as digital photographic system **300** of FIG. **3**A), which is configured to sample a photographic scene. In various embodiments, a camera module **330** may include optical elements configured to focus optical scene information representing the photographic scene onto an image sensor, which may be configured to convert the optical scene

information to an electronic representation of the photographic scene. Further, a shutter release command may be generated through any technically feasible mechanism, such as a virtual button, which may be activated by a touch gesture on a touch entry display system comprising display unit **312**, or a physical button, which may be located on any face or surface of the mobile device **376**. Of course, in other embodiments, any number of other buttons, external inputs/outputs, or digital inputs/outputs may be included on the mobile device **376**, and which may be used in conjunction with the camera module **330**.

[0180] As shown, in one embodiment, a touch entry display system comprising display unit **312** is disposed on the opposite side of mobile device **376** from camera module **330**. In certain embodiments, the mobile device **376** includes a user-facing camera module **331** and may include a user-facing strobe unit (not shown). Of course, in other embodiments, the mobile device **376** may include any number of user-facing camera modules or rear-facing camera modules, as well as any number of user-facing strobe units or rear-facing strobe units.

[0181] In some embodiments, the digital camera **302** and the mobile device **376** may each generate and store a synthetic image based on an image stack sampled by camera module **330**. The image stack may include one or more images sampled under ambient lighting conditions, one or more images sampled under strobe illumination from strobe unit **336**, or a combination thereof.

[0182] FIG. **3**E illustrates camera module **330**, in accordance with one embodiment. As an option, the camera module **330** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera module **330** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0183] In one embodiment, the camera module **330** may be configured to control strobe unit **336** through strobe control signal **338**. As shown, a lens **390** is configured to focus optical scene information **352** onto image sensor **332** to be sampled. In one embodiment, image sensor **332** advantageously controls detailed timing of the strobe unit **336** though the strobe control signal **338** to reduce inter-sample time between an image sampled with the strobe unit **336** enabled, and an image sampled with the strobe unit **336** disabled. For example, the image sensor **332** may enable the strobe unit **336** to emit strobe illumination **350** less than one microsecond (or any desired length) after image sensor **332** completes an exposure time associated with sampling an ambient image and prior to sampling a strobe image.

[0184] In other embodiments, the strobe illumination **350** may be configured based on a desired one or more target points. For example, in one embodiment, the strobe illumination **350** may light up an object in the foreground, and depending on the length of exposure time, may also light up an object in the background of the image. In one embodiment, once the strobe unit **336** is enabled, the image sensor **332** may then immediately begin exposing a strobe image. The image sensor **332** may thus be able to directly control sampling operations, including enabling and disabling the strobe unit **336** associated with generating an image stack, which may comprise at least one image sampled with the strobe unit **336** disabled, and at least one image sampled with the strobe unit **336** either enabled or disabled. In one embodiment, data comprising the image stack sampled by the image sensor **332** is transmitted via interconnect **334** to a camera interface unit **386** within processor complex **310**. In some embodiments, the camera module **330** may include an image sensor controller, which may be configured to generate the strobe control signal **338** in conjunction with controlling operation of the image sensor **332**.

[0185] FIG. **3**F illustrates a camera module **330**, in accordance with one embodiment. As an option, the camera module **330** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera module **330** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0186] In one embodiment, the camera module **330** may be configured to sample an image based on state information for strobe unit **336**. The state information may include, without limitation, one or more strobe parameters (e.g. strobe intensity, strobe color, strobe time, etc.), for directing the strobe unit **336** to generate a specified intensity and/or color of the strobe illumination **350**. In one embodiment, commands for configuring the state information associated with the strobe unit **336** may be transmitted through a strobe control signal **338**, which may be monitored by the camera module **330** to detect when the strobe unit **336** is enabled. For example, in one embodiment, the camera module **330** may detect when the strobe unit **336** is enabled or disabled within a microsecond or less of the strobe unit **336** being enabled or disabled by the strobe control signal **338**. To sample an image requiring strobe illumination, a camera interface unit **386** may enable the strobe unit **336** by sending an enable command through the strobe control signal **338**. In one embodiment, the camera interface unit **386** may be included as an interface of input/output interfaces **384** in a processor subsystem **360** of the processor complex **310** of FIG. **3**B The enable command may comprise a signal level transition, a data packet, a register write, or any other technically feasible transmission of a command. The camera module **330** may sense that the strobe unit **336** is enabled and then cause image sensor **332** to sample one or more images requiring strobe illumination while the strobe unit **336** is enabled. In such an implementation, the image sensor **332** may be configured to wait for an enable signal destined for the strobe unit **336** as a trigger signal to begin sampling a new exposure.

[0187] In one embodiment, camera interface unit **386** may transmit exposure parameters and commands to camera module **330** through interconnect **334**. In certain embodiments, the camera interface unit **386** may be configured to directly control strobe unit **336** by transmitting control commands to the strobe unit **336** through strobe control signal **338**. By directly controlling both the camera module **330** and the strobe unit **336**, the camera interface unit **386** may cause the camera module **330** and the strobe unit **336** to perform their respective operations in precise time synchronization. In one embodiment, precise time synchronization may be less than five hundred microseconds of event timing error. Additionally, event timing error may be a difference in time from an intended event occurrence to the time of a corresponding actual event occurrence.

[0188] In another embodiment, camera interface unit **386** may be configured to accumulate statistics while receiving image data from camera module **330**. In particular, the camera interface unit **386** may accumulate exposure statistics for a given image while receiving image data for the image through interconnect **334**. Exposure statistics may include, without limitation, one or more of an intensity histogram, a count of over-exposed pixels, a count of under-exposed pixels, an intensity-weighted sum of pixel intensity, or any combination thereof. The camera interface unit **386** may present the exposure statistics as memory-mapped storage locations within a physical or virtual address space defined by a processor, such as one or more of CPU cores **370**, within processor complex **310**. In one embodiment, exposure statistics reside in storage circuits that are mapped into a memory-mapped register space, which may be accessed through the interconnect **334**. In other embodiments, the exposure statistics are transmitted in conjunction with transmitting pixel data for a captured image. For example, the exposure statistics for a given image may be transmitted as in-line data, following transmission of pixel intensity data for the captured image. Exposure statistics may be calculated, stored, or cached within the camera interface unit **386**.

[0189] In one embodiment, camera interface unit **386** may accumulate color statistics for estimating scene white-balance. Any technically feasible color statistics may be accumulated for estimating white balance, such as a sum of intensities for different color channels comprising red, green, and blue color channels. The sum of color channel intensities may then be used to perform a white-balance color correction on an associated image, according to a white-balance model such as a gray-world white-balance model. In other embodiments, curve-fitting statistics are accumulated for a linear or a quadratic curve fit used for implementing white-balance correction on an image.

[0190] In one embodiment, camera interface unit **386** may accumulate spatial color statistics for performing color-matching between or among images, such as between or among an ambient image and one or more images sampled with strobe illumination. As with the exposure statistics, the color statistics may be presented as memory-mapped storage locations within processor complex **310**. In one embodiment, the color statistics are mapped in a memory-mapped register space, which may be accessed through interconnect **334**, within processor subsystem **360**. In other embodiments, the color statistics may be transmitted in conjunction with transmitting pixel data for a captured image. For example, in one embodiment, the color statistics for a given image may be transmitted as in-line data, following transmission of pixel intensity data for the image. Color statistics may be calculated, stored, or cached within the camera interface **386**.

[0191] In one embodiment, camera module **330** may transmit strobe control signal **338** to strobe unit **336**, enabling the strobe unit **336** to generate illumination while the camera module **330** is sampling an image. In another embodiment, camera module **330** may sample an image illuminated by strobe unit **336** upon receiving an indication signal from camera interface unit **386** that the strobe unit **336** is enabled. In yet another embodiment, camera module **330** may sample an image illuminated by strobe unit **336** upon detecting strobe illumination within a photographic scene via a rapid rise in scene illumination. In one embodiment, a rapid rise in scene illumination may include at least a rate of increasing intensity consistent with that of enabling strobe unit **336**. In still yet another embodiment, camera module **330** may enable strobe unit **336** to generate strobe illumination while sampling one image, and disable the strobe unit **336** while sampling a different image.

[0192] FIG. **3**G illustrates camera module **330**, in accordance with one embodiment. As an option, the camera module **330** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera module **330** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0193] In one embodiment, the camera module **330** may be in communication with an application processor **335**. The camera module **330** is shown to include image sensor **332** in communication with a controller **333**. Further, the controller **333** is shown to be in communication with the application processor **335**.

[0194] In one embodiment, the application processor **335** may reside outside of the camera module **330**. As shown, the lens **390** may be configured to focus optical scene information onto image sensor **332** to be sampled. The optical scene information sampled by the image sensor **332** may then be communicated from the image sensor **332** to the controller **333** for at least one of subsequent processing and communication to the application processor **335**. In another embodiment, the controller **333** may control storage of the optical scene information sampled by the image sensor **332**, or storage of processed optical scene information.

[0195] In another embodiment, the controller **333** may enable a strobe unit to emit strobe illumination for a short time duration (e.g. less than one microsecond, etc.) after image sensor **332** completes an exposure time associated with sampling an ambient image. Further, the controller **333** may be configured to generate strobe control signal **338** in conjunction with controlling operation of the image sensor **332**.

[0196] In one embodiment, the image sensor **332** may be a complementary metal oxide semiconductor (CMOS) sensor or a charge-coupled device (CCD) sensor. In another embodiment, the controller **333** and the image sensor **332** may be packaged together as an integrated system or integrated circuit. In yet another embodiment, the controller **333** and the image sensor **332** may comprise discrete packages. In one embodiment, the controller **333** may provide circuitry for receiving optical scene information from the image sensor **332**, processing of the optical scene information, timing of various functionalities, and signaling associated with the application processor **335**. Further, in another embodiment, the controller **333** may provide circuitry for control of one or more of exposure, shuttering, white balance, and gain adjustment. Processing of the optical scene information by the circuitry of the controller **333** may include one or more of gain application, amplification, and analog-to-digital conversion. After processing the optical scene information, the controller **333** may transmit corresponding digital pixel data, such as to the application processor **335**.

[0197] In one embodiment, the application processor **335** may be implemented on processor complex **310** and at least one of volatile memory **318** and NV memory **316**, or any other memory device and/or system. The application processor **335** may be previously configured for processing of received optical scene information or digital pixel data communicated from the camera module **330** to the application processor **335**.
[0198] FIG. **4** illustrates a network service system **400**, in accordance with one embodiment. As an option, the network service system **400** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the network service system **400** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0199] In one embodiment, the network service system **400** may be configured to provide network access to a device implementing a digital photographic system. As shown, network service system **400** includes a wireless mobile device **376**, a wireless access point **472**, a data network **474**, data center **480**, and a data center **481**. The wireless mobile device **376** may communicate with the wireless access point **472** via a digital radio link **471** to send and receive digital data, including data associated with digital images. The wireless mobile device **376** and the wireless access point **472** may implement any technically feasible transmission techniques for transmitting digital data via digital a radio link **471** without departing the scope and spirit of the present invention. In certain embodiments, one or more of data centers **480**, **481** may be implemented using virtual constructs so that each system and subsystem within a given data center **480**, **481** may comprise virtual machines configured to perform specified data processing and network tasks. In other implementations, one or more of data centers **480**, **481** may be physically distributed over a plurality of physical sites.
[0200] The wireless mobile device **376** may comprise a smart phone configured to include a digital camera, a digital camera configured to include wireless network connectivity, a reality augmentation device, a laptop configured to include a digital camera and wireless network connectivity, or any other technically feasible computing device configured to include a digital photographic system and wireless network connectivity.
[0201] In various embodiments, the wireless access point **472** may be configured to communicate with wireless mobile device **376** via the digital radio link **471** and to communicate with the data network **474** via any technically feasible transmission media, such as any electrical, optical, or radio transmission media. For example, in one embodiment, wireless access point **472** may communicate with data network **474** through an optical fiber coupled to the wireless access point **472** and to a router system or a switch system within the data network **474**. A network link **475**, such as a wide area network (WAN) link, may be configured to transmit data between the data network **474** and the data center **480**.
[0202] In one embodiment, the data network **474** may include routers, switches, long-haul transmission systems, provisioning systems, authorization systems, and any technically feasible combination of communications and operations subsystems configured to convey data between network endpoints, such as between the wireless access point **472** and the data center **480**. In one implementation, a wireless the mobile device **376** may comprise one of a plurality of wireless mobile devices configured to communicate with the data center **480** via one or more wireless access points coupled to the data network **474**.
[0203] Additionally, in various embodiments, the data center **480** may include, without limitation, a switch/router **482** and at least one data service system **484**. The switch/router **482** may be configured to forward data traffic between and among a network link **475**, and each data service system **484**. The switch/router **482** may implement any technically feasible transmission techniques, such as Ethernet media layer transmission, layer **2** switching, layer **3** routing, and the like. The switch/router **482** may comprise one or more individual systems configured to transmit data between the data service systems **484** and the data network **474**.
[0204] In one embodiment, the switch/router **482** may implement session-level load balancing

among a plurality of data service systems **484**. Each data service system **484** may include at least one computation system **488** and may also include one or more storage systems **486**. Each computation system **488** may comprise one or more processing units, such as a central processing unit, a graphics processing unit, or any combination thereof. A given data service system **484** may be implemented as a physical system comprising one or more physically distinct systems configured to operate together. Alternatively, a given data service system **484** may be implemented as a virtual system comprising one or more virtual systems executing on an arbitrary physical system. In certain scenarios, the data network **474** may be configured to transmit data between the data center **480** and another data center **481**, such as through a network link **476**.

[0205] In another embodiment, the network service system **400** may include any networked mobile devices configured to implement one or more embodiments of the present invention. For example, in some embodiments, a peer-to-peer network, such as an ad-hoc wireless network, may be established between two different wireless mobile devices. In such embodiments, digital image data may be transmitted between the two wireless mobile devices without having to send the digital image data to a data center **480**.

[0206] FIG. **5** shows a system **500** for outputting a HDR pixel, in accordance with one embodiment. As an option, the system **500** may be implemented in the context of the any of the Figures. Of course, however, the system **500** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0207] As shown, the system **500** includes a non-linear mix function **530**. In one embodiment, the non-linear mix function **530** includes receiving a brighter pixel **550** and a darker pixel **552**. In one embodiment, the brighter pixel **550** and the darker pixel **552** may be blended via a mix function **566**, resulting in a HDR pixel **559**.

[0208] In one embodiment, the mix function **566** may include any function which is capable of combining two input values (e.g. pixels, etc.). The mix function **566** may define a linear blend operation for generating a vec3 value associated with HDR pixel **559** by blending a vec3 value associated with the brighter pixel **550** and a vec3 value associated with the darker pixel **552** based on mix value **558**. For example the mix function **566** may implement the well-known OpenGL mix function. In other examples, the mix function may include normalizing a weighted sum of values for two different pixels, summing and normalizing vectors (e.g. RGB, etc.) associated with the input pixels, computing a weighted average for the two input pixels, and/or applying any other function which may combine in some manner the brighter pixel and the darker pixel. In one embodiment, mix value **558** may range from 0 to 1, and mix function **566** mixes darker pixel **552** and brighter pixel **550** based on the mix value **558**. In another embodiment, the mix value **558** ranges from 0 to an arbitrarily large value, however the mix function **566** is configured to respond to mix values greater than 1 as though such values are equal to 1. Further still, the mix value may be a scalar.

[0209] In one embodiment, a mix value function may include a product of two polynomials and may include a strength coefficient. In a specific example, the mix value function is implemented as mix value surface **564**, which operates to generate mix value **558**. One exemplary mix value function is illustrated below in Equation 1:

[00001] $z = p1(x) * p2(y) * s \quad \text{(Eq. 1)}$ [0210] where: [0211] z is resulting mix value for first and second pixels; [0212] p1 is a first polynomial in x, where x may be a pixel attribute for first (darker) pixel; [0213] p2 is a second polynomial in y, where y may be a pixel attribute for second (lighter) pixel; and [0214] s is a strength coefficient (s==0: no mixing, s==1.0: nominal mixing, s>1.0: exaggerated mixing).

[0215] In Equation 1, the strength coefficient(s) may cause the resulting mix value to reflect no mixing (e.g. s=0, etc.), nominal mixing (e.g. s=1, etc.), and exaggerated mixing (e.g. s>1.0, etc.) between the first and second pixels.

[0216] In another specific embodiment, a mix function may include a specific polynomial form:

[00002] $z = (1 - (1 - (1 - x)^A)^B) * ((1 - (1 - y)^C)^D) * s$ (Eq. 2)

[0217] As shown, p1(x) of Equation 1 may be implemented in Equations 2 as the term (1−(1−(1−x){circumflex over ( )}A){circumflex over ( )}B), while p2(y) of Equation 2 may be implemented as the term (1−(1−y){circumflex over ( )}C){circumflex over ( )}D). In one embodiment, Equation 2 may include the following coefficients: A=8, B=2, C=8, and D=2. Of course, in other embodiments, other coefficient values may be used to optimize overall mixing, which may include subjective visual quality associated with mixing the first and second pixels. In certain embodiments, Equation 2 may be used to generate a mix value for a combination of an “EV0” pixel (e.g. a pixel from an image having an EV 0 exposure), an “EV −” pixel (e.g. a pixel from an image having an exposure of EV −1, EV −2, or EV −3, etc.), and an “EV +” pixel (e.g. a pixel from an image having an exposure of EV +1, EV +2, or EV +3, etc.). Further, in another embodiment, Equation 2 may be used to generate mix values for pixels associated with images having a bright exposure, median exposure, and/or dark exposure in any combination.

[0218] In another embodiment, when z=0, the darker pixel may be given full weight, and when z=1, the brighter pixel may be given full weight. In one embodiment, Equation 2 may correspond with the surface diagrams as shown in FIGS. **10**A and **10**B.

[0219] In another specific embodiment, a mix function may include a specific polynomial form:

[00003] $z = ((1 - (1 - x)^A)^B) * ((1 - (1 - y)^C)^D) * s$ (Eq. 3)

[0220] As shown, p1(x) of Equation 1 may be implemented in Equations 3 as the term ((1−(1−x){circumflex over ( )}A){circumflex over ( )}B), while p2(y) of Equation 3 may be implemented as the term ((1−(1−y){circumflex over ( )}C){circumflex over ( )}D). In one embodiment, Equation 3 may include the following coefficients: A=8, B=2, C=2, and D=2. Of course, in other embodiments, other coefficient values may be used to optimize the mixing. In another embodiment, Equation 3 may be used to generate a mix value for an “EV 0” pixel, and an “EV −” pixel (e.g., EV −1, EV −2, or EV −3) pixel. Further, in another embodiment, Equation 3 may be used to generate mix values for pixels associated with images having a bright exposure, median exposure, and/or dark exposure in any combination.

[0221] In another embodiment, when z=0, the brighter pixel may be given full weight, and when z=1, the darker pixel may be given full weight. In one embodiment, Equation 3 may correspond with the surface diagrams as shown in FIGS. **11**A and **11**B.

[0222] In another embodiment, the brighter pixel **550** may be received by a pixel attribute function **560**, and the darker pixel **552** may be received a pixel attribute function **562**. In various embodiments, the pixel attribute function **560** and/or **562** may include any function which is capable of determining an attribute associated with the input pixel (e.g. brighter pixel, darker pixel, etc.). For example, in various embodiments, the pixel attribute function **560** and/or **562** may include determining an intensity, a saturation, a hue, a color space value (e.g. EGB, Y CbCr, Y UV, etc.), an RGB blend, a brightness, an RGB color, a luminance, a chrominance, and/or any other feature which may be associated with a pixel in some manner.

[0223] In response to the pixel attribute function **560**, a pixel attribute **555** associated with brighter pixel **550** results and is inputted into a mix value function, such as mix value surface **564**. Additionally, in response to the pixel attribute function **562**, a pixel attribute **556** associated with darker pixel **552** results and is inputted into the mix value function.

[0224] In one embodiment, a given mix value function may be associated with a surface diagram. For example, in one embodiment, an x value may be associated with a polynomial associated with the first pixel attribute (or a plurality of pixel attributes), and a y value may be associated with a polynomial associated with the second pixel attribute (or a plurality of pixel attributes). Further, in another embodiment, a strength function may be used to scale the mix value calculated by the mix value function. In one embodiment, the mix value may include a scalar.

[0225] In one embodiment, the mix value **558** determined by the mix value function may be selected from a table that embodies the surface diagram. In another embodiment, a first value associated with a first polynomial and a second value associated with a second polynomial may each be used to select a corresponding value from a table, and the two or more values may be used to interpolate a mix value. In other words, at least a portion of the mix value function may be implemented as a table (e.g. lookup table) indexed in x and y to determine a value of z. Each value of z may be directly represented in the table or interpolated from sample points comprising the table. Accordingly, a scalar may be identified by at least one of generating, selecting, and interpolating.

[0226] As shown, a mix value **558** results from the mix value surface **564** and is inputted into the mix function **566**, described previously.

[0227] HDR Pixel **559** may be generated based on the brighter pixel **550** and the darker pixel **552**, in accordance with various embodiments described herein.

[0228] FIG. **6** illustrates a method **600** for generating a HDR pixel based on combined HDR pixel and effects function, in accordance with another embodiment. As an option, the method **600** may be implemented in the context of the details of any of the Figures. Of course, however, the method **600** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0229] As shown, in one embodiment, a medium-bright HDR pixel may be generated based on a medium exposure pixel and a bright exposure pixel. See operation **602**. Additionally, a medium-dark HDR pixel may be generated based on a medium exposure pixel and a dark exposure pixel. See operation **604**. For example, in one embodiment, a medium exposure pixel may include an EV 0 exposure and a bright exposure pixel may include an EV +1 exposure, and medium-bright HDR pixel may be a blend between the EV 0 exposure pixel and the EV +1 exposure pixel. Of course, a bright exposure pixel may include an exposure greater (e.g. in any amount, etc.) than the medium exposure value.

[0230] In another embodiment, a medium exposure pixel may include an EV 0 exposure and a dark exposure pixel may include an EV −1 exposure, and a medium-dark HDR pixel may be a blend between the EV 0 exposure and the EV −1 exposure. Of course, a dark exposure pixel may include an exposure (e.g. in any amount, etc.) less than the medium exposure value.

[0231] As shown, a combined HDR pixel may be generated based on a medium-bright HDR pixel and a medium-dark HDR pixel. See operation **606**. In another embodiment, the combined HDR pixel may be generated based on multiple medium-bright HDR pixels and multiple medium-dark HDR pixels.

[0232] In a separate embodiment, a second combined HDR pixel may be based on the combined HDR pixel and a medium-bright HDR pixel, or may be based on the combined HDR pixel and a medium-dark HDR pixel. In a further embodiment, a third combined HDR pixel may be based on a first combined HDR pixel, a second combined HDR pixel, a medium-bright HDR pixel, a medium-dark HDR pixel, and/or any combination thereof.

[0233] Further, as shown, an output HDR pixel may be generated based on a combined HDR pixel and an effects function. See operation **608**. For example in one embodiment, an effect function may include a function to alter an intensity, a saturation, a hue, a color space value (e.g. EGB, Y CbCr, Y UV, etc.), a RGB blend, a brightness, an RGB color, a luminance, a chrominance, a contrast, an attribute levels function, and/or an attribute curves function. Further, an effect function may include a filter, such as but not limited to, a pastel look, a watercolor function, a charcoal look, a graphic pen look, an outline of detected edges, a change of grain or of noise, a change of texture, and/or any other modification which may alter the output HDR pixel in some manner.

[0234] FIG. **7** illustrates a system **700** for outputting a HDR pixel, in accordance with another embodiment. As an option, the system **700** may be implemented in the context of the details of any of the Figures. Of course, however, the system **700** may be carried out in any desired environment.

Further, the aforementioned definitions may equally apply to the description below.
[0235] In one embodiment, the system **700** may include a pixel blend operation **702**. In one embodiment, the pixel blend operation **702** may include receiving a bright exposure pixel **710** and a medium exposure pixel **712** at a non-linear mix function **732**. In another embodiment, the non-linear mix function **732** may operate in a manner consistent with non-linear mix function **530** of FIG. **5**. In another embodiment, the pixel blend operation **702** may include receiving a dark exposure pixel **714** and a medium exposure pixel **712** at a non-linear mix function **734**. In another embodiment, the non-linear mix function **734** may operate in a manner consistent with item **530** of FIG. **5**.
[0236] In various embodiments, the non-linear mix function **732** and/or **734** may receive an input from a bright mix limit **720** or dark mix limit **722**, respectively. In one embodiment, the bright mix limit **720** and/or the dark mix limit **722** may include an automatic or manual setting. For example, in some embodiments, the mix limit may be set by predefined settings (e.g. optimized settings, etc.). In one embodiment, each mix limit may be predefined to optimize the mix function. In another embodiment, the manual settings may include receiving a user input. For example, in one embodiment, the user input may correspond with a slider setting on a sliding user interface. Each mix limit may correspond to a respective strength coefficient, described above in conjunction with Equations 1-3.
[0237] For example, in one embodiment, a mix value function may include a product of two polynomials and may include a strength coefficient. In a specific example, the mix value function is implemented as mix value surface **564**, which operates to generate mix value **558**. One exemplary mix value function is illustrated below in Equation 1:
[00004] $z = p1(x) * p2(y) * s \quad (\text{Eq. } 1)$ [0238] where: [0239] z is resulting mix value for first and second pixels; [0240] p1 is a first polynomial in x, where x may be a pixel attribute for first (darker) pixel; [0241] p2 is a second polynomial in y, where y may be a pixel attribute for second (lighter) pixel; and [0242] s is a strength coefficient (s==0: no mixing, s==1.0: nominal mixing, s>1.0: exaggerated mixing).
[0243] In Equation 1, the strength coefficient(s) may cause the resulting mix value to reflect no mixing (e.g. s=0, etc.), nominal mixing (e.g. s=1, etc.), and exaggerated mixing (e.g. s>1.0, etc.) between the first and second pixels.
[0244] In another specific embodiment, a mix function may include a specific polynomial form:
[00005] $z = (1 - (1 - (1 - x)\hat{}A)\hat{}B) * ((1 - (1 - y)\hat{}C)\hat{}D) * s \quad (\text{Eq. } 2)$
[0245] As shown, p1(x) of Equation 1 may be implemented in Equations 2 as the term (1−(1−(1−x){circumflex over ( )}A){circumflex over ( )}B), while p2(y) of Equation 2 may be implemented as the term ((1−(1−y){circumflex over ( )}C){circumflex over ( )}D). In one embodiment, Equation 2 may include the following coefficients: A=8, B=2, C=8, and D=2. Of course, in other embodiments, other coefficient values may be used to optimize overall mixing, which may include subjective visual quality associated with mixing the first and second pixels. In certain embodiments, Equation 2 may be used to generate a mix value for a combination of an “EV0” pixel (e.g. a pixel from an image having an EV0 exposure), an “EV−” pixel (e.g. a pixel from an image having an exposure of EV −1, EV −2, or EV −3, etc.), and an “EV+” pixel (e.g. a pixel from an image having an exposure of EV +1, EV +2, or EV +3, etc.). Further, in another embodiment, Equation 2 may be used to generate mix values for pixels associated with images having a bright exposure, median exposure, and/or dark exposure in any combination.
[0246] In another embodiment, when z=0, the darker pixel may be given full weight, and when z=1, the brighter pixel may be given full weight. In one embodiment, Equation 2 may correspond with the surface diagrams as shown in FIGS. **10**A and **10**B.
[0247] In another specific embodiment, a mix function may include a specific polynomial form:
[00006] $z = ((1 - (1 - x)\hat{}A)\hat{}B) * ((1 - (1 - y)\hat{}C)\hat{}D) * s \quad (\text{Eq. } 3)$

[0248] As shown, p1(x) of Equation 1 may be implemented in Equations 3 as the term ((1−(1−x){circumflex over ( )}A){circumflex over ( )}B), while p2(y) of Equation 3 may be implemented as the term ((1−(1−y){circumflex over ( )}C){circumflex over ( )}D). In one embodiment, Equation 3 may include the following coefficients: A=8, B=2, C=2, and D=2. Of course, in other embodiments, other coefficient values may be used to optimize the mixing. In another embodiment, Equation 3 may be used to generate a mix value for an “EV0” pixel, and an “EV−” pixel (e.g., EV−1, EV−2, or EV−3) pixel. Further, in another embodiment, Equation 3 may be used to generate mix values for pixels associated with images having a bright exposure, median exposure, and/or dark exposure in any combination.
[0249] In another embodiment, when z=0, the brighter pixel may be given full weight, and when z=1, the darker pixel may be given full weight. In one embodiment, Equation 3 may correspond with the surface diagrams as shown in FIGS. **11**A and **11**B.
[0250] As shown, in one embodiment, the non-linear mix function **732** results in a medium-bright HDR pixel **740**. In another embodiment, the non-linear mix function **734** results in a medium-dark HDR pixel **742**. In one embodiment, the medium-bright HDR pixel **740** and the medium-dark HDR pixel **742** are inputted into a combiner function **736**. In another embodiment, the combiner function **736** blends the medium-bright HDR pixel **740** and the medium-dark HDR pixel **742**.
[0251] In various embodiments, the combiner function **736** may include taking an average of two or more pixel values, summing and normalizing a color attribute associated with each pixel value (e.g. a summation of a red/green/blue component in a RGB color space, etc.), determining a RGB (or any color space) vector length which may then be normalized, using an average pixel value in combination with a brighter pixel or a darker pixel, and/or using any other combination to blend the medium-bright HDR pixel **740** and the medium-dark HDR pixel **742**.
[0252] In one embodiment, the combiner function **736** results in a combined HDR pixel **744**. In various embodiments, the combined HDR pixel **744** may include any type of blend associated with the medium-bright pixel **740** and the medium-dark HDR pixel **742**. For example, in some embodiments, the combined HDR pixel may include a resulting pixel with no HDR effect applied, whereas in other embodiments, any amount of HDR or even amplification may be applied and be reflected in the resulting combined HDR pixel.
[0253] In various embodiments, the combined HDR pixel **744** is inputted into an effects function **738**. In one embodiment, the effects function **738** may receive a saturation parameter **724**, level mapping parameters **726**, and/or any other function parameter which may cause the effects function **738** to modify the combined HDR pixel **744** in some manner. Of course, in other embodiments, the effects function **738** may include a function to alter an intensity, a hue, a color space value (e.g. EGB, Y CbCr, Y UV, etc.), a brightness, an RGB color, a luminance, a chrominance, a contrast, and/or a curves function. Further, an effect function may include a filter, such as but not limited to, a pastel look, a watercolor function, a charcoal look, a graphic pen look, an outline of detected edges, a change of grain or of noise, a change of texture, and/or any other modification which may alter the combined HDR pixel **744** in some manner. In some embodiments, output HDR pixel **746** may be generated by effects function **738**. Alternatively, effects function **738** may be configured to have no effect and output HDR pixel **746** is equivalent to combined HDR pixel **744**. In one embodiment, the effects function **738** implements equalization, such as an equalization technique known in the art as contrast limited adaptive histogram equalization (CLAHE).
[0254] In some embodiments, and in the alternative, the combined HDR pixel **744** may have no effects applied. After passing through an effects function **738**, an output HDR pixel **746** results.
[0255] FIG. **8** illustrates a method **800** for generating a HDR pixel based on a combined HDR pixel and an effects function, in accordance with another embodiment. As an option, the method **800** may be implemented in the context of the details of any of the Figures. Of course, however, the method **800** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0256] In one embodiment, a medium exposure parameter may be estimated for a medium exposure image. See operation **802**. Additionally, a dark exposure parameter is estimated for a dark exposure image (see operation **804**) and a bright exposure parameter is estimated for a bright exposure image (see operation **806**).
[0257] In various embodiments, an exposure parameter (e.g. associated with medium exposure, dark exposure, or bright exposure, etc.) may include an ISO, an exposure time, an exposure value, an aperture, and/or any other parameter which may affect image capture time. In one embodiment, the capture time may include the amount of time that the image sensor is exposed to optical information presented by a corresponding camera lens.
[0258] In one embodiment, estimating a medium exposure parameter, a dark exposure parameter, and/or a bright exposure parameter may include metering an image associated with a photographic scene. For example, in various embodiments, the brightness of light within a lens' field of view may be determined. Further, the metering of the image may include a spot metering (e.g. narrow area of coverage, etc.), an average metering (e.g. metering across the entire photo, etc.), a multi-pattern metering (e.g. matrix metering, segmented metering, etc.), and/or any other type of metering system. The metering of the image may be performed at any resolution, including a lower resolution than available from the image sensor, which may result in faster metering latency.
[0259] As shown, a dark exposure image, a medium exposure image, and a bright exposure image are captured. See operation **808**. In various embodiments, capturing an image (e.g. a dark exposure image, a medium exposure image, a bright exposure image, etc.) may include committing the image (e.g. as seen through the corresponding camera lens, etc.) to an image processor and/or otherwise store the image temporarily in some manner. Of course, in other embodiments, the capturing may include a photodiode which may detect light (e.g. RGB light, etc.), a bias voltage or capacitor (e.g. to store intensity of the light, etc.), and/or any other circuitry necessary to receive the light intensity and store it. In other embodiments, the photodiode may charge or discharge a capacitor at a rate that is proportional to the incident light intensity (e.g. associated with the exposure time, etc.).
[0260] Additionally, in one embodiment, a combined HDR image may be generated based on a dark exposure image, a medium exposure image, and a bright exposure image. See operation **810**. In various embodiments, the combined HDR image may be generated in a manner consistent with combined HDR pixel **744** in FIG. **7**. Further, in one embodiment, an output HDR image may be generated based on a combined HDR image comprising combined HDR pixel **744** and an effects function. See operation **812**. In various embodiments, the output HDR image may be generated in a manner consistent with Output HDR Pixel **746** in FIG. **7**.
[0261] FIG. **9** illustrates a method **900** for generating a HDR pixel based on combined HDR pixel and an effects function, in accordance with another embodiment. As an option, the method **900** may be implemented in the context of the details of any of the Figures. Of course, however, the method **900** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0262] In one embodiment, a medium exposure parameter may be estimated for medium exposure image. See operation **902**. In various embodiments, the medium exposure parameter may include an ISO, an exposure time, an exposure value, an aperture, and/or any other parameter which may affect the capture time. In one embodiment, the capture time may include the amount of time that the image sensor is exposed to optical information presented by a corresponding camera lens. In one embodiment, estimating a medium exposure parameter may include metering the image. For example, in various embodiments, the brightness of light within a lens' field of view may be determined. Further, the metering of the image may include a spot metering (e.g. narrow area of coverage, etc.), an average metering (e.g. metering across the entire photo, etc.), a multi-pattern metering (e.g. matrix metering, segmented metering, etc.), and/or any other type of metering system. The metering of the image may be performed at any resolution, including a lower

resolution than available from the image sensor, which may result in faster metering latency. Additionally, in one embodiment, the metering for a medium exposure image may include an image at EV 0. Of course, however, in other embodiments, the metering may include an image at any shutter stop and/or exposure value.

[0263] As shown, in one embodiment, an analog image may be captured within an image sensor based on medium exposure parameters. See operation **904**. In various embodiments, capturing the analog image may include committing the image (e.g. as seen through the corresponding camera lens, etc.) to an image sensor and/or otherwise store the image temporarily in some manner. Of course, in other embodiments, the capturing may include a photodiode which may detect light (e.g. RGB light, etc.), a bias voltage or capacitor (e.g. to store intensity of the light, etc.), and/or any other circuitry necessary to receive the light intensity and store it. In other embodiments, the photodiode may charge or discharge a capacitor at a rate that is proportional to the incident light intensity (e.g. associated with the exposure time, etc.).

[0264] Additionally, in one embodiment, a medium exposure image may be generated based on an analog image. See operation **906**. Additionally, a dark exposure image may be generated based on an analog image (see operation **908**), and a brighter exposure image may be generated based on an analog image (see operation **910**). In various embodiments, generating an exposure image (e.g. medium, dark, bright, etc.) may include applying an ISO or film speed to the analog image. Of course, in another embodiment, any function which may alter the analog image's sensitivity to light may be applied. In one embodiment, the same analog image may be sampled repeatedly to generate multiple images (e.g. medium exposure image, dark exposure image, bright exposure image, etc.). For example, in one embodiment, the current stored within the circuitry may be used multiple times.

[0265] Additionally, in one embodiment, a combined HDR image may be generated based on a dark exposure image, a medium exposure image, and a bright exposure image. See operation **912**. In various embodiments, the combined HDR image may be generated in a manner consistent with Combined HDR Pixel **744** in FIG. **7**. Further, in one embodiment, an output HDR image may be generated based on a combined HDR image and an effects function. See operation **914**. In various embodiments, the output HDR image may be generated in a manner consistent with Output HDR Pixel **746** in FIG. **7**.

[0266] FIG. **10**A illustrates a surface diagram **1000**, in accordance with another embodiment. As an option, the surface diagram **1000** may be implemented in the context of the details of any of the Figures. Of course, however, the surface diagram **1000** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0267] In one embodiment, surface diagram **1000** depicts a surface associated with Equation 2 for determining a mix value for two pixels, based on two pixel attributes for the two pixels. As shown, the surface diagram **1000** is illustrated within a unit cube having an x axis **1002**, a y axis **1004**, and a z axis **1006**. As described in Equation 2, variable “x” is associated with an attribute for a first (e.g. darker) pixel, and variable “y” is associated with an attribute for a second (e.g. lighter) pixel. For example, each attribute may represent an intensity value ranging from 0 to 1 along a respective x and y axis of the unit cube. An attribute for the first pixel may correspond to pixel attribute **556** of FIG. **5**, while an attribute for the second pixel may correspond to pixel attribute **555**. As described in Equation 2, variable “z” is associated with the mix value, such as mix value **558**, for generating a HDR pixel, such as HDR pixel **559**, from the two pixels. A mix value of 0 (e.g. z=0) may result in a HDR pixel that is substantially identical to the first pixel, while a mix value of 1 (e.g. z=1) may result in a HDR pixel that is substantially identical to the second pixel.

[0268] As shown, surface diagram **1000** includes a flat region **1014**, a transition region **1010**, and a saturation region **1012**. The transition region **1010** is associated with x values below an x threshold and y values below a y threshold. The transition region **1010** is generally characterized as having monotonically increasing z values for corresponding monotonically increasing x and y values. The flat region **1014** is associated with x values above the x threshold. The flat region **1014** is characterized as having substantially constant z values independent of corresponding x and y values. The saturation region **1012** is associated with x values below the x threshold and above the y threshold. The saturation region **1012** is characterized as having z values that are a function of corresponding x values while being relatively independent of y values. For example, with x=x1, line **1015** shows z monotonically increasing through the transition region **1010**, and further shows z remaining substantially constant within the saturation region **1012**. In one embodiment mix value surface **564** implements surface diagram **1000**. In another embodiment, non-linear mix function **732** of FIG. **7** implements surface diagram **1000**. In yet another embodiment, non-linear mix function **734** of FIG. **7** implements surface diagram **1000**.

[0269] FIG. **10**B illustrates a surface diagram **1008**, in accordance with another embodiment. As an option, the surface diagram **1008** may be implemented in the context of the details of any of the Figures. Of course, however, the surface diagram **1008** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0270] In one embodiment, the surface diagram **1008** provides a separate view (e.g. top down view, etc.) of surface diagram **1000** of FIG. **10**A. Additionally, the description relating to FIG. **10**A may be applied to FIG. **10**B as well.

[0271] FIG. **11**A illustrates a surface diagram **1100**, in accordance with another embodiment. As an option, the surface diagram **1100** may be implemented in the context of the details of any of the Figures. Of course, however, the surface diagram **1100** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0272] In one embodiment, surface diagram **1100** depicts a surface associated with Equation 3 for determining a mix value for two pixels, based on two pixel attributes for the two pixels. As described in Equation 3, variable “x” is associated with an attribute for a first (e.g. darker) pixel, and variable “y” is associated with an attribute for a second (e.g. lighter) pixel. The flat region **1114** may correspond in general character to flat region **1014** of FIG. **10**A. Transition region **1110** may correspond in general character to transition region **1010**. Saturation region **1112** may correspond in general character to saturation region **1012**. While each region of surface diagram **1100** may correspond in general character to similar regions for surface diagram **1000**, the size of corresponding regions may vary between surface diagram **1100** and surface diagram **1000**. For example, the x threshold associated with surface diagram **1100** is larger than the x threshold associated with surface diagram **1000**, leading to a generally smaller flat region **1114**. As shown, the surface diagram **1100** may include a flat region **1114**, a transition region **1110**, and a saturation region **1112**.

[0273] FIG. **11**B illustrates a surface diagram **1102**, in accordance with another embodiment. As an option, the surface diagram **1102** may be implemented in the context of the details of any of the Figures. Of course, however, the surface diagram **1102** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0274] In one embodiment, the surface diagram **1102** provides a separate view (e.g. top down view, etc.) of surface diagram **1100** of FIG. **11**A. Additionally, in various embodiments, the description relating to FIG. **11**A and FIG. **10**A may be applied to FIG. **11**B as well.

[0275] FIG. **12** illustrates a levels mapping function **1200**, in accordance with another embodiment. As an option, the levels mapping function **1200** may be implemented in the context of the details of any of the Figures. Of course, however, the levels mapping function **1200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0276] In various embodiments, the levels mapping function **1200** maps an input range **1210** to an output range **1220**. More specifically, a white point **1216** may be mapped to a new white point in the output range **1220**, a median point **1214** may be mapped to a new median point in the output range **1220**, and a black point **1212** may be mapped to a new black point in the output range **1220**.

In one embodiment, the input range **1210** may be associated with an input image and the output range **1220** may be associated with a mapped image. In one embodiment, levels mapping may include an adjustment of intensity levels of an image based on a black point, a white point, a mid point, a median point, or any other arbitrary mapping function.

[0277] In certain embodiments, the white point, median point, black point, or any combination thereof, may be mapped based on an automatic detection of corresponding points or manually by a user. For example, in one embodiment, it may be determined that an object in the input image corresponds with a black point (or a white point, or a median point, etc.), such as through object recognition. For example, it may be determined that a logo is present in an image, and accordingly, set a color point (e.g. white, median, black, etc.) based off of an identified object. In other embodiments, the automatic settings may be associated with one or more settings associated with a camera device. For example, in some embodiments, the camera device may correct for a lens deficiency, a processor deficiency, and/or any other deficiency associated with the camera device by applying, at least in part, a set of one or more settings to the levels mapping.

[0278] FIG. **13** illustrates a levels mapping function **1300**, in accordance with another embodiment. As an option, the levels mapping function **1300** may be implemented in the context of the details of any of the Figures. Of course, however, the levels mapping function **1300** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0279] In one embodiment, a histogram **1302** may be associated with the input image of FIG. **12**. In some embodiments, the histogram **1302** may include statistics for identifying a black point **1312** and a white point **1316**. As indicated with respect to FIG. **12**, the setting of the color points (e.g. black, white, etc.) may be based on user input (or another manual input, etc.) or on an automatic setting.

[0280] Based on the setting of a new black point and a new white point, a new mapped image may be created from the input image. The mapped image may be associated with a new histogram **1304**. In one embodiment, after applying the new level mapping to the input image, the new level mapping (e.g. as visualized on the histogram, etc.) may be further modified as desired. For example, in one embodiment, a black point and white point may be automatically selected (e.g. based on optimized settings, etc.). After applying the black point and white point, the user may desire to further refine (or reset) the black point or white point. Of course, in such an embodiment, any color point may be set by the user.

[0281] In one embodiment, the white point (or any color point, etc.) may be controlled directly by a user. For example, a slider associated with a white point (or any color point, etc.) may directly control the white point of the pixel or image. In another embodiment, a slider associated with an image may control several settings, including an automatic adjustment to both black and white points (or any color point, etc.) to optimize the resulting pixel or image.

[0282] FIG. **14** illustrates an image synthesis operation **1400**, in accordance with another embodiment. As an option, the image synthesis operation **1400** may be implemented in the context of the details of any of the Figures. Of course, however, the image synthesis operation **1400** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0283] As shown, an image blend operation **1440** comprising the image synthesis operation **1400** may generate a synthetic image **1450** from an image stack **1402**, according to one embodiment of the present invention. Additionally, in various embodiments, the image stack **1402** may include images **1410**, **1412**, and **1414** of a scene, which may comprise a high brightness region **1420** and a low brightness region **1422**. In such an embodiment, medium exposure image **1412** is exposed according to overall scene brightness, thereby generally capturing scene detail.

[0284] In another embodiment, medium exposure image **1412** may also potentially capture some detail within high brightness region **1420** and some detail within low brightness region **1422**.

Additionally, dark exposure image **1410** may be exposed to capture image detail within high brightness region **1420**. In one embodiment, in order to capture high brightness detail within the scene, image **1410** may be exposed according to an exposure offset from medium exposure image **1412**.

[0285] In a separate embodiment, dark exposure image **1410** may be exposed according to local intensity conditions for one or more of the brightest regions in the scene. In such an embodiment, dark exposure image **1410** may be exposed according to high brightness region **1420**, to the exclusion of other regions in the scene having lower overall brightness. Similarly, bright exposure image **1414** is exposed to capture image detail within low brightness region **1422**. Additionally, in one embodiment, in order to capture low brightness detail within the scene, bright exposure image **1414** may be exposed according to an exposure offset from medium exposure image **1412**. Alternatively, bright exposure image **1414** may be exposed according to local intensity conditions for one or more of the darkest regions of the scene.

[0286] As shown, in one embodiment, an image blend operation **1440** may generate synthetic image **1450** from image stack **1402**. Additionally, in another embodiment, synthetic image **1450** may include overall image detail, as well as image detail from high brightness region **1420** and low brightness region **1422**. Further, in another embodiment, image blend operation **1440** may implement any technically feasible operation for blending an image stack. For example, in one embodiment, any high dynamic range (HDR) blending technique may be implemented to perform image blend operation **1440**, including but not limited to bilateral filtering, global range compression and blending, local range compression and blending, and/or any other technique which may blend the one or more images. In one embodiment, image blend operation **1440** includes a pixel blend operation **1442**. The pixel blend operation **1442** may generate a pixel within synthetic image **1450** based on values for corresponding pixels received from at least two images of images **1410**, **1412**, and **1414**. In one embodiment, pixel blend operation **1442** comprises pixel blend operation **702** of FIG. **7**.

[0287] In one embodiment, in order to properly perform a blend operation, all of the images (e.g. dark exposure image, medium exposure image, bright exposure image, etc.) may need to be aligned so that visible detail in each image is positioned in the same location in each image. For example, feature **1425** in each image should be located in the same position for the purpose of blending the images **1410**, **1412**, **1414** to generate synthetic image **1450**. In certain embodiments, at least two images of images **1410**, **1412**, **1414** are generated from a single analog image, as described in conjunction with method **900** of FIG. **9**, thereby substantially eliminating any alignment processing needed prior to blending the images **1410**, **1412**, **1414**.

[0288] FIG. **15** illustrates a user interface (UI) system **1500** for generating a combined image **1520**, according to one embodiment. As an option, the UI system **1500** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the UI system **1500** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0289] In one embodiment, a combined image **1520** comprises a combination of at least two related digital images. In one embodiment, the combined image **1520** comprises, without limitation, a combined rendering of a first digital image and a second digital image. In another embodiment, the digital images used to compute the combined image **1520** may be generated by amplifying an analog signal with at least two different gains, where the analog signal includes optical scene information captured based on an optical image focused on an image sensor. In yet another embodiment, the analog signal may be amplified using the at least two different gains on a pixel-by-pixel, line-by-line, or frame-by-frame basis.

[0290] In one embodiment, the UI system **1500** presents a display image **1510** that includes, without limitation, a combined image **1520**, a slider control **1530** configured to move along track **1532**, and two or more indication points **1540**, which may each include a visual marker displayed within display image **1510**.

[0291] In one embodiment, the UI system **1500** is generated by an adjustment tool executing within a processor complex **310** of a digital photographic system **300**, and the display image **1510** is displayed on display unit **312**. In one embodiment, at least two digital images, such as the at least two related digital images, comprise source images for generating the combined image **1520**. The at least two digital images may reside within NV memory **316**, volatile memory **318**, memory subsystem **362**, or any combination thereof. In another embodiment, the UI system **1500** is generated by an adjustment tool executing within a computer system, such as a laptop computer or a desktop computer. The at least two digital images may be transmitted to the computer system or may be generated by an attached camera device. In yet another embodiment, the UI system **1500** may be generated by a cloud-based server computer system, which may download the at least two digital images to a client browser, which may execute combining operations described below. In another embodiment, the UI system **1500** is generated by a cloud-based server computer system, which receives the at least two digital images from a digital photographic system in a mobile device, and which may execute the combining operations described below in conjunction with generating combined image **1520**.

[0292] The slider control **1530** may be configured to move between two end points corresponding to indication points **1540-**A and **1540-**C. One or more indication points, such as indication point **1540-**B may be positioned between the two end points. Each indication point **1540** may be associated with a specific version of combined image **1520**, or a specific combination of the at least two digital images. For example, the indication point **1540-**A may be associated with a first digital image generated utilizing a first gain, and the indication point **1540-**C may be associated with a second digital image generated utilizing a second gain, where both of the first digital image and the second digital image are generated from a same analog signal of a single captured photographic scene. In one embodiment, when the slider control **1530** is positioned directly over the indication point **1540-**A, only the first digital image may be displayed as the combined image **1520** in the display image **1510**, and similarly when the slider control **1530** is positioned directly over the indication point **1540-**C, only the second digital image may be displayed as the combined image **1520** in the display image **1510**.

[0293] In one embodiment, indication point **1540-**B may be associated with a blending of the first digital image and the second digital image. For example, when the slider control **1530** is positioned at the indication point **1540-**B, the combined image **1520** may be a blend of the first digital image and the second digital image. In one embodiment, blending of the first digital image and the second digital image may comprise alpha blending, brightness blending, dynamic range blending, and/or tone mapping or other non-linear blending and mapping operations. In another embodiment, any blending of the first digital image and the second digital image may provide a new image that has a greater dynamic range or other visual characteristics that are different than either of the first image and the second image alone. Thus, a blending of the first digital image and the second digital image may provide a new computed HDR image that may be displayed as combined image **1520** or used to generate combined image **1520**. To this end, a first digital signal and a second digital signal may be combined, resulting in at least a portion of a HDR image. Further, one of the first digital signal and the second digital signal may be further combined with at least a portion of another digital image or digital signal. In one embodiment, the other digital image may include another HDR image.

[0294] In one embodiment, when the slider control **1530** is positioned at the indication point **1540-**A, the first digital image is displayed as the combined image **1520**, and when the slider control **1530** is positioned at the indication point **1540-**C, the second digital image is displayed as the combined image **1520**; furthermore, when slider control **1530** is positioned at indication point **1540-**B, a blended image is displayed as the combined image **1520**. In such an embodiment, when the slider control **1530** is positioned between the indication point **1540-**A and the indication point

1540-C, a mix (e.g. blend) weight may be calculated for the first digital image and the second digital image. For the first digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **1530** is at indication point **1540**-C and a value of 1.0 when slider control **1530** is at indication point **1540**-A, with a range of mix weight values between 0.0 and 1.0 located between the indication points **1540**-C and **1540**-A, respectively. Referencing the mix operation instead to the second digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **1530** is at indication point **1540**-A and a value of 1.0 when slider control **1530** is at indication point **1540**-C, with a range of mix weight values between 0.0 and 1.0 located between the indication points **1540**-A and **1540**-C, respectively.

[0295] A mix operation may be applied to the first digital image and the second digital image based upon at least one mix weight value associated with at least one of the first digital image and the second digital image. In one embodiment, a mix weight of 1.0 gives complete mix weight to the digital image associated with the 1.0 mix weight. In this way, a user may blend between the first digital image and the second digital image. To this end, a first digital signal and a second digital signal may be blended in response to user input. For example, sliding indicia may be displayed, and a first digital signal and a second digital signal may be blended in response to the sliding indicia being manipulated by a user.

[0296] This system of mix weights and mix operations provides a UI tool for viewing the first digital image, the second digital image, and a blended image as a gradual progression from the first digital image to the second digital image. In one embodiment, a user may save a combined image **1520** corresponding to an arbitrary position of the slider control **1530**. The adjustment tool implementing the UI system **1500** may receive a command to save the combined image **1520** via any technically feasible gesture or technique. For example, the adjustment tool may be configured to save the combined image **1520** when a user gestures within the area occupied by combined image **1520**. Alternatively, the adjustment tool may save the combined image **1520** when a user presses, but does not otherwise move the slider control **1530**. In another implementation, the adjustment tool may save the combined image **1520** when a user gestures, such as by pressing a UI element (not shown), such as a save button, dedicated to receive a save command.

[0297] To this end, a slider control may be used to determine a contribution of two or more digital images to generate a final computed image, such as combined image **1520**. Persons skilled in the art will recognize that the above system of mix weights and mix operations may be generalized to include two or more indication points, associated with two or more related images. Such related images may comprise, without limitation, any number of digital images that have been generated using a same analog signal to have different brightness values, which may have zero interframe time.

[0298] Furthermore, a different continuous position UI control, such as a rotating knob, may be implemented rather than the slider **1530** to provide mix weight input or color adjustment input from the user.

[0299] Of course, in other embodiments, other user interfaces may be used to receive input relating to selecting one or more points of interest (e.g. for focus, for metering, etc.), adjusting one or more parameters associated with the image (e.g. white balance, saturation, exposure, etc.), and/or any other input which may affect the image in some manner.

[0300] FIG. **16** is a flow diagram of method **1600** for generating a combined image, according to one embodiment. As an option, the method **1600** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the method **1600** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0301] The method **1600** begins in step **1610**, where an adjustment tool executing within a processor complex, such as processor complex **310**, loads at least two related source images, such as the first digital image and the second digital image described in the context of FIG. **15**. In step

1612, the adjustment tool initializes a position for a UI control, such as slider control **1530** of FIG. **15**, to a default setting. In one embodiment, the default setting comprises an end point, such as indication point **1540**-A, for a range of values for the UI control. In another embodiment, the default setting comprises a calculated value based on one or more of the at least two related source images. In certain embodiments, the default setting is initialized to a value previously selected by a user in association with an image object comprising at least the first digital image and the second digital image.

[0302] In step **1614**, the adjustment tool generates and displays a combined image, such as combined image **1520** of FIG. **15**, based on a position of the UI control and the at least two related source images. In one embodiment, generating the combined image comprises mixing the at least two related source images as described previously in FIG. **15**. In step **1616**, the adjustment tool receives user input. The user input may include, without limitation, a UI gesture such as a selection gesture or click gesture within display image **1510**. If, in step **1620**, the user input should change the position of the UI control, then the adjustment tool changes the position of the UI control and the method proceeds back to step **1614**. Otherwise, the method proceeds to step **1630**.

[0303] If, in step **1630**, the user input does not comprise a command to exit, then the method proceeds to step **1640**, where the adjustment tool performs a command associated with the user input. In one embodiment, the command comprises a save command and the adjustment tool then saves the combined image, which is generated according to a position of the UI control. The method then proceeds back to step **1616**.

[0304] Returning to step **1630**, if the user input comprises a command to exit, then the method terminates in step **1690**, where the adjustment tool exits, thereby terminating execution.

[0305] In summary, a technique is disclosed for generating a new digital photograph that beneficially blends a first digital image and a second digital image, where the first digital image and the second digital image are both based on a single analog signal received from an image sensor. The first digital image may be blended with the second digital image based on a function that implements any technically feasible blend technique. An adjustment tool may implement a user interface technique that enables a user to select and save the new digital photograph from a gradation of parameters for combining related images.

[0306] One advantage of the disclosed embodiments is that a digital photograph may be selectively generated based on user input using two or more different exposures of a single capture of a photographic scene. Accordingly, the digital photograph generated based on the user input may have a greater dynamic range than any of the individual exposures. Further, the generation of an HDR image using two or more different exposures with zero interframe time allows for the rapid generation of HDR images without motion artifacts.

[0307] FIG. **17**A illustrates a user interface (UI) system **1700** for adjusting a white point and a black point, in accordance with another embodiment. As an option, the UI system **1700** may be implemented in the context of the details of any of the Figures. Of course, however, the UI system **1700** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0308] As shown, in one embodiment, a slider bar **1720** may include a black point slider **1722** and a white point slider **1724**. In various embodiments, the white point slider and the black point slider may be adjusted as desired by the user. Additionally, in another embodiment, the white point slider and the black point may be automatically adjusted. For example, in one embodiment, the black point slider may correspond with a darkest detected point in the image. Additionally, in one embodiment, the white point slider may correspond with the brightest detected point in the image. In one embodiment, the black point slider and the white point slider may each determine a corresponding black point and white point for remapping an input image to generate a resulting image **1712**, such as through levels mapping function **1200** of FIG. **12**. In other embodiments, the black point slider and the white point slider may bend or reshape a levels mapping curve that maps input range **1210** to output range **1220**. As shown, the resulting image **1712**, the slider bar **1720**, and the sliders **1722**, **1724** may be rendered within an application window **1710**.

[0309] In some embodiments, the white point and the black point may be based on a histogram. For example, in one embodiment, the white point and black point may reflect high and low percentage thresholds associated with the histogram.

[0310] In one embodiment, a user may move the white point slider and the black point slider back and forth independently to adjust the black point and white point of the resulting image **1712**. In another embodiment, touching the black point slider **1722** may allow the user to drag and drop the black point on a specific point on the image. In like manner, touching the white point slider **1724** may allow the user to drag and drop the white point on a specific point on the image. Of course, in other embodiments, the user may interact with the white point and the black point (or any other point) in any manner such that the user may select and/or adjust the white point and the black point (or any other point).

[0311] FIG. **17**B illustrates a user interface (UI) system **1702** for adjusting a white point, median point, and a black point, in accordance with another embodiment. As an option, the UI system **1702** may be implemented in the context of the details of any of the Figures. Of course, however, the UI system **1702** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0312] As shown, in one embodiment, a slider bar **1720** may include a white point slider **1722**, a median point slider **1723**, and a white point slider **1724**. In one embodiment, UI system **1702** is configured to operate substantially identically to UI system **1700**, with the addition of median point slider **1723** and corresponding median point levels adjustment within an associated levels adjustment function. The median point may be adjusted manually by the user by moving the median point slider **1723** or automatically based on, for example, information within an input image.

[0313] Still yet, in various embodiments, one or more of the techniques disclosed herein may be applied to a variety of markets and/or products. For example, although the techniques have been disclosed in reference to a still photo capture, they may be applied to televisions, video capture, web conferencing (or live streaming capabilities, etc.), security cameras (e.g. increase contrast to determine characteristic, etc.), automobiles (e.g. driver assist systems, in-car infotainment systems, etc.), and/or any other product which includes a camera input.

[0314] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

[0315] FIG. **18-1** illustrates a system **18-100** for obtaining multiple exposures with zero interframe time, in accordance with one possible embodiment. As an option, the system **18-100** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **18-100** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0316] As shown, a signal amplifier **18-133** receives an analog signal **18-104** from an image sensor **18-132**. In response to receiving the analog signal **18-104**, the signal amplifier **18-133** amplifies the analog signal **18-104** utilizing a first gain, and transmits a first amplified analog signal **18-106**. Further, in response to receiving the analog signal **18-104**, the signal amplifier **18-133** also amplifies the analog signal **18-104** utilizing a second gain, and transmits a second amplified analog signal **18-108**.

[0317] In one specific embodiment, the analog signal **18-106** and the analog signal **18-108** are transmitted on a common electrical interconnect. In alternative embodiments, the analog signal **18-106** and the analog signal **18-108** are transmitted on different electrical interconnects.

[0318] In one embodiment, the analog signal **18-104** generated by image sensor **18-132** includes an electronic representation of an optical image that has been focused on the image sensor **18-132**. In such an embodiment, the optical image may be focused on the image sensor **18-132** by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene.
[0319] In one embodiment, the image sensor **18-132** may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor.
[0320] In an embodiment, the signal amplifier **18-133** may include a transimpedance amplifier (TIA), which may be dynamically configured, such as by digital gain values, to provide a selected gain to the analog signal **18-104**. For example, a TIA could be configured to apply a first gain to the analog signal. The same TIA could then be configured to subsequently apply a second gain to the analog signal. In other embodiments, the gain may be specified to the signal amplifier **18-133** as a digital value. Further, the specified gain value may be based on a specified sensitivity or ISO. The specified sensitivity may be specified by a user of a photographic system, or instead may be set by software or hardware of the photographic system, or some combination of the foregoing working in concert.
[0321] In one embodiment, the signal amplifier **18-133** includes a single amplifier. In such an embodiment, the amplified analog signals **18-106** and **18-108** are transmitted or output in sequence. For example, in one embodiment, the output may occur through a common electrical interconnect. For example, the amplified analog signal **18-106** may first be transmitted, and then the amplified analog signal **18-108** may subsequently be transmitted. In another embodiment, the signal amplifier **18-133** may include a plurality of amplifiers. In such an embodiment, the amplifier **18-133** may transmit the amplified analog signal **18-106** in parallel with the amplified analog signal **18-108**. To this end, the analog signal **18-106** may be amplified utilizing the first gain in serial with the amplification of the analog signal **18-108** utilizing the second gain, or the analog signal **18-106** may be amplified utilizing the first gain in parallel with the amplification of the analog signal **18-108** utilizing the second gain. In one embodiment, the amplified analog signals **18-106** and **18-108** each include gain-adjusted analog pixel data.
[0322] Each instance of gain-adjusted analog pixel data may be converted to digital pixel data by subsequent processes and/or hardware. For example, the amplified analog signal **18-106** may subsequently be converted to a first digital signal comprising a first set of digital pixel data representative of the optical image that has been focused on the image sensor **18-132**. Further, the amplified analog signal **18-108** may subsequently or concurrently be converted to a second digital signal comprising a second set of digital pixel data representative of the optical image that has been focused on the image sensor **18-132**. In one embodiment, any differences between the first set of digital pixel data and the second set of digital pixel data are a function of a difference between the first gain and the second gain applied by the signal amplifier **18-133**. Further, each set of digital pixel data may include a digital image of the photographic scene. Thus, the amplified analog signals **18-106** and **18-108** may be used to generate two different digital images of the photographic scene. Furthermore, in one embodiment, each of the two different digital images may represent a different exposure level.
[0323] FIG. **18-2** illustrates a method **18-200** for obtaining multiple exposures with zero interframe time, in accordance with one embodiment. As an option, the method **18-200** may be carried out in the context of any of the Figures disclosed herein. Of course, however, the method **18-200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0324] As shown in operation **18-202**, an analog signal associated with an image is received from

at least one pixel of an image sensor. In the context of the present embodiment, the analog signal may include analog pixel data for at least one pixel of an image sensor. In one embodiment, the analog signal may include analog pixel data for every pixel of an image sensor. In another embodiment, each pixel of an image sensor may include a plurality of photodiodes. In such an embodiment, the analog pixel data received in the analog signal may include an analog value for each photodiode of each pixel of the image sensor. Each analog value may be representative of a light intensity measured at the photodiode associated with the analog value. Accordingly, an analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values, and analog pixel data may be analog signal values associated with one or more given pixels.

[0325] Additionally, as shown in operation **18-204**, a first amplified analog signal associated with the image is generated by amplifying the analog signal utilizing a first gain, and a second amplified analog signal associated with the image is generated by amplifying the analog signal utilizing a second gain. Accordingly, the analog signal is amplified utilizing both the first gain and the second gain, resulting in the first amplified analog signal and the second amplified analog signal, respectively. In one embodiment, the first amplified analog signal may include first gain-adjusted analog pixel data. In such an embodiment, the second amplified analog signal may include second gain-adjusted analog pixel data. In accordance with one embodiment, the analog signal may be amplified utilizing the first gain simultaneously with the amplification of the analog signal utilizing the second gain. In another embodiment, the analog signal may be amplified utilizing the first gain during a period of time other than when the analog signal is amplified utilizing the second gain. For example, the first gain and the second gain may be applied to the analog signal in sequence. In one embodiment, a sequence for applying the gains to the analog signal may be predetermined.

[0326] Further, as shown in operation **18-206**, the first amplified analog signal and the second amplified analog signal are both transmitted, such that multiple amplified analog signals are transmitted based on the analog signal associated with the image. In the context of one embodiment, the first amplified analog signal and the second amplified analog signal are transmitted in sequence. For example, the first amplified analog signal may be transmitted prior to the second amplified analog signal. In another embodiment, the first amplified analog signal and the second amplified signal may be transmitted in parallel.

[0327] The embodiments disclosed herein advantageously enable a camera module to sample images comprising an image stack with lower (e.g. at or near zero, etc.) inter-sample time (e.g. interframe, etc.) than conventional techniques. In certain embodiments, images comprising the image stack are effectively sampled during overlapping time intervals, which may reduce inter-sample time to zero. In other embodiments, the camera module may sample images in coordination with the strobe unit to reduce inter-sample time between an image sampled without strobe illumination and an image sampled with strobe illumination.

[0328] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.

[0329] FIG. **18-3**A illustrates a system for capturing optical scene information for conversion to an electronic representation of a photographic scene, in accordance with one embodiment. As an option, the system of FIG. **18-3**A may be implemented in the context of the details of any of the Figures.

[0330] As shown in FIG. **18-3**A, a pixel array **18-510** is in communication with row logic **18-512** and a column read out circuit **18-520**. Further, the row logic **18-512** and the column read out circuit **18-520** are both in communication with a control unit **18-514**. Still further, the pixel array **18-510** is shown to include a plurality of pixels **18-540**, where each pixel **18-540** may include four cells, cells **18-542-18-545**. In the context of the present description, the pixel array **18-510** may be included in

an image sensor, such as image sensor **132** or image sensor **332** of camera module **330**.
[0331] As shown, the pixel array **18-510** includes a 2-dimensional array of the pixels **18-540**. For example, in one embodiment, the pixel array **18-510** may be built to comprise 4,000 pixels **18-540** in a first dimension, and 3,000 pixels **18-540** in a second dimension, for a total of 12,000,000 pixels **18-540** in the pixel array **18-510**, which may be referred to as a 12 megapixel pixel array. Further, as noted above, each pixel **18-540** is shown to include four cells **18-542-18-545**. In one embodiment, cell **18-542** may be associated with (e.g. selectively sensitive to, etc.) a first color of light, cell **18-543** may be associated with a second color of light, cell **18-544** may be associated with a third color of light, and cell **18-545** may be associated with a fourth color of light. In one embodiment, each of the first color of light, second color of light, third color of light, and fourth color of light are different colors of light, such that each of the cells **18-542-18-545** may be associated with different colors of light. In another embodiment, at least two cells of the cells **18-542-18-545** may be associated with a same color of light. For example, the cell **18-543** and the cell **18-544** may be associated with the same color of light.
[0332] Further, each of the cells **18-542-18-545** may be capable of storing an analog value. In one embodiment, each of the cells **18-542-18-545** may be associated with a capacitor for storing a charge that corresponds to an accumulated exposure during an exposure time. In such an embodiment, asserting a row select signal to circuitry of a given cell may cause the cell to perform a read operation, which may include, without limitation, generating and transmitting a current that is a function of the stored charge of the capacitor associated with the cell. In one embodiment, prior to a readout operation, current received at the capacitor from an associated photodiode may cause the capacitor, which has been previously charged, to discharge at a rate that is proportional to an incident light intensity detected at the photodiode. The remaining charge of the capacitor of the cell may then be read using the row select signal, where the current transmitted from the cell is an analog value that reflects the remaining charge on the capacitor. To this end, an analog value received from a cell during a readout operation may reflect an accumulated intensity of light detected at a photodiode. The charge stored on a given capacitor, as well as any corresponding representations of the charge, such as the transmitted current, may be referred to herein as a type of analog pixel data. Of course, analog pixel data may include a set of spatially discrete intensity samples, each represented by continuous analog values.
[0333] Still further, the row logic **18-512** and the column read out circuit **18-520** may work in concert under the control of the control unit **18-514** to read a plurality of cells **18-542-18-545** of a plurality of pixels **18-540**. For example, the control unit **18-514** may cause the row logic **18-512** to assert a row select signal comprising row control signals **18-530** associated with a given row of pixels **18-540** to enable analog pixel data associated with the row of pixels to be read. As shown in FIG. **18-3**A, this may include the row logic **18-512** asserting one or more row select signals comprising row control signals **18-530**(**0**) associated with a row **18-534**(**0**) that includes pixel **18-540**(**0**) and pixel **18-540**(*a*). In response to the row select signal being asserted, each pixel **18-540** on row **18-534**(**0**) transmits at least one analog value based on charges stored within the cells **18-542-18-545** of the pixel **18-540**. In certain embodiments, cell **18-542** and cell **18-543** are configured to transmit corresponding analog values in response to a first row select signal, while cell **18-544** and cell **18-545** are configured to transmit corresponding analog values in response to a second row select signal.
[0334] In one embodiment, analog values for a complete row of pixels **18-540** comprising each row **18-534**(**0**) through **18-534**(*r*) may be transmitted in sequence to column read out circuit **18-520** through column signals **18-532**. In one embodiment, analog values for a complete row or pixels or cells within a complete row of pixels may be transmitted simultaneously. For example, in response to row select signals comprising row control signals **18-530**(**0**) being asserted, the pixel **18-540**(**0**) may respond by transmitting at least one analog value from the cells **18-542-18-545** of the pixel **18-540**(**0**) to the column read out circuit **18-520** through one or more signal paths comprising

column signals **18-532(0)**; and simultaneously, the pixel **18-540**(*a*) will also transmit at least one analog value from the cells **18-542-18-545** of the pixel **18-540**(*a*) to the column read out circuit **18-520** through one or more signal paths comprising column signals **18-532**(*c*). Of course, one or more analog values may be received at the column read out circuit **18-520** from one or more other pixels **18-540** concurrently to receiving the at least one analog value from pixel **18-540(0)** and concurrently receiving the at least one analog value from the pixel **18-540**(*a*). Together, a set of analog values received from the pixels **18-540** comprising row **18-534(0)** may be referred to as an analog signal, and this analog signal may be based on an optical image focused on the pixel array **18-510**. An analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values.

[0335] Further, after reading the pixels **18-540** comprising row **18-534(0)**, the row logic **18-512** may select a second row of pixels **18-540** to be read. For example, the row logic **18-512** may assert one or more row select signals comprising row control signals **18-530**(*r*) associated with a row of pixels **18-540** that includes pixel **18-540**(*b*) and pixel **18-540**(*z*). As a result, the column read out circuit **18-520** may receive a corresponding set of analog values associated with pixels **18-540** comprising row **18-534**(*r*).

[0336] The column read out circuit **18-520** may serve as a multiplexer to select and forward one or more received analog values to an analog-to-digital converter circuit, such as analog-to-digital unit **18-622** of FIG. **18-4**. The column read out circuit **18-520** may forward the received analog values in a predefined order or sequence. In one embodiment, row logic **18-512** asserts one or more row selection signals comprising row control signals **18-530**, causing a corresponding row of pixels to transmit analog values through column signals **18-532**. The column read out circuit **18-520** receives the analog values and sequentially selects and forwards one or more of the analog values at a time to the analog-to-digital unit **18-622**. Selection of rows by row logic **18-512** and selection of columns by column read out circuit **18-620** may be directed by control unit **18-514**. In one embodiment, rows **18-534** are sequentially selected to be read, starting with row **18-534(0)** and ending with row **18-534**(*r*), and analog values associated with sequential columns are transmitted to the analog-to-digital unit **18-622**. In other embodiments, other selection patterns may be implemented to read analog values stored in pixels **18-540**.

[0337] Further, the analog values forwarded by the column read out circuit **18-520** may comprise analog pixel data, which may later be amplified and then converted to digital pixel data for generating one or more digital images based on an optical image focused on the pixel array **18-510**.

[0338] FIGS. **18-3**B-**18-3**D illustrate three optional pixel configurations, according to one or more embodiments. As an option, these pixel configurations may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, these pixel configurations may be implemented in any desired environment. By way of a specific example, any of the pixels **18-540** of FIGS. **18-3**B-**18-3**D may operate as one or more of the pixels **18-540** of the pixel array **18-510**.

[0339] As shown in FIG. **18-3**B, a pixel **18-540** is illustrated to include a first cell (R) for measuring red light intensity, second and third cells (G) for measuring green light intensity, and a fourth cell (B) for measuring blue light intensity, in accordance with one embodiment. As shown in FIG. **18-3**C, a pixel **18-540** is illustrated to include a first cell (R) for measuring red light intensity, a second cell (G) for measuring green light intensity, a third cell (B) for measuring blue light intensity, and a fourth cell (W) for measuring white light intensity, in accordance with another embodiment. As shown in FIG. **18-3**D, a pixel **18-540** is illustrated to include a first cell (C) for measuring cyan light intensity, a second cell (M) for measuring magenta light intensity, a third cell (Y) for measuring yellow light intensity, and a fourth cell (W) for measuring white light intensity, in accordance with yet another embodiment.

[0340] Of course, while pixels **18-540** are each shown to include four cells, a pixel **18-540** may be configured to include fewer or more cells for measuring light intensity. Still further, in another embodiment, while certain of the cells of pixel **18-540** are shown to be configured to measure a single peak wavelength of light, or white light, the cells of pixel **18-540** may be configured to measure any wavelength, range of wavelengths of light, or plurality of wavelengths of light.

[0341] Referring now to FIG. **18-3**E, a system is shown for capturing optical scene information focused as an optical image on an image sensor **332**, in accordance with one embodiment. As an option, the system of FIG. **18-3**E may be implemented in the context of the details of any of the Figures. Of course, however, the system of FIG. **18-3**E may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0342] As shown in FIG. **18-3**E, an image sensor **332** is shown to include a first cell **18-544**, a second cell **18-545**, and a third cell **18-548**. Further, each of the cells **18-544-548** is shown to include a photodiode **18-562**. Still further, upon each of the photodiodes **18-562** is a corresponding filter **18-564**, and upon each of the filters **18-564** is a corresponding microlens **18-566**. For example, the cell **18-544** is shown to include photodiode **18-562**(**0**), upon which is filter **18-564**(**0**), and upon which is microlens **18-566**(**0**). Similarly, the cell **18-545** is shown to include photodiode **18-562**(**1**), upon which is filter **18-564**(**1**), and upon which is microlens **18-566**(**1**). Still yet, as shown in FIG. **18-3**E, pixel **18-540** is shown to include each of cells **18-544** and **18-545**, photodiodes **18-562**(**0**) and **18-562**(**1**), filters **18-564**(**0**) and **18-564**(**1**), and microlenses **18-566**(**0**) and **18-566**(**1**).**460**

[0343] In one embodiment, each of the microlenses **18-566** may be any lens with a diameter of less than 50 microns. However, in other embodiments each of the microlenses **18-566** may have a diameter greater than or equal to 50 microns. In one embodiment, each of the microlenses **18-566** may include a spherical convex surface for focusing and concentrating received light on a supporting substrate beneath the microlens **18-566**. For example, as shown in FIG. **18-3**E, the microlens **18-566**(**0**) focuses and concentrates received light on the filter **18-564**(**0**). In one embodiment, a microlens array **18-567** may include microlenses **18-566**, each corresponding in placement to photodiodes **18-562** within cells **18-544** of image sensor **332**.

[0344] In the context of the present description, the photodiodes **18-562** may comprise any semiconductor diode that generates a potential difference, or changes its electrical resistance, in response to photon absorption. Accordingly, the photodiodes **18-562** may be used to detect or measure light intensity. Further, each of the filters **18-564** may be optical filters for selectively transmitting light of one or more predetermined wavelengths. For example, the filter **18-564**(**0**) may be configured to selectively transmit substantially only green light received from the corresponding microlens **18-566**(**0**), and the filter **18-564**(**1**) may be configured to selectively transmit substantially only blue light received from the microlens **18-566**(**1**). Together, the filters **18-564** and microlenses **18-566** may be operative to focus selected wavelengths of incident light on a plane. In one embodiment, the plane may be a 2-dimensional grid of photodiodes **18-562** on a surface of the image sensor **332**. Further, each photodiode **18-562** receives one or more predetermined wavelengths of light, depending on its associated filter. In one embodiment, each photodiode **18-562** receives only one of red, blue, or green wavelengths of filtered light. As shown with respect to FIGS. **18-3**B-**18-3**D, it is contemplated that a photodiode may be configured to detect wavelengths of light other than only red, green, or blue. For example, in the context of FIGS. **18-3**C-**18-3**D specifically, a photodiode may be configured to detect white, cyan, magenta, yellow, or non-visible light such as infrared or ultraviolet light.

[0345] To this end, each coupling of a cell, photodiode, filter, and microlens may be operative to receive light, focus and filter the received light to isolate one or more predetermined wavelengths of light, and then measure, detect, or otherwise quantify an intensity of light received at the one or more predetermined wavelengths. The measured or detected light may then be represented as an analog value stored within a cell. For example, in one embodiment, the analog value may be stored within the cell utilizing a capacitor, as discussed in more detail above. Further, the analog value stored within the cell may be output from the cell based on a selection signal, such as a row selection signal, which may be received from row logic **18-512**. Further still, the analog value transmitted from a single cell may comprise one analog value in a plurality of analog values of an analog signal, where each of the analog values is output by a different cell. Accordingly, the analog signal may comprise a plurality of analog pixel data values from a plurality of cells. In one embodiment, the analog signal may comprise analog pixel data values for an entire image of a photographic scene. In another embodiment, the analog signal may comprise analog pixel data values for a subset of the entire image of the photographic scene. For example, the analog signal may comprise analog pixel data values for a row of pixels of the image of the photographic scene. In the context of FIGS. **18-3**A-**18-3**E, the row **18-534**(**0**) of the pixels **18-540** of the pixel array **18-510** may be one such row of pixels of the image of the photographic scene.

[0346] FIG. **18-4** illustrates a system for converting analog pixel data to digital pixel data, in accordance with an embodiment. As an option, the system of FIG. **18-4** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system of FIG. **18-4** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0347] As shown in FIG. **18-4**, analog pixel data **18-621** is received from column read out circuit **18-520** at analog-to-digital unit **18-622** under the control of control unit **18-514**. The analog pixel data **18-621** may be received within an analog signal, as noted hereinabove. Further, the analog-to-digital unit **18-622** generates digital pixel data **18-625** based on the received analog pixel data **18-621**.

[0348] More specifically, and as shown in FIG. **18-4**, the analog-to-digital unit **18-622** includes an amplifier **18-650** and an analog-to-digital converter **18-654**. In one embodiment, the amplifier **18-650** receives both the analog pixel data **18-621** and a gain **18-652**, and applies the gain **18-652** to the analog pixel data **18-621** to generate gain-adjusted analog pixel data **18-623**. The gain-adjusted analog pixel data **18-623** is transmitted from the amplifier **18-650** to the analog-to-digital converter **18-654**. The analog-to-digital converter **18-654** receives the gain-adjusted analog pixel data **18-623**, and converts the gain-adjusted analog pixel data **18-623** to the digital pixel data **18-625**, which is then transmitted from the analog-to-digital converter **18-654**. In other embodiments, the amplifier **18-650** may be implemented within the column read out circuit **18-520** instead of within the analog-to-digital unit **18-622**. The analog-to-digital converter **18-654** may convert the gain-adjusted analog pixel data **18-623** to the digital pixel data **18-625** using any technically feasible analog-to-digital conversion system.

[0349] In an embodiment, the gain-adjusted analog pixel data **18-623** results from the application of the gain **18-652** to the analog pixel data **18-621**. In one embodiment, the gain **18-652** may be selected by the analog-to-digital unit **18-622**. In another embodiment, the gain **18-652** may be selected by the control unit **18-514**, and then supplied from the control unit **18-514** to the analog-to-digital unit **18-622** for application to the analog pixel data **18-621**.

[0350] It should be noted, in one embodiment, that a consequence of applying the gain **18-652** to the analog pixel data **18-621** is that analog noise may appear in the gain-adjusted analog pixel data **18-623**. If the amplifier **18-650** imparts a significantly large gain to the analog pixel data **18-621** in order to obtain highly sensitive data from of the pixel array **18-510**, then a significant amount of noise may be expected within the gain-adjusted analog pixel data **18-623**. In one embodiment, the detrimental effects of such noise may be reduced by capturing the optical scene information at a reduced overall exposure. In such an embodiment, the application of the gain **18-652** to the analog pixel data **18-621** may result in gain-adjusted analog pixel data with proper exposure and reduced noise.

[0351] In one embodiment, the amplifier **18-650** may be a transimpedance amplifier (TIA). Furthermore, the gain **18-652** may be specified by a digital value. In one embodiment, the digital value specifying the gain **18-652** may be set by a user of a digital photographic device, such as by operating the digital photographic device in a “manual” mode. Still yet, the digital value may be set by hardware or software of a digital photographic device. As an option, the digital value may be set by the user working in concert with the software of the digital photographic device.

[0352] In one embodiment, a digital value used to specify the gain **18-652** may be associated with an ISO. In the field of photography, the ISO system is a well-established standard for specifying light sensitivity. In one embodiment, the amplifier **18-650** receives a digital value specifying the gain **18-652** to be applied to the analog pixel data **18-621**. In another embodiment, there may be a mapping from conventional ISO values to digital gain values that may be provided as the gain **18-652** to the amplifier **18-650**. For example, each of ISO 100, ISO 200, ISO 400, ISO 800, ISO 1600, etc. may be uniquely mapped to a different digital gain value, and a selection of a particular ISO results in the mapped digital gain value being provided to the amplifier **18-650** for application as the gain **18-652**. In one embodiment, one or more ISO values may be mapped to a gain of 1. Of course, in other embodiments, one or more ISO values may be mapped to any other gain value.

[0353] Accordingly, in one embodiment, each analog pixel value may be adjusted in brightness given a particular ISO value. Thus, in such an embodiment, the gain-adjusted analog pixel data **18-623** may include brightness corrected pixel data, where the brightness is corrected based on a specified ISO. In another embodiment, the gain-adjusted analog pixel data **18-623** for an image may include pixels having a brightness in the image as if the image had been sampled at a certain ISO.

[0354] In accordance with an embodiment, the digital pixel data **18-625** may comprise a plurality of digital values representing pixels of an image captured using the pixel array **18-510**.

[0355] FIG. **18-5** illustrates a system **18-700** for converting analog pixel data of an analog signal to digital pixel data, in accordance with an embodiment. As an option, the system **18-700** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system **18-700** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0356] The system **18-700** is shown in FIG. **18-5** to include an analog storage plane **18-702**, an analog-to-digital unit **18-722**, a first digital image **18-732**, and a second digital image **18-734**. Additionally, in one embodiment, analog values may each be depicted as a “V” within the analog storage plane **18-702** and corresponding digital values may each be depicted as a “D” within first digital image **18-732** and second digital image **18-734**.

[0357] In the context of the present description, the analog storage plane **18-702** may comprise any collection of one or more analog values. In one embodiment, the analog storage plane **18-702** may comprise one or more analog pixel values. In some embodiments, the analog storage plane **18-702** may comprise at least one analog pixel value for each pixel of a row or line of a pixel array. Still yet, in another embodiment, the analog storage plane **18-702** may comprise at least one analog pixel value for each pixel of an entirety of a pixel array, which may be referred to as a frame. In one embodiment, the analog storage plane **18-702** may comprise an analog value for each cell of a pixel. In yet another embodiment, the analog storage plane **18-702** may comprise an analog value for each cell of each pixel of a row or line of a pixel array. In another embodiment, the analog storage plane **18-702** may comprise an analog value for each cell of each pixel of multiple lines or rows of a pixel array. For example, the analog storage plane **18-702** may comprise an analog value for each cell of each pixel of every line or row of a pixel array.

[0358] Further, the analog values of the analog storage plane **18-702** are output as analog pixel data **18-704** to the analog-to-digital unit **18-722**. In one embodiment, the analog-to-digital unit **18-722** may be substantially identical to the analog-to-digital unit **18-622** described within the context of FIG. **18-4**. For example, the analog-to-digital unit **18-722** may comprise at least one amplifier and at least one analog-to-digital converter, where the amplifier is operative to receive a gain value and utilize the gain value to gain-adjust analog pixel data received at the analog-to-digital unit **18-722**. Further, in such an embodiment, the amplifier may transmit gain-adjusted analog pixel data to an analog-to-digital converter, which then generates digital pixel data from the gain-adjusted analog pixel data.

[0359] In the context of the system **18-700** of FIG. **18-5**, the analog-to-digital unit **18-722** receives the analog pixel data **18-704**, and applies at least two different gains to the analog pixel data **18-704** to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data. Further, the analog-to-digital unit **18-722** converts each generated gain-adjusted analog pixel data to digital pixel data, and then outputs at least two digital outputs. To this end, the analog-to-digital unit **18-722** provides a different digital output corresponding to each gain applied to the analog pixel data **18-704**. With respect to FIG. **18-5** specifically, the analog-to-digital unit **18-722** is shown to generate a first digital signal comprising first digital pixel data **18-723** corresponding to a first gain **18-652**, and a second digital signal comprising second digital pixel data **18-724** corresponding to a second gain **18-752**.

[0360] In one embodiment, the analog-to-digital unit **18-722** applies in sequence the at least two gains to the analog values. For example, the analog-to-digital unit **18-722** first applies the first gain **18-652** to the analog pixel data **18-704**, and then subsequently applies the second gain **18-752** to the same analog pixel data **18-704**. In other embodiments, the analog-to-digital unit **18-722** may apply in parallel the at least two gains to the analog values. For example, the analog-to-digital unit **18-722** may apply the first gain **652** to the analog pixel data **18-704** in parallel with the application of the second gain **18-752** to the analog pixel data **18-704**. To this end, as a result of applying the at least two gains, the analog pixel data **18-704** is amplified utilizing at least the first gain **18-652** and the second gain **18-752**.

[0361] In accordance with one embodiment, the at least two gains may be determined using any technically feasible technique based on an exposure of a photographic scene, metering data, user input, detected ambient light, a strobe control, or any combination of the foregoing. For example, a first gain of the at least two gains may be determined such that half of the digital values from the analog storage plane **18-702** are converted to digital values above a specified threshold (e.g., a threshold of 0.5 in a range of 0.0 to 1.0) for the dynamic range associated with digital values comprising the first digital image **18-732**, which can be characterized as having an “EV0” exposure. Continuing the example, a second gain of the at least two gains may be determined as being twice that of the first gain to generate a second digital image **18-734** characterized as having an “EV+1” exposure.

[0362] In one embodiment, the analog-to-digital unit **18-722** converts in sequence the first gain-adjusted analog pixel data to the first digital pixel data **18-723**, and the second gain-adjusted analog pixel data to the second digital pixel data **18-724**. For example, the analog-to-digital unit **18-722** first converts the first gain-adjusted analog pixel data to the first digital pixel data **18-723**, and then subsequently converts the second gain-adjusted analog pixel data to the second digital pixel data **18-724**. In other embodiments, the analog-to-digital unit **18-722** may perform such conversions in parallel, such that the first digital pixel data **18-723** is generated in parallel with the second digital pixel data **18-724**.

[0363] Still further, as shown in FIG. **18-5**, the first digital pixel data **18-723** is used to provide the first digital image **18-732**. Similarly, the second digital pixel data **18-724** is used to provide the second digital image **18-734**. The first digital image **18-732** and the second digital image **18-734** are both based upon the same analog pixel data **18-704**, however the first digital image **18-732** may differ from the second digital image **18-734** as a function of a difference between the first gain **18-652** (used to generate the first digital image **18-732**) and the second gain **18-752** (used to generate the second digital image **18-752**). Specifically, the digital image generated using the largest gain of the at least two gains may be visually perceived as the brightest or more exposed. Conversely, the digital image generated using the smallest gain of the at least two gains may be visually perceived as the darkest and less exposed. To this end, a first light sensitivity value may be associated with the first digital pixel data **18-723**, and a second light sensitivity value may be associated with the second digital pixel data **18-724**. Further, because each of the gains may be associated with a different light sensitivity value, the first digital image or first digital signal may be associated with a first light sensitivity value, and the second digital image or second digital signal may be associated with a second light sensitivity value.

[0364] It should be noted that while a controlled application of gain to the analog pixel data may greatly aid in HDR image generation, an application of too great of gain may result in a digital image that is visually perceived as being noisy, over-exposed, and/or blown-out. In one embodiment, application of two stops of gain to the analog pixel data may impart visually perceptible noise for darker portions of a photographic scene, and visually imperceptible noise for brighter portions of the photographic scene. In another embodiment, a digital photographic device may be configured to provide an analog storage plane of analog pixel data for a captured photographic scene, and then perform at least two analog-to-digital samplings of the same analog pixel data using the analog-to-digital unit **18-722**. To this end, a digital image may be generated for each sampling of the at least two samplings, where each digital image is obtained at a different exposure despite all the digital images being generated from the same analog sampling of a single optical image focused on an image sensor.

[0365] In one embodiment, an initial exposure parameter may be selected by a user or by a metering algorithm of a digital photographic device. The initial exposure parameter may be selected based on user input or software selecting particular capture variables. Such capture variables may include, for example, ISO, aperture, and shutter speed. An image sensor may then capture a single exposure of a photographic scene at the initial exposure parameter, and populate an analog storage plane with analog values corresponding to an optical image focused on the image sensor. Next, a first digital image may be obtained utilizing a first gain in accordance with the above systems and methods. For example, if the digital photographic device is configured such that the initial exposure parameter includes a selection of ISO 400, the first gain utilized to obtain the first digital image may be mapped to, or otherwise associated with, ISO 400. This first digital image may be referred to as an exposure or image obtained at exposure value 0 (EV 0). Further at least one more digital image may be obtained utilizing a second gain in accordance with the above systems and methods. For example, the same analog pixel data used to generate the first digital image may be processed utilizing a second gain to generate a second digital image.

[0366] In one embodiment, at least two digital images may be generated using the same analog pixel data and blended to generate an HDR image. The at least two digital images generated using the same analog signal may be blended by blending a first digital signal and a second digital signal. Because the at least two digital images are generated using the same analog pixel data, there may be zero interframe time between the at least two digital images. As a result of having zero interframe time between at least two digital images of a same photographic scene, an HDR image may be generated without motion blur or other artifacts typical of HDR photographs.

[0367] In another embodiment, the second gain may be selected based on the first gain. For example, the second gain may be selected on the basis of it being one stop away from the first gain. More specifically, if the first gain is mapped to or associated with ISO 400, then one stop down from ISO 400 provides a gain associated with ISO 200, and one stop up from ISO 400 provides a gain associated with ISO 800. In such an embodiment, a digital image generated utilizing the gain associated with ISO 200 may be referred to as an exposure or image obtained at exposure value −1 (EV −1), and a digital image generated utilizing the gain associated with ISO 800 may be referred to as an exposure or image obtained at exposure value +1 (EV +1).

[0368] Still further, if a more significant difference in exposures is desired between digital images generated utilizing the same analog signal, then the second gain may be selected on the basis of it being two stops away from the first gain. For example, if the first gain is mapped to or associated with ISO 400, then two stops down from ISO 400 provides a gain associated with ISO 100, and two stops up from ISO 400 provides a gain associated with ISO 1600. In such an embodiment, a digital image generated utilizing the gain associated with ISO 100 may be referred to as an exposure or image obtained at exposure value −2 (EV −2), and a digital image generated utilizing the gain associated with ISO 1600 may be referred to as an exposure or image obtained at exposure value +2 (EV +2).

[0369] In one embodiment, an ISO and exposure of the EV 0 image may be selected according to a preference to generate darker or more saturated digital images. In such an embodiment, the intention may be to avoid blowing out or overexposing what will be the brightest digital image, which is the digital image generated utilizing the greatest gain. In another embodiment, an EV −1 digital image or EV −2 digital image may be a first generated digital image. Subsequent to generating the EV −1 or EV −2 digital image, an increase in gain at an analog-to-digital unit may be utilized to generate an EV0 digital image, and then a second increase in gain at the analog-to-digital unit may be utilized to generate an EV +1 or EV +2 digital image. In one embodiment, the initial exposure parameter corresponds to an EV-N digital image and subsequent gains are used to obtain an EV 0 digital image, an EV +M digital image, or any combination thereof, where N and M are values ranging from 0 to **−10**.

[0370] In one embodiment, an EV −2 digital image, an EV 0 digital image, and an EV +2 digital image may be generated in parallel by implementing three analog-to-digital units. Such an implementation may be also capable of simultaneously generating all of an EV −1 digital image, an EV 0 digital image, and an EV +1 digital image. Similarly, any combination of exposures may be generated in parallel from two or more analog-to-digital units, three or more analog-to-digital units, or an arbitrary number of analog-to-digital units.

[0371] FIG. **18-6** illustrates various timing configurations for amplifying analog signals, in accordance with various embodiments. As an option, the timing configurations of FIG. **18-6** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the timing configurations of FIG. **18-6** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0372] Specifically, as shown in FIG. **18-6**, per pixel timing configuration **18-801** is shown to amplify analog signals on a pixel-by-pixel basis. Further, per line timing configuration **18-811** is shown to amplify analog signals on a line-by-line basis. Finally, per frame timing configuration **18-821** is shown to amplify analog signals on a frame-by-frame basis. Each amplified analog signal associated with analog pixel data may be converted to a corresponding digital signal value.

[0373] In systems that implement per pixel timing configuration **18-801**, an analog signal containing analog pixel data may be received at an analog-to-digital unit. Further, the analog pixel data may include individual analog pixel values. In such an embodiment, a first analog pixel value associated with a first pixel may be identified within the analog signal and selected. Next, each of a first gain **18-803**, a second gain **18-805**, and a third gain **18-807** may be applied in sequence or concurrently to the same first analog pixel value. In some embodiments less than or more than three different gains may be applied to a selected analog pixel value. For example, in some embodiments applying only two different gains to the same analog pixel value may be sufficient for generating a satisfactory HDR image. In one embodiment, after applying each of the first gain **18-803**, the second gain **18-805**, and the third gain **18-807**, a second analog pixel value associated with a second pixel may be identified within the analog signal and selected. The second pixel may be a neighboring pixel of the first pixel. For example, the second pixel may be in a same row as the first pixel and located adjacent to the first pixel on a pixel array of an image sensor. Next, each of the first gain **18-803**, the second gain **18-805**, and the third gain **18-807** may be applied in sequence or concurrently to the same second analog pixel value. To this end, in the per pixel timing configuration **18-801**, a plurality of sequential analog pixel values may be identified within an analog signal, and a set of at least two gains are applied to each pixel in the analog signal on a pixel-by-pixel basis.

[0374] Further, in systems that implement the per pixel timing configuration **18-801**, a control unit may select a next gain to be applied after each pixel is amplified using a previously selected gain.

In another embodiment, a control unit may control an amplifier to cycle through a set of predetermined gains that will be applied to a first analog pixel value, such a first analog pixel data value comprising analog pixel data **18-704**, associated with a first pixel so that each gain in the set may be used to amplify the first analog pixel data before applying the set of predetermined gains to a second analog pixel data that subsequently arrives at the amplifier. In one embodiment, and as shown in the context of FIG. **18-6**, this may include selecting a first gain, applying the first gain to a received first analog pixel value, selecting a second gain, applying the second gain to the received first analog pixel value, selecting a third gain, applying the third selected gain to the received first analog pixel value, and then receiving a second analog pixel value and applying the three selected gains to the second pixel value in the same order as applied to the first pixel value. In one embodiment, each analog pixel value may be read a plurality of times. In general, an analog storage plane may be utilized to hold the analog pixel values of the pixels for reading.

[0375] In systems that implement per line timing configuration **18-811**, an analog signal containing analog pixel data may be received at an analog-to-digital unit. Further, the analog pixel data may include individual analog pixel values. In one embodiment, a first line of analog pixel values associated with a first line of pixels of a pixel array may be identified within the analog signal and selected. Next, each of a first gain **18-813**, a second gain **18-815**, and a third gain **18-817** may be applied in sequence or concurrently to the same first line of analog pixel values. In some embodiments less than or more than three different gains may be applied to a selected line of analog pixel values. For example, in some embodiments applying only two different gains to the same line of analog pixel values may be sufficient for generating a satisfactory HDR image. In one embodiment, after applying each of the first gain **18-813**, the second gain **18-815**, and the third gain **18-817**, a second line of analog pixel values associated with a second line of pixels may be identified within the analog signal and selected. The second line of pixels may be a neighboring line of the first line of pixels. For example, the second line of pixels may be located immediately above or immediately below the first line of pixels in a pixel array of an image sensor. Next, each of the first gain **18-813**, the second gain **18-815**, and the third gain **18-817** may be applied in sequence or concurrently to the same second line of analog pixel values. To this end, in the per line timing configuration **18-811**, a plurality of sequential lines of analog pixel values are identified within an analog signal, and a set of at least two gains are applied to each line of analog pixel values in the analog signal on a line-by-line basis.

[0376] Further, in systems that implement the per line timing configuration **18-811**, a control unit may select a next gain to be applied after each line is amplified using a previously selected gain. In another embodiment, a control unit may control an amplifier to cycle through a set of predetermined gains that will be applied to a line so that each gain in the set is used to amplify a first line of analog pixel values before applying the set of predetermined gains to a second line of analog pixel values that arrives at the amplifier subsequent to the first line of analog pixel values. In one embodiment, and as shown in the context of FIG. **18-6**, this may include selecting a first gain, applying the first gain to a received first line of analog pixel values, selecting a second gain, applying the second gain to the received first line of analog pixel values, selecting a third gain, applying the third selected gain to the received first line of analog pixel values, and then receiving a second line of analog pixel values and applying the three selected gains to the second line of analog pixel values in the same order as applied to the first line of analog pixel values. In one embodiment, each line of analog pixel values may be read a plurality of times. In another embodiment, an analog storage plane may be utilized to hold the analog pixel data values of one or more lines for reading.

[0377] In systems that implement per frame timing configuration **18-821**, an analog signal that contains a plurality of analog pixel data values comprising analog pixel values may be received at an analog-to-digital unit. In such an embodiment, a first frame of analog pixel values associated with a first frame of pixels may be identified within the analog signal and selected. Next, each of a first gain **18-823**, a second gain **18-825**, and a third gain **18-827** may be applied in sequence or concurrently to the same first frame of analog pixel values. In some embodiments less than or more than three different gains may be applied to a selected frame of analog pixel values. For example, in some embodiments applying only two different gains to the same frame of analog pixel values may be sufficient for generating a satisfactory HDR image.

[0378] In one embodiment, after applying each of the first gain **18-823**, the second gain **18-825**, and the third gain **18-827**, a second frame of analog pixel values associated with a second frame of pixels may be identified within the analog signal and selected. The second frame of pixels may be a next frame in a sequence of frames that capture video data associated with a photographic scene. For example, a digital photographic system may be operative to capture 30 frames per second of video data. In such digital photographic systems, the first frame of pixels may be one frame of said thirty frames, and the second frame of pixels may be a second frame of said thirty frames. Further still, each of the first gain **18-823**, the second gain **18-825**, and the third gain **18-827** may be applied in sequence to the analog pixel values of the second frame. To this end, in the per frame timing configuration **18-821**, a plurality of sequential frames of analog pixel values may be identified within an analog signal, and a set of at least two gains are applied to each frame of analog pixel values on a frame-by-frame basis.

[0379] Further, in systems that implement the per frame timing configuration **18-821**, a control unit may select a next gain to be applied after each frame is amplified using a previously selected gain. In another embodiment, a control unit may control an amplifier to cycle through a set of predetermined gains that will be applied to a frame so that each gain is used to amplify a analog pixel values associated with the first frame before applying the set of predetermined gains to analog pixel values associated with a second frame that subsequently arrive at the amplifier. In one embodiment, and as shown in the context of FIG. **18-6**, this may include selecting a first gain, applying the first gain to analog pixel values associated with the first frame, selecting a second gain, applying the second gain to analog pixel values associated with the first frame, selecting a third gain, and applying the third gain to analog pixel values associated with the first frame. In another embodiment, analog pixel values associated with a second frame may be received following the application of all three selected gains to analog pixel values associated with the first frame, and the three selected gains may then be applied to analog pixel values associated with the second frame in the same order as applied to the first frame.

[0380] In yet another embodiment, selected gains applied to the first frame may be different than selected gains applied to the second frame, such as may be the case when the second frame includes different content and illumination than the first frame. In general, an analog storage plane may be utilized to hold the analog pixel data values of one or more frames for reading.

[0381] In certain embodiments, an analog-to-digital unit is assigned for each different gain and the analog-to-digital units are configured to operate concurrently. Resulting digital values may be interleaved for output or may be output in parallel. For example, analog pixel data for a given row may be amplified according to gain **18-803** and converted to corresponding digital values by a first analog-to-digital unit, while, concurrently, the analog pixel data for the row may be amplified according to gain **18-805** and converted to corresponding digital values by a second analog-to-digital unit. Furthermore, and concurrently, the analog pixel data for the row may be amplified according to gain **18-807** and converted to corresponding digital values by a third analog-to-digital unit. Digital values from the first through third analog-to-digital units may be output as sets of pixels, with each pixel in a set of pixels corresponding to one of the three gains **18-803**, **18-805**, **18-807**. Similarly, output data values may be organized as lines having different gain values, with each line comprising pixels with a gain corresponding to one of the three gains **18-803**, **18-805**, **18-807**.

[0382] FIG. **18-7** illustrates a system **18-900** for converting in parallel analog pixel data to multiple signals of digital pixel data, in accordance with one embodiment. As an option, the system **18-900** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system **18-900** may be implemented in any desired environment. Further, the

aforementioned definitions may equally apply to the description below.
[0383] In the context of FIG. **18-7**, the system **18-900** is shown to receive as input analog pixel data **18-621**. The analog pixel data **18-621** may be received within an analog signal, as noted hereinabove. Further, the analog-to-digital units **18-622** may be configured to generate digital pixel data **18-625** based on the received analog pixel data **18-621**.
[0384] As shown in FIG. **18-7**, the system **18-900** is configured to mirror the current of the analog pixel data **18-621** such that each of analog-to-digital unit **18-622**(**0**), analog-to-digital unit **18-622**(**1**), and analog-to-digital unit **18-622**(*n*) receive a scaled copy of the analog pixel data **18-621**. In one embodiment, each of the analog-to-digital unit **18-622**(**0**), the analog-to-digital unit **18-622**(**1**), and the analog-to-digital unit **18-622**(*n*) may be configured to apply a unique gain to the analog pixel data **18-621**. Each scaled copy may be scaled according to physical dimensions for the transistors comprising system **18-900**, which comprises a structure known in the art as a current mirror. As shown, each current i1, i2, i3 may be generated in an arbitrary ratio relative to input current Iin, based on the physical dimensions. For example, currents i1, i2, i3 may be generated in a ratio of 1:1:1, 1:2:4, 0.5:1:2, or any other technically feasible ratio relative to lin.
[0385] In an embodiment, the unique gains may be configured at each of the analog-to-digital units **18-622** by a controller. By way of a specific example, the analog-to-digital unit **18-622**(**0**) may be configured to apply a gain of 1.0 to the analog pixel data **18-621**, the analog-to-digital unit **18-622**(**1**) may be configured to apply a gain of 2.0 to the analog pixel data **18-621**, and the analog-to-digital unit **18-622**(*n*) may be configured to apply a gain of 4.0 to the analog pixel data **18-621**. Accordingly, while the same analog pixel data **18-621** may be input transmitted to each of the analog-to-digital unit **18-622**(**0**), the analog-to-digital unit **18-622**(**1**), and the analog-to-digital unit **18-622**(*n*), each of digital pixel data **18-625**(**0**), digital pixel data **18-625**(**1**), and digital pixel data **18-625**(*n*) may include different digital values based on the different gains applied within the analog-to-digital units **18-622**, and thereby provide unique exposure representations of the same photographic scene.
[0386] In the embodiment described above, where the analog-to-digital unit **18-622**(**0**) may be configured to apply a gain of 1.0, the analog-to-digital unit **18-622**(**1**) may be configured to apply a gain of 2.0, and the analog-to-digital unit **18-622**(*n*) may be configured to apply a gain of 4.0, the digital pixel data **18-625**(**0**) may provide the least exposed corresponding digital image. Conversely, the digital pixel data **18-625**(*n*) may provide the most exposed digital image. In another embodiment, the digital pixel data **18-625**(**0**) may be utilized for generating an EV −1 digital image, the digital pixel data **18-625**(**1**) may be utilized for generating an EV 0 digital image, and the digital pixel data **18-625**(*n*) may be utilized for generating an EV +2 image. In another embodiment, system **18-900** is configured to generate currents i1, i2, and i3 in a ratio of 2:1:4, and each analog-to-digital unit **18-622** may be configured to apply a gain of 1.0, which results in corresponding digital images having exposure values of EV −1, EV 0, and EV +1 respectively. In such an embodiment, further differences in exposure value may be achieved by applying non-unit gain within one or more analog-to-digital unit **18-622**.
[0387] While the system **18-900** is illustrated to include three analog-to-digital units **18-622**, it is contemplated that multiple digital images may be generated by similar systems with more or less than three analog-to-digital units **18-622**. For example, a system with two analog-to-digital units **18-622** may be implemented for simultaneously generating two exposures of a photographic scene with zero interframe time in a manner similar to that described above with respect to system **18-900**. In one embodiment, the two analog-to-digital units **18-622** may be configured to generate two exposures each, for a total of four different exposures relative to one frame of analog pixel data.
[0388] FIG. **18-8** illustrates a message sequence **18-1200** for generating a combined image utilizing a network, according to one embodiment. As an option, the message sequence **18-1200** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the message sequence **18-1200** may be carried out in any desired environment. Further,

the aforementioned definitions may equally apply to the description below.

[0389] As shown in FIG. **18-8**, a wireless mobile device **18-376**(**0**) generates at least two digital images. In one embodiment, the at least two digital images may be generated by amplifying an analog signal with at least two gains, where each generated digital image corresponds to digital output of an applied gain. As described previously, at least two different gains may be applied by one or more amplifiers to an analog signal containing analog pixel data in order to generate gain-adjusted analog pixel data. Further, the gain-adjusted analog pixel data may then be converted to the at least two digital images utilizing at least one analog-to-digital converter, where each of the digital images provides a different exposure of a same photographic scene. For example, in one embodiment, the at least two digital images may include an EV −1 exposure of the photographic scene and an EV +1 exposure of the photographic scene. In another embodiment, the at least two digital images may include an EV −2 exposure of the photographic scene, an EV 0 exposure of the photographic scene, and an EV +2 exposure of the photographic scene.

[0390] Referring again to FIG. **18-8**, the at least two digital images are transmitted from the wireless mobile device **18-376**(**0**) to a data center **18-480** by way of a data network **18-474**. The at least two digital images may be transmitted by the wireless mobile device **18-376**(**0**) to the data center **18-480** using any technically feasible network communication method.

[0391] Further, in one embodiment, the data center **18-480** may then process the at least two digital images to generate a first computed image. The processing of the at least two digital images may include any processing of the at least two digital images that blends or merges at least a portion of each of the at least two digital images to generate the first computed image. To this end, the first digital image and the second digital image may be combined remotely from the wireless mobile device **18-376**(**0**). For example, the processing of the at least two digital images may include an any type of blending operation, including but not limited to, an HDR image combining operation. In one embodiment, the processing of the at least two digital images may include any computations that produce a first computed image having a greater dynamic range than any one of the digital images received at the data center **18-480**. Accordingly, in one embodiment, the first computed image generated by the data center **18-480** may be an HDR image. In other embodiments, the first computed image generated by the data center **18-480** may be at least a portion of an HDR image.

[0392] After generating the first computed image, the data center **18-480** may then transmit the first computed image to the wireless mobile device **18-376**(**0**). In one embodiment, the transmission of the at least two digital images from the wireless mobile device **18-376**(**0**), and the receipt of the first computed image at the wireless device **18-376**(**0**), may occur without any intervention or instruction being received from a user of the wireless mobile device **18-376**(**0**). For example, in one embodiment, the wireless mobile device **18-376**(**0**) may transmit the at least two digital images to the data center **18-480** immediately after capturing a photographic scene and generating the at least two digital images utilizing an analog signal representative of the photographic scene. The photographic scene may be captured based on a user input or selection of an electronic shutter control, or pressing of a manual shutter button, on the wireless mobile device **18-376**(**0**). Further, in response to receiving the at least two digital images, the data center **18-480** may generate an HDR image based on the at least two digital images, and transmit the HDR image to the wireless mobile device **18-376**(**0**). The wireless mobile device **18-376**(**0**) may then display the received HDR image. Accordingly, a user of the wireless mobile device **18-376**(**0**) may view on the display of the wireless mobile device **18-376**(**0**) an HDR image computed by the data center **18-480**. Thus, even though the wireless mobile device **18-376**(**0**) does not perform any HDR image processing, the user may view on the wireless mobile device **18-376**(**0**) the newly computed HDR image substantially instantaneously after capturing the photographic scene and generating the at least two digital images on which the HDR image is based.

[0393] As shown in FIG. **18-8**, the wireless mobile device **18-376**(**0**) requests adjustment in processing of the at least two digital images. In one embodiment, upon receiving the first computed image from the data center **18-480**, the wireless mobile device **18-376(0)** may display the first computed image in a UI system, such as the UI system **1500** of FIG. **15**. In such an embodiment, the user may control a slider control, such as the slider control **1530**, to adjust the processing of the at least two digital images transmitted to the data center **18-480**. For example, user manipulation of a slider control may result in commands being transmitted to the data center **18-480**. In one embodiment, the commands transmitted to the data center **18-480** may include mix weights for use in adjusting the processing of the at least two digital images. In other embodiments, the request to adjust processing of the at least two digital images includes any instructions from the wireless mobile device **18-376(0)** that the data center **18-480** may use to again process the at least two digital images and generate a second computed image.

[0394] As shown in FIG. **18-8**, upon receiving the request to adjust processing, the data center **18-480** re-processes the at least two digital images to generate a second computed image. In one embodiment, the data center **18-480** may re-process the at least two digital images using parameters received from the wireless mobile device **18-376(0)**. In such an embodiment, the parameters may be provided as input with the at least two digital images to an HDR processing algorithm that executes at the data center **18-480**. After generating the second computed image, the second computed image may be then transmitted from the data center **18-480** to the wireless mobile device **18-376(0)** for display to the user.

[0395] Referring again to FIG. **18-8**, the wireless mobile device **18-376(0)** shares the second computed image with another wireless mobile device **18-376(1)**. In one embodiment, the wireless mobile device **18-376(0)** may share any computed image received from the data center **18-480** with the other wireless mobile device **18-376(1)**. For example, the wireless mobile device **18-376(0)** may share the first computed image received from the data center **18-480**. As shown in FIG. **18-8**, the data center **18-480** communicates with the wireless mobile device **18-376(0)** and the wireless mobile device **18-376(1)** over the same data network **18-474**. Of course, in other embodiments the wireless mobile device **18-376(0)** may communicate with the data center **18-480** via a network different than a network utilized by the data center **18-480** and the wireless mobile device **18-376(1)** for communication.

[0396] In another embodiment, the wireless mobile device **18-376(0)** may share a computed image with the other wireless mobile device **18-376(1)** by transmitting a sharing request to data center **18-480**. For example, the wireless mobile device **18-376(0)** may request that the data center **18-480** forward the second computed to the other wireless mobile device **18-376(1)**. In response to receiving the sharing request, the data center **18-480** may then transmit the second computed image to the wireless mobile device **18-376(1)**. In an embodiment, transmitting the second computed image to the other wireless mobile device **18-376(1)** may include sending a URL at which the other wireless mobile device **18-376(1)** may access the second computed image.

[0397] Still further, as shown in FIG. **18-8**, after receiving the second computed image, the other wireless mobile device **18-376(1)** may send to the data center **18-480** a request to adjust processing of the at least two digital images. For example, the other wireless mobile device **18-376(1)** may display the second computed image in a UI system, such as the UI system **1500** of FIG. **15**. A user of the other wireless mobile device **18-376(1)** may manipulate UI controls to adjust the processing of the at least two digital images transmitted to the data center **18-480** by the wireless mobile device **18-376(0)**. For example, user manipulation of a slider control at the other wireless mobile device **18-376(1)** may result in commands being generated and transmitted to data center **18-480** for processing. In an embodiment, the request to adjust the processing of the at least two digital images sent from the other wireless mobile device **18-376(1)** includes the commands generated based on the user manipulation of the slider control at the other wireless mobile device **18-376(1)**. In other embodiments, the request to adjust processing of the at least two digital images includes any instructions from the wireless mobile device **18-376(1)** that the data center **18-480** may use to again process the at least two digital images and generate a third computed image.

[0398] As shown in FIG. **18-8**, upon receiving the request to adjust processing, the data center **18-480** re-processes the at least two digital images to generate a third computed image. In one embodiment, the data center **18-480** may re-process the at least two digital images using mix weights received from the wireless mobile device **18-376**(**1**). In such an embodiment, the mix weights received from the wireless mobile device **18-376**(**1**) may be provided as input with the at least two digital images to an HDR processing algorithm that executes at the data center **18-480**. After generating the third computed image, the third computed image is then transmitted from the data center **18-480** to the wireless mobile device **18-376**(**1**) for display. Still further, after receiving the third computed image, the wireless mobile device **18-376**(**1**) may send to the data center **18-480** a request to store the third computed image. In another embodiment, other wireless mobile devices **18-376** in communication with the data center **18-480** may request storage of a computed image. For example, in the context of FIG. **18-8**, the wireless mobile device **18-376**(**0**) may at any time request storage of the first computed image or the second computed image.
[0399] In response to receiving a request to store a computed image, the data center **18-480** may store the computed image for later retrieval. For example, the stored computed image may be stored such that the computed image may be later retrieved without re-applying the processing that was applied to generate the computed image. In one embodiment, the data center **18-480** may store computed images within a storage system **18-486** local to the data center **18-480**. In other embodiments, the data center **18-480** may store computed images within hardware devices not local to the data center **18-480**, such as a data center **18-481**. In such embodiments, the data center **18-480** may transmit the computed images over the data network **18-474** for storage.
[0400] Still further, in some embodiments, a computed image may be stored with a reference to the at least two digital images utilized to generate the computed image. For example, the computed image may be associated with the at least two digital images utilized to generate the computed image, such as through a URL served by data center **18-480** or **18-481**. By linking the stored computed image to the at least two digital images, any user or device with access to the computed image may also be given the opportunity to subsequently adjust the processing applied to the at least two digital images, and thereby generate a new computed image.
[0401] To this end, users of wireless mobile devices **18-376** may leverage processing capabilities of a data center **18-480** accessible via a data network **18-474** to generate an HDR image utilizing digital images that other wireless mobile devices **18-376** have captured and subsequently provided access to. For example, digital signals comprising digital images may be transferred over a network for being combined remotely, and the combined digital signals may result in at least a portion of a HDR image. Still further, a user may be able to adjust a blending of two or more digital images to generate a new HDR photograph without relying on their wireless mobile device **18-376** to perform the processing or computation necessary to generate the new HDR photograph. Subsequently, the user's device may receive at least a portion of a HDR image resulting from a combination of two or more digital signals. Accordingly, the user's wireless mobile device **18-376** may conserve power by offloading HDR processing to a data center. Further, the user may be able to effectively capture HDR photographs despite not having a wireless mobile device **18-376** capable of performing high-power processing tasks associated with HDR image generation. Finally, the user may be able to obtain an HDR photograph generated using an algorithm determined to be best for a photographic scene without having to select the HDR algorithm himself or herself and without having installed software that implements such an HDR algorithm on their wireless mobile device **18-376**. For example, the user may rely on the data center **18-480** to identify and to select a best HDR algorithm for a particular photographic scene.
[0402] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their

equivalents.

[0403] FIG. **19-1** illustrates a system **19-100** for simultaneously capturing multiple images, in accordance with one possible embodiment. As an option, the system **19-100** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **19-100** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0404] As shown in FIG. **19-1**, the system **19-100** includes a first input **19-102** that is provided to a first sample storage node **19-133(0)** based on a photodiode **19-101**, and a second input **19-104** provided simultaneously, at least in part, to a second sample storage node **19-133(1)** based on the photodiode **19-101**. Accordingly, based on the input **19-102** to the first sample storage node **19-133(0)** and the input **19-104** to the second sample storage node **19-133(1)**, a first sample is stored to the first sample storage node **19-133(0)** simultaneously, at least in part, with storage of a second sample to the second sample storage node **19-133(1)**. In one embodiment, simultaneous storage of the first sample during a first time duration and storing the second sample during a second time duration includes storing the first sample and the second sample at least partially contemporaneously. In one embodiment, an entirety of the first sample may be stored simultaneously with storage of at least a portion of the second sample. For example, storage of the second sample may occur during an entirety of the storing of the first sample; however, because storage of the second sample may occur over a greater period of time than storage of the first sample, storage of the first sample may occur during only a portion of the storing of the second sample. In an embodiment, storage of the first sample and the second sample may be started at the same time.

[0405] While the following discussion describes an image sensor apparatus and method for simultaneously capturing multiple images using one or more photodiodes of an image sensor, any photo-sensing electrical element or photosensor may be used or implemented.

[0406] In one embodiment, the photodiode **19-101** may comprise any semiconductor diode that generates a potential difference, current, or changes its electrical resistance, in response to photon absorption. Accordingly, the photodiode **19-101** may be used to detect or measure a light intensity. Further, the input **19-102** and the input **19-104** received at sample storage nodes **19-133(0)** and **19-133(1)**, respectively, may be based on the light intensity detected or measured by the photodiode **19-101**. In such an embodiment, the first sample stored at the first sample storage node **19-133(0)** may be based on a first exposure time to light at the photodiode **19-101**, and the second sample stored at the second sample storage node **19-133(1)** may be based on a second exposure time to the light at the photodiode **19-101**.

[0407] In one embodiment, the first input **19-102** may include an electrical signal from the photodiode **19-101** that is received at the first sample storage node **19-133(0)**, and the second input **19-104** may include an electrical signal from the photodiode **19-101** that is received at the second sample storage node **19-133(1)**. For example, the first input **19-102** may include a current that is received at the first sample storage node **19-133(0)**, and the second input **19-104** may include a current that is received at the second sample storage node **19-133(1)**. In another embodiment, the first input **19-102** and the second input **19-104** may be transmitted, at least partially, on a shared electrical interconnect. In other embodiments, the first input **19-102** and the second input **19-104** may be transmitted on different electrical interconnects. In some embodiments, the input **19-102** may be the same as the input **19-104**. For example, the input **19-102** and the input **19-104** may each include the same current. In other embodiments, the input **19-102** may include a first current, and the input **19-104** may include a second current that is different than the first current. In yet other embodiments, the first input **19-102** may include any input from which the first sample storage node **19-133(0)** may be operative to store a first sample, and the second input **19-104** may include any input from which the second sample storage node **19-133(1)** may be operative to store a second sample.

[0408] In one embodiment, the first input **19-102** and the second input **19-104** may include an electronic representation of a portion of an optical image that has been focused on an image sensor that includes the photodiode **19-101**. In such an embodiment, the optical image may be focused on the image sensor by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene. In some embodiments, the photodiode **19-101** may be a single photodiode of an array of photodiodes of an image sensor. Such an image sensor may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor. In other embodiments, photodiode **19-101** may include two or more photodiodes.
[0409] In one embodiment, each sample storage node **19-133** includes a charge storing device for storing a sample, and the stored sample may be a function of a light intensity detected at the photodiode **19-101**. For example, each sample storage node **19-133** may include a capacitor for storing a charge as a sample. In such an embodiment, each capacitor stores a charge that corresponds to an accumulated exposure during an exposure time or sample time. For example, current received at each capacitor from an associated photodiode may cause the capacitor, which has been previously charged, to discharge at a rate that is proportional to an incident light intensity detected at the photodiode. The remaining charge of each capacitor may be subsequently output from the capacitor as a value. For example, the remaining charge of each capacitor may be output as an analog value that is a function of the remaining charge on the capacitor.
[0410] To this end, an analog value received from a capacitor may be a function of an accumulated intensity of light detected at an associated photodiode. In some embodiments, each sample storage node **19-133** may include circuitry operable for receiving input based on a photodiode. For example, such circuitry may include one or more transistors. The one or more transistors may be configured for rendering the sample storage node **19-133** responsive to various control signals, such as sample, reset, and row select signals received from one or more controlling devices or components. In other embodiments, each sample storage node **19-133** may include any device for storing any sample or value that is a function of a light intensity detected at the photodiode **19-101**.
[0411] Further, as shown in FIG. **19-1**, the first sample storage node **19-133(0)** outputs first value **19-106**, and the second sample storage node **19-133(1)** outputs second value **19-108**. In one embodiment, the first sample storage node **19-133(0)** outputs the first value **19-106** based on the first sample stored at the first sample storage node **19-133(0)**, and the second sample storage node **19-133(1)** outputs the second value **19-108** based on the second sample stored at the second sample storage node **19-133(1)**.
[0412] In some embodiments, the first sample storage node **19-133(0)** outputs the first value **19-106** based on a charge stored at the first sample storage node **19-133(0)**, and the second sample storage node **19-133(1)** outputs the second value **19-108** based on a second charge stored at the second sample storage node **19-133(1)**. The first value **19-106** may be output serially with the second value **19-108**, such that one value is output prior to the other value; or the first value **19-106** may be output in parallel with the output of the second value **19-108**. In various embodiments, the first value **19-106** may include a first analog value, and the second value **19-108** may include a second analog value. Each of these values may include a current, which may be output for inclusion in an analog signal that includes at least one analog value associated with each photodiode of a photodiode array. In such embodiments, the first analog value **19-106** may be included in a first analog signal, and the second analog value **19-108** may be included in a second analog signal that is different than the first analog signal. In other words, a first analog signal may be generated to include an analog value associated with each photodiode of a photodiode array, and a second analog signal may also be generated to include a different analog value associated with

each of the photodiodes of the photodiode array. An analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values.

[0413] To this end, a single photodiode array may be utilized to generate a plurality of analog signals. The plurality of analog signal may be generated concurrently or in parallel. Further, the plurality of analog signals may each be amplified utilizing two or more gains, and each amplified analog signal may be converted to one or more digital signals such that two or more digital signals may be generated in total, where each digital signal may include a digital image. Accordingly, due to the partially contemporaneous storage of the first sample and the second sample, a single photodiode array may be utilized to concurrently generate multiple digital signals or digital images, where each digital signal is associated with a different exposure time or sample time of the same photographic scene. In such an embodiment, multiple digital signals having different exposure characteristics may be simultaneously generated for a single photographic scene. Such a collection of digital signals or digital images may be referred to as an image stack.

[0414] In certain embodiments, an analog signal comprises a plurality of distinct analog signals, and a signal amplifier comprises a corresponding set of distinct signal amplifier circuits. For example, each pixel within a row of pixels of an image sensor may have an associated distinct analog signal within an analog signal, and each distinct analog signal may have a corresponding distinct signal amplifier circuit. Further, two or more amplified analog signals may each include gain-adjusted analog pixel data representative of a common analog value from at least one pixel of an image sensor. For example, for a given pixel of an image sensor, a given analog value may be output in an analog signal, and then, after signal amplification operations, the given analog value is represented by a first amplified value in a first amplified analog signal, and by a second amplified value in a second amplified analog signal. Analog pixel data may be analog signal values associated with one or more given pixels.

[0415] FIG. **19-2** illustrates a method **19-200** for simultaneously capturing multiple images, in accordance with one embodiment. As an option, the method **19-200** may be carried out in the context of any of the Figures disclosed herein. Of course, however, the method **19-200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0416] As shown in operation **19-202**, a first sample is stored based on an electrical signal from a photodiode of an image sensor. Further, simultaneous, at least in part, with the storage of the first sample, a second sample is stored based on the electrical signal from the photodiode of the image sensor at operation **19-204**. As noted above, the photodiode of the image sensor may comprise any semiconductor diode that generates a potential difference, or changes its electrical resistance, in response to photon absorption. Accordingly, the photodiode may be used to detect or measure light intensity, and the electrical signal from the photodiode may include a photodiode current.

[0417] In some embodiments, each sample may include an electronic representation of a portion of an optical image that has been focused on an image sensor that includes the photodiode. In such an embodiment, the optical image may be focused on the image sensor by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene. The photodiode may be a single photodiode of an array of photodiodes of the image sensor. Such an image sensor may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor

[0418] In the context of one embodiment, each of the samples may be stored by storing energy. For example, each of the samples may include a charged stored on a capacitor. In such an embodiment, the first sample may include a first charge stored at a first capacitor, and the second sample may include a second charge stored at a second capacitor. In one embodiment, the first sample may be different than the second sample. For example, the first sample may include a first charge stored at a first capacitor, and the second sample may include a second charge stored at a second capacitor that is different than the first charge. In one embodiment, the first sample may be different than the second sample due to different sample times. For example, the first sample may be stored by charging or discharging a first capacitor for a first period of time, and the second sample may be stored by charging or discharging a second capacitor for a second period of time, where the first capacitor and the second capacitor may be substantially identical and charged or discharged at a substantially identical rate. Further, the second capacitor may be charged or discharged simultaneously, at least in part, with the charging or discharging of the first capacitor.

[0419] In another embodiment, the first sample may be different than the second sample due to, at least partially, different storage characteristics. For example, the first sample may be stored by charging or discharging a first capacitor for a period of time, and the second sample may be stored by charging or discharging a second capacitor for the same period of time, where the first capacitor and the second capacitor may have different storage characteristics and/or be charged or discharged at different rates. M ore specifically, the first capacitor may have a different capacitance than the second capacitor. Of course, the second capacitor may be charged or discharged simultaneously, at least in part, with the charging or discharging of the first capacitor.

[0420] Additionally, as shown at operation **19-206**, after storage of the first sample and the second sample, a first value is output based on the first sample, and a second value is output based on the second sample, for generating at least one image. In the context of one embodiment, the first value and the second value are transmitted or output in sequence. For example, the first value may be transmitted prior to the second value. In another embodiment, the first value and the second value may be transmitted in parallel.

[0421] In one embodiment, each output value may comprise an analog value. For example, each output value may include a current representative of the associated stored sample. More specifically, the first value may include a current value representative of the stored first sample, and the second value may include a current value representative of the stored second sample. In one embodiment, the first value is output for inclusion in a first analog signal, and the second value is output for inclusion in a second analog signal different than the first analog signal. Further, each value may be output in a manner such that it is combined with other values output based on other stored samples, where the other stored samples are stored responsive to other electrical signals received from other photodiodes of an image sensor. For example, the first value may be combined in a first analog signal with values output based on other samples, where the other samples were stored based on electrical signals received from photodiodes that neighbor the photodiode from which the electrical signal utilized for storing the first sample was received. Similarly, the second value may be combined in a second analog signal with values output based on other samples, where the other samples were stored based on electrical signals received from the same photodiodes that neighbor the photodiode from which the electrical signal utilized for storing the second sample was received.

[0422] Finally, at operation **19-208**, at least one of the first value and the second value are amplified utilizing two or more gains. In one embodiment, where each output value comprises an analog value, amplifying at least one of the first value and the second value may result in at least two amplified analog values. In another embodiment, where the first value is output for inclusion in a first analog signal, and the second value is output for inclusion in a second analog signal different than the first analog signal, one of the first analog signal or the second analog signal may be amplified utilizing the two or more gains. For example, a first analog signal that includes the first value may be amplified with a first gain and a second gain, such that the first value is amplified with the first gain and the second gain. Of course, more than two analog signals may be amplified using two or more gains. In one embodiment, each amplified analog signal may be converted to a digital signal comprising a digital image.

[0423] To this end, an array of photodiodes may be utilized to generate a first analog signal based on a first set of samples captured at a first exposure time or sample time, and a second analog signal based on a second set of samples captured at a second exposure time or sample time, where the first set of samples and the second set of samples may be two different sets of samples of the same photographic scene. Further, each analog signal may include an analog value generated based on each photodiode of each pixel of an image sensor. Each analog value may be representative of a light intensity measured at the photodiode associated with the analog value. Accordingly, an analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values, and analog pixel data may be analog signal values associated with one or more given pixels. Still further, each analog signal may undergo subsequent processing, such as amplification, which may facilitate conversion of the analog signal into one or more digital signals, each including digital pixel data, which may each comprise a digital image.
[0424] The embodiments disclosed herein may advantageously enable a camera module to sample images comprising an image stack with lower (e.g. at or near zero, etc.) inter-sample time (e.g. interframe, etc.) than conventional techniques. In certain embodiments, images comprising the image stack are effectively sampled or captured simultaneously, which may reduce inter-sample time to zero. In other embodiments, the camera module may sample images in coordination with the strobe unit to reduce inter-sample time between an image sampled without strobe illumination and an image sampled with strobe illumination.
[0425] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.
[0426] FIG. **19-3** illustrates a circuit diagram for a photosensitive cell **19-600**, in accordance with one possible embodiment. As an option, the cell **19-600** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **19-600** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0427] As shown in FIG. **19-3**, a photosensitive cell **19-600** includes a photodiode **19-602** coupled to a first analog sampling circuit **19-603(0)** and a second analog sampling circuit **19-603(1)**. The photodiode **19-602** may be implemented as the photodiode **19-101** described within the context of FIG. **19-1**, or any of the photodiodes **18-562** of FIG. **18-3**E. Further, an analog sampling circuit **19-603** may be implemented as a sample storage node **19-133** described within the context of FIG. **19-1**. In one embodiment, a unique instance of photosensitive cell **19-600** may be implemented as each of cells **18-542-18-545** comprising a pixel **18-540** within the context of FIGS. **18-3**A-**18-3**E.
[0428] As shown, the photosensitive cell **19-600** comprises two analog sampling circuits **19-603**, and a photodiode **19-602**. The two analog sampling circuits **19-603** include a first analog sampling circuit **19-603(0)** which is coupled to a second analog sampling circuit **19-603(1)**. As shown in FIG. **19-3**, the first analog sampling circuit **19-603(0)** comprises transistors **19-606(0)**, **19-610(0)**, **19-612(0)**, **19-614(0)**, and a capacitor **19-604(0)**; and the second analog sampling circuit **19-603(1)** comprises transistors **19-606(1)**, **19-610(1)**, **19-612(1)**, **19-614(1)**, and a capacitor **19-604(1)**. In one embodiment, each of the transistors **19-606**, **19-610**, **19-612**, and **19-614** may be a field-effect transistor.
[0429] The photodiode **19-602** may be operable to measure or detect incident light **19-601** of a photographic scene. In one embodiment, the incident light **19-601** may include ambient light of the photographic scene. In another embodiment, the incident light **19-601** may include light from a strobe unit utilized to illuminate the photographic scene. Of course, the incident light **19-601** may include any light received at and measured by the photodiode **19-602**. Further still, and as discussed above, the incident light **19-601** may be concentrated on the photodiode **19-602** by a

microlens, and the photodiode **19-602** may be one photodiode of a photodiode array that is configured to include a plurality of photodiodes arranged on a two-dimensional plane.

[0430] In one embodiment, the analog sampling circuits **19-603** may be substantially identical. For example, the first analog sampling circuit **19-603(0**) and the second analog sampling circuit **19-603(1**) may each include corresponding transistors, capacitors, and interconnects configured in a substantially identical manner. Of course, in other embodiments, the first analog sampling circuit **19-603(0**) and the second analog sampling circuit **19-603(1**) may include circuitry, transistors, capacitors, interconnects and/or any other components or component parameters (e.g. capacitance value of each capacitor **19-604**) which may be specific to just one of the analog sampling circuits **19-603**.

[0431] In one embodiment, each capacitor **19-604** may include one node of a capacitor comprising gate capacitance for a transistor **19-610** and diffusion capacitance for transistors **19-606** and **19-614**. The capacitor **19-604** may also be coupled to additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any other technically feasible capacitor structures.

[0432] With respect to analog sampling circuit **19-603(0)**, when reset **19-616(0**) is active (low), transistor **19-614(0**) provides a path from voltage source V2 to capacitor **19-604(0**), causing capacitor **19-604(0**) to charge to the potential of V2. When sample signal **19-618(0**) is active, transistor **19-606(0**) provides a path for capacitor **19-604(0)** to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **19-602** in response to the incident light **19-601**. In this way, photodiode current I_PD is integrated for a first exposure time when the sample signal **19-618(0**) is active, resulting in a corresponding first voltage on the capacitor **19-604(0**). This first voltage on the capacitor **19-604(0**) may also be referred to as a first sample. When row select **19-634(0**) is active, transistor **19-612(0**) provides a path for a first output current from V1 to output **19-608(0**). The first output current is generated by transistor **19-610(0**) in response to the first voltage on the capacitor **19-604(0**). When the row select **19-634(0**) is active, the output current at the output **19-608(0**) may therefore be proportional to the integrated intensity of the incident light **19-601** during the first exposure time. In one embodiment, sample signal **19-618(0**) is asserted substantially simultaneously over substantially all photo sensitive cells **19-600** comprising an image sensor to implement a global shutter for all first samples within the image sensor.

[0433] With respect to analog sampling circuit **19-603(1**), when reset **19-616(1**) is active (low), transistor **19-614(1**) provides a path from voltage source V2 to capacitor **19-604(1**), causing capacitor **19-604(1**) to charge to the potential of V2. When sample signal **19-618(1**) is active, transistor **19-606(1**) provides a path for capacitor **19-604(1**) to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **19-602** in response to the incident light **19-601**. In this way, photodiode current I_PD is integrated for a second exposure time when the sample signal **19-618(1**) is active, resulting in a corresponding second voltage on the capacitor **19-604(1**). This second voltage on the capacitor **19-604(1**) may also be referred to as a second sample. When row select **19-634(1**) is active, transistor **19-612(1**) provides a path for a second output current from V1 to output **19-608(1**). The second output current is generated by transistor **19-610(1**) in response to the second voltage on the capacitor **19-604(1**). When the row select **19-634(1**) is active, the output current at the output **19-608(1**) may therefore be proportional to the integrated intensity of the incident light **19-601** during the second exposure time. In one embodiment, sample signal **19-618(1**) is asserted substantially simultaneously over substantially all photo sensitive cells **19-600** comprising an image sensor to implement a global shutter for all second samples within the image sensor.

[0434] To this end, by controlling the first exposure time and the second exposure time such that the first exposure time is different than the second exposure time, the capacitor **19-604(0**) may store a first voltage or sample, and the capacitor **19-604(1**) may store a second voltage or sample different than the first voltage or sample, in response to a same photodiode current I_PD being generated by the photodiode **19-602**. In one embodiment, the first exposure time and the second exposure time begin at the same time, overlap in time, and end at different times. Accordingly, each of the analog sampling circuits **19-603** may be operable to store an analog value corresponding to a different exposure. As a benefit of having two different exposure times, in situations where a photodiode **19-602** is exposed to a sufficient threshold of incident light **19-601**, a first capacitor **19-604**(**0**) may provide a blown out, or over-exposed image portion, and a second capacitor **19-604**(**1**) of the same cell **19-600** may provide an analog value suitable for generating a digital image. Thus, for each cell **19-600**, a first capacitor **19-604** may more effectively capture darker image content than another capacitor **19-604** of the same cell **19-600**.

[0435] In other embodiments, it may be desirable to use more than two analog sampling circuits for the purpose of storing more than two voltages or samples. For example, an embodiment with three or more analog sampling circuits could be implemented such that each analog sampling circuit concurrently samples for a different exposure time the same photodiode current I_PD being generated by a photodiode. In such an embodiment, three or more voltages or samples could be obtained. To this end, a current I_PD generated by the photodiode **19-602** may be split over a number of analog sampling circuits **19-603** coupled to the photodiode **19-602** at any given time. Consequently, exposure sensitivity may vary as a function of the number of analog sampling circuits **19-603** that are coupled to the photodiode **19-602** at any given time, and the amount of capacitance that is associated with each analog sampling circuit **19-603**. Such variation may need to be accounted for in determining an exposure time or sample time for each analog sampling circuit **19-603**.

[0436] In various embodiments, capacitor **19-604**(**0**) may be substantially identical to capacitor **19-604**(**1**). For example, the capacitors **19-604**(**0**) and **19-604**(**1**) may have substantially identical capacitance values. In such embodiments, the photodiode current I_PD may be split evenly between the capacitors **19-604**(**0**) and **19-604**(**1**) during a first portion of time where the capacitors are discharged at a substantially identical rage. The photodiode current may be subsequently directed to one selected capacitor of the capacitors **19-604**(**0**) and **19-604**(**1**) during a second portion of time in which the selected capacitor discharges at twice the rate associated with the first portion of time. In one embodiment, to obtain different voltages or samples between the capacitors **19-604**(**0**) and **19-604**(**1**), a sample signal **19-618** of one of the analog sampling circuits may be activated for a longer or shorter period of time than a sample signal **19-618** is activated for any other analog sampling circuits **19-603** receiving at least a portion of photodiode current I_PD.

[0437] In an embodiment, an activation of a sample signal **19-618** of one analog sampling circuit **19-603** may be configured to be controlled based on an activation of another sample signal **19-618** of another analog sampling circuit **19-603** in the same cell **19-600**. For example, the sample signal **19-618**(**0**) of the first analog sampling circuit **19-603**(**0**) may be activated for a period of time that is controlled to be at a ratio of 2:1 with respect to an activation period for the sample signal **19-618**(**1**) of the second analog sampling circuit **19-603**(**1**). By way of a more specific example, a controlled ratio of 2:1 may result in the sample signal **19-618**(**0**) being activated for a period of 1/30 of a second when the sample signal **19-618**(**1**) has been selected to be activated for a period of 1/60 of a second. Of course activation or exposure times for each sample signal **19-618** may be controlled to be for other periods of time, such as for 1 second, 1/120 of a second, 1/1000 of a second, etc., or for other ratios, such as 0.5:1, 1.2:1, 1.5:1, 3:1, etc. In one embodiment, a period of activation of at least one of the sample signals **19-618** may be controlled by software executing on a digital photographic system, such as digital photographic system **300**, or by a user, such as a user interacting with a “manual mode” of a digital camera. For example, a period of activation of at least one of the sample signals **19-618** may be controlled based on a user selection of a shutter speed. To achieve a 2:1 exposure, a 3:1 exposure time may be needed due to current splitting during a portion of the overall exposure process.

[0438] In other embodiments, the capacitors **19-604**(**0**) and **19-604**(**1**) may have different capacitance values. In one embodiment, the capacitors **19-604**(**0**) and **19-604**(**1**) may have different capacitance values for the purpose of rendering one of the analog sampling circuits **19-603** more or less sensitive to the current I_PD from the photodiode **19-602** than other analog sampling circuits **19-603** of the same cell **19-600**. For example, a capacitor **19-604** with a significantly larger capacitance than other capacitors **19-604** of the same cell **19-600** may be less likely to fully discharge when capturing photographic scenes having significant amounts of incident light **19-601**. In such embodiments, any difference in stored voltages or samples between the capacitors **19-604**(**0**) and **19-604**(**1**) may be a function of the different capacitance values in conjunction with different activation times of the sample signals **19-618**.

[0439] In an embodiment, sample signal **19-618**(**0**) and sample signal **19-618**(**1**) may be asserted to an active state independently. In another embodiment, the sample signal **19-618**(**0**) and the sample signal **19-618**(**1**) are asserted to an active state simultaneously, and one is deactivated at an earlier time than the other, to generate images that are sampled substantially simultaneously for a portion of time, but with each having a different effective exposure time or sample time. Whenever both the sample signal **19-618**(**0**) and the sample signal **19-618**(**1**) are asserted simultaneously, photodiode current I_PD may be divided between discharging capacitor **19-604**(**0**) and discharging capacitor **19-604**(**1**).

[0440] In one embodiment, the photosensitive cell **19-600** may be configured such that the first analog sampling circuit **19-603**(**0**) and the second analog sampling circuit **19-603**(**1**) share at least one shared component. In various embodiments, the at least one shared component may include a photodiode **19-602** of an image sensor. In other embodiments, the at least one shared component may include a reset, such that the first analog sampling circuit **19-603**(**0**) and the second analog sampling circuit **19-603**(**1**) may be reset concurrently utilizing the shared reset. In the context of FIG. **19-3**, the photosensitive cell **19-600** may include a shared reset between the analog sampling circuits **19-603**(**0**) and **19-603**(**1**). For example, reset **19-616**(**0**) may be coupled to reset **19-616**(**1**), and both may be asserted together such that the reset **19-616**(**0**) is the same signal as the reset **19-616**(**1**), which may be used to simultaneously reset both of the first analog sampling circuit **19-603**(**0**) and the second analog sampling circuit **19-603**(**1**). After reset, the first analog sampling circuit **19-603**(**0**) and the second analog sampling circuit **19-603**(**1**) may be asserted to sample together.

[0441] In another embodiment, a sample signal **19-618**(**0**) for the first analog sampling circuit **19-603**(**0**) may be independent of a sample signal **19-618**(**1**) for the second analog sampling circuit **19-603**(**1**). In one embodiment, a row select **19-634**(**0**) for the first analog sampling circuit **19-603**(**0**) may be independent of a row select **19-634**(**1**) for the second analog sampling circuit **19-603**(**1**). In other embodiments, the row select **19-634**(**0**) for the first analog sampling circuit **19-603**(**0**) may include a row select signal that is shared with the row select **19-634**(**1**) for the second analog sampling circuit **19-603**(**1**). In yet another embodiment, output signal at output **19-608**(**0**) of the first analog sampling circuit **19-603**(**0**) may be independent of output signal at output **19-608**(**1**) of the second analog sampling circuit **19-603**(**1**). In another embodiment, the output signal of the first analog sampling circuit **19-603**(**0**) may utilize an output shared with the output signal of the second analog sampling circuit **19-603**(**1**). In embodiments sharing an output, it may be necessary for the row select **19-634**(**0**) of the first analog sampling circuit **19-603**(**0**) to be independent of the row select **19-634**(**1**) of the second analog sampling circuit **19-603**(**1**). In embodiments sharing a row select signal, it may be necessary for a line of the output **19-608**(**0**) of the first analog sampling circuit **19-603**(**0**) to be independent of a line of the output **19-608**(**1**) of the second analog sampling circuit **19-603**(**1**).

[0442] In one embodiment, a column signal **18-532** of FIG. **18-3**A may comprise one output signal of a plurality of independent output signals of the outputs **19-608**(**0**) and **19-608**(**1**). Further, a row control signal **18-530** of FIG. **18-3**A may comprise one of independent row select signals of the row selects **19-634**(**0**) and **19-634**(**1**), which may be shared for a given row of pixels. In

embodiments of cell **19-600** that implement a shared row select signal, the row select **19-634**(**0**) may be coupled to the row select **19-634**(**1**), and both may be asserted together simultaneously.
[0443] In an embodiment, a given row of pixels may include one or more rows of cells, where each row of cells includes multiple instances of the photosensitive cell **19-600**, such that each row of cells includes multiple pairs of analog sampling circuits **19-603**(**0**) and **19-603**(**1**). For example, a given row of cells may include a plurality of first analog sampling circuits **19-603**(**0**), and may further include a different second analog sampling circuit **19-603**(**1**) paired to each of the first analog sampling circuits **19-603**(**0**). In one embodiment, the plurality of first analog sampling circuits **19-603**(**0**) may be driven independently from the plurality of second analog sampling circuits **19-603**(**1**). In another embodiment, the plurality of first analog sampling circuits **19-603**(**0**) may be driven in parallel with the plurality of second analog sampling circuits **19-603**(**1**). For example, each output **19-608**(**0**) of each of the first analog sampling circuits **19-603**(**0**) of the given row of cells may be driven in parallel through one set of column signals **18-532**. Further, each output **19-608**(**1**) of each of the second analog sampling circuits **19-603**(**1**) of the given row of cells may be driven in parallel through a second, parallel, set of column signals **18-532**.
[0444] To this end, the photosensitive cell **19-600** may be utilized to simultaneously, at least in part, generate and store both of a first sample and a second sample based on the incident light **19-601**. Specifically, the first sample may be captured and stored on a first capacitor during a first exposure time, and the second sample may be simultaneously, at least in part, captured and stored on a second capacitor during a second exposure time. Further, an output current signal corresponding to the first sample of the two different samples may be coupled to output **19-608**(**0**) when row select **19-634**(**0**) is activated, and an output current signal corresponding to the second sample of the two different samples may be coupled to output **19-608**(**1**) when row select **19-634**(**1**) is activated.
[0445] In one embodiment, the first value may be included in a first analog signal containing first analog pixel data for a plurality of pixels at the first exposure time, and the second value may be included in a second analog signal containing second analog pixel data for the plurality of pixels at the second exposure time. Further, the first analog signal may be utilized to generate a first stack of one or more digital images, and the second analog signal may be utilized to generate a second stack of one or more digital images. Any differences between the first stack of images and the second stack of images may be based on, at least in part, a difference between the first exposure time and the second exposure time. Accordingly, an array of photosensitive cells **19-600** may be utilized for simultaneously capturing multiple digital images.
[0446] In one embodiment, a unique instance of analog pixel data **19-621** may include, as an ordered set of individual analog values, all analog values output from all corresponding analog sampling circuits or sample storage nodes. For example, in the context of the foregoing figures, each cell of cells **18-542-18-545** of a plurality of pixels **18-540** of a pixel array **18-510** may include both a first analog sampling circuit **19-603**(**0**) and a second analog sampling circuit **19-603**(**1**). Thus, the pixel array **18-510** may include a plurality of first analog sampling circuits **19-603**(**0**) and also include a plurality of second analog sampling circuits **19-603**(**1**). In other words, the pixel array **18-510** may include a first analog sampling circuit **19-603**(**0**) for each cell, and also include a second analog sampling circuit **19-603**(**1**) for each cell. In an embodiment, a first instance of analog pixel data **19-621** may be received containing a discrete analog value from each analog sampling circuit of a plurality of first analog sampling circuits **19-603**(**0**), and a second instance of analog pixel data **19-621** may be received containing a discrete analog value from each analog sampling circuit of a plurality of second analog sampling circuits **19-603**(**1**). Thus, in embodiments where cells of a pixel array include two or more analog sampling circuits, the pixel array may output two or more discrete analog signals, where each analog signal includes a unique instance of analog pixel data **19-621**.
[0447] In some embodiments, only a subset of the cells of a pixel array may include two or more analog sampling circuits. For example, not every cell may include both a first analog sampling

circuit **19-603(0)** and a second analog sampling circuit **19-603(1)**.

[0448] With continuing reference to FIG. **18-4**, the analog-to-digital unit **18-622** includes an amplifier **18-650** and an analog-to-digital converter **18-654**. In one embodiment, the amplifier **18-650** receives an instance of analog pixel data **18-621** and a gain **18-652**, and applies the gain **18-652** to the analog pixel data **18-621** to generate gain-adjusted analog pixel data **18-623**. The gain-adjusted analog pixel data **18-623** is transmitted from the amplifier **18-650** to the analog-to-digital converter **18-654**. The analog-to-digital converter **18-654** receives the gain-adjusted analog pixel data **18-623**, and converts the gain-adjusted analog pixel data **18-623** to the digital pixel data **18-625**, which is then transmitted from the analog-to-digital converter **18-654**. In other embodiments, the amplifier **18-650** may be implemented within the column read out circuit **18-520** instead of within the analog-to-digital unit **18-622**. The analog-to-digital converter **18-654** may convert the gain-adjusted analog pixel data **18-623** to the digital pixel data **18-625** using any technically feasible analog-to-digital conversion technique.

[0449] In an embodiment, the gain-adjusted analog pixel data **18-623** results from the application of the gain **18-652** to the analog pixel data **18-621**. In one embodiment, the gain **18-652** may be selected by the analog-to-digital unit **18-622**. In another embodiment, the gain **18-652** may be selected by the control unit **18-514**, and then supplied from the control unit **18-514** to the analog-to-digital unit **18-622** for application to the analog pixel data **18-621**.

[0450] It should be noted, in one embodiment, that a consequence of applying the gain **18-652** to the analog pixel data **18-621** is that analog noise may appear in the gain-adjusted analog pixel data **18-623**. If the amplifier **18-650** imparts a significantly large gain to the analog pixel data **18-621** in order to obtain highly sensitive data from of the pixel array **18-510**, then a significant amount of noise may be expected within the gain-adjusted analog pixel data **18-623**. In one embodiment, the detrimental effects of such noise may be reduced by capturing the optical scene information at a reduced overall exposure. In such an embodiment, the application of the gain **18-652** to the analog pixel data **18-621** may result in gain-adjusted analog pixel data with proper exposure and reduced noise.

[0451] In one embodiment, the amplifier **18-650** may be a transimpedance amplifier (TIA). Furthermore, the gain **18-652** may be specified by a digital value. In one embodiment, the digital value specifying the gain **18-652** may be set by a user of a digital photographic device, such as by operating the digital photographic device in a “manual” mode. Still yet, the digital value may be set by hardware or software of a digital photographic device. As an option, the digital value may be set by the user working in concert with the software of the digital photographic device.

[0452] In one embodiment, a digital value used to specify the gain **18-652** may be associated with an ISO. In the field of photography, the ISO system is a well-established standard for specifying light sensitivity. In one embodiment, the amplifier **18-650** receives a digital value specifying the gain **18-652** to be applied to the analog pixel data **18-621**. In another embodiment, there may be a mapping from conventional ISO values to digital gain values that may be provided as the gain **18-652** to the amplifier **18-650**. For example, each of ISO 100, ISO 200, ISO 400, ISO 800, ISO 1600, etc. may be uniquely mapped to a different digital gain value, and a selection of a particular ISO results in the mapped digital gain value being provided to the amplifier **18-650** for application as the gain **18-652**. In one embodiment, one or more ISO values may be mapped to a gain of 1. Of course, in other embodiments, one or more ISO values may be mapped to any other gain value.

[0453] Accordingly, in one embodiment, each analog pixel value may be adjusted in brightness given a particular ISO value. Thus, in such an embodiment, the gain-adjusted analog pixel data **18-623** may include brightness corrected pixel data, where the brightness is corrected based on a specified ISO. In another embodiment, the gain-adjusted analog pixel data **18-623** for an image may include pixels having a brightness in the image as if the image had been sampled at a certain ISO.

[0454] In accordance with an embodiment, the digital pixel data **18-625** may comprise a plurality

of digital values representing pixels of an image captured using the pixel array **18-510**.
[0455] In one embodiment, an instance of digital pixel data **18-625** may be output for each instance of analog pixel data **18-621** received. Thus, where a pixel array **18-510** includes a plurality of first analog sampling circuits **19-603(0)** and also includes a plurality of second analog sampling circuits **19-603(1)**, then a first instance of analog pixel data **18-621** may be received containing a discrete analog value from each of the first analog sampling circuits **19-603(0)** and a second instance of analog pixel data **18-621** may be received containing a discrete analog value from each of the second analog sampling circuits **19-603(1)**. In such an embodiment, a first instance of digital pixel data **18-625** may be output based on the first instance of analog pixel data **18-621**, and a second instance of digital pixel data **18-625** may be output based on the second instance of analog pixel data **18-621**.
[0456] Further, the first instance of digital pixel data **18-625** may include a plurality of digital values representing pixels of a first image captured using the plurality of first analog sampling circuits **19-603(0)** of the pixel array **18-510**, and the second instance of digital pixel data **18-625** may include a plurality of digital values representing pixels of a second image captured using the plurality of second analog sampling circuits **19-603(1)** of the pixel array **18-510**. Where the first instance of digital pixel data **18-625** and the second instance of digital pixel data **18-625** are generated utilizing the same gain **18-652**, then any differences between the instances of digital pixel data may be a function of a difference between the exposure time of the plurality of first analog sampling circuits **19-603(0)** and the exposure time of the plurality of second analog sampling circuits **19-603(1)**.
[0457] In some embodiments, two or more gains **18-652** may be applied to an instance of analog pixel data **18-621**, such that two or more instances of digital pixel data **18-625** may be output for each instance of analog pixel data **18-621**. For example, two or more gains may be applied to both of a first instance of analog pixel data **18-621** and a second instance of analog pixel data **18-621**. In such an embodiment, the first instance of analog pixel data **18-621** may contain a discrete analog value from each of a plurality of first analog sampling circuits **19-603(0)** of a pixel array **18-510**, and the second instance of analog pixel data **18-621** may contain a discrete analog value from each of a plurality of second analog sampling circuits **19-603(1)** of the pixel array **18-510**. Thus, four or more instances of digital pixel data **18-625** associated with four or more corresponding digital images may be generated from a single capture by the pixel array **18-510** of a photographic scene.
[0458] FIG. **19-4** illustrates a system **19-700** for converting analog pixel data of an analog signal to digital pixel data, in accordance with an embodiment. As an option, the system **19-700** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system **19-700** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0459] The system **19-700** is shown in FIG. **19-4** to include a first analog storage plane **19-702(0)**, a first analog-to-digital unit **19-722(0)**, and a first digital image stack **19-732(0)**, and is shown to further include a second analog storage plane **19-702(1)**, a second analog-to-digital unit **19-722(1)**, and a second digital image stack **19-732(1)**. Accordingly, the system **19-700** is shown to include at least two analog storage planes **19-702(0)** and **19-702(1)**. As illustrated in FIG. **19-4**, a plurality of analog values are each depicted as a “V” within each of the analog storage planes **19-702**, and corresponding digital values are each depicted as a “D” within digital images of each of the image stacks **19-732**.
[0460] In the context of certain embodiments, each analog storage plane **19-702** may comprise any collection of one or more analog values. In some embodiments, each analog storage plane **19-702** may comprise at least one analog pixel value for each pixel of a row or line of a pixel array. Still yet, in another embodiment, each analog storage plane **19-702** may comprise at least one analog pixel value for each pixel of an entirety of a pixel array, which may be referred to as a frame. For example, each analog storage plane **19-702** may comprise an analog pixel value, or more generally,

an analog value for each cell of each pixel of every line or row of a pixel array.
[0461] Further, the analog values of each analog storage plane **19-702** are output as analog pixel data **19-704** to a corresponding analog-to-digital unit **19-722**. For example, the analog values of analog storage plane **19-702**(**0**) are output as analog pixel data **19-704**(**0**) to analog-to-digital unit **19-722**(**0**), and the analog values of analog storage plane **19-702**(**1**) are output as analog pixel data **19-704**(**1**) to analog-to-digital unit **19-722**(**1**). In one embodiment, each analog-to-digital unit **19-722** may be substantially identical to the analog-to-digital unit **18-622** described within the context of FIG. **18-4**. For example, each analog-to-digital unit **19-722** may comprise at least one amplifier and at least one analog-to-digital converter, where the amplifier is operative to receive a gain value and utilize the gain value to gain-adjust analog pixel data received at the analog-to-digital unit **19-722**. Further, in such an embodiment, the amplifier may transmit gain-adjusted analog pixel data to an analog-to-digital converter, which then generates digital pixel data from the gain-adjusted analog pixel data. To this end, an analog-to-digital conversion may be performed on the contents of each of two or more different analog storage planes **19-702**.
[0462] In the context of the system **19-700** of FIG. **19-4**, each analog-to-digital unit **19-722** receives corresponding analog pixel data **19-704**, and applies at least two different gains to the received analog pixel data **19-704** to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data. For example, the analog-to-digital unit **19-722**(**0**) receives analog pixel data **19-704**(**0**), and applies at least two different gains to the analog pixel data **19-704**(**0**) to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **19-704**(**0**); and the analog-to-digital unit **19-722**(**1**) receives analog pixel data **19-704**(**1**), and applies at least two different gains to the analog pixel data **19-704**(**1**) to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **19-704**(**1**).
[0463] Further, each analog-to-digital unit **19-722** converts each generated gain-adjusted analog pixel data to digital pixel data, and then outputs at least two digital outputs. In one embodiment, each analog-to-digital unit **19-722** provides a different digital output corresponding to each gain applied to the received analog pixel data **19-704**. With respect to FIG. **19-4** specifically, the analog-to-digital unit **19-722**(**0**) is shown to generate a first digital signal comprising first digital pixel data **19-723**(**0**) corresponding to a first gain (Gain1), a second digital signal comprising second digital pixel data **19-724**(**0**) corresponding to a second gain (Gain2), and a third digital signal comprising third digital pixel data **19-725**(**0**) corresponding to a third gain (Gain3). Similarly, the analog-to-digital unit **19-722**(**1**) is shown to generate a first digital signal comprising first digital pixel data **19-723**(**1**) corresponding to a first gain (Gain1), a second digital signal comprising second digital pixel data **19-724**(**1**) corresponding to a second gain (Gain2), and a third digital signal comprising third digital pixel data **19-725**(**1**) corresponding to a third gain (Gain3). Each instance of each digital pixel data may comprise a digital image, such that each digital signal comprises a digital image.
[0464] Accordingly, as a result of the analog-to-digital unit **19-722**(**0**) applying each of Gain1, Gain2, and Gain3 to the analog pixel data **19-704**(**0**), and thereby generating first digital pixel data **19-723**(**0**), second digital pixel data **19-724**(**0**), and third digital pixel data **19-725**(**0**), the analog-to-digital unit **19-722**(**0**) generates a stack of digital images, also referred to as an image stack **19-732**(**0**). Similarly, as a result of the analog-to-digital unit **19-722**(**1**) applying each of Gain1, Gain2, and Gain3 to the analog pixel data **19-704**(**1**), and thereby generating first digital pixel data **19-723**(**1**), second digital pixel data **19-724**(**1**), and third digital pixel data **19-725**(**1**), the analog-to-digital unit **19-722**(**1**) generates a second stack of digital images, also referred to as an image stack **19-732**(**1**).
[0465] In one embodiment, each analog-to-digital unit **19-722** applies in sequence at least two gains to the analog values. For example, within the context of FIG. **19-4**, the analog-to-digital unit **19-722**(**0**) first applies Gain1 to the analog pixel data **19-704**(**0**), then subsequently applies Gain2

to the same analog pixel data **19-704**(**0**), and then subsequently applies Gain3 to the same analog pixel data **19-704**(**0**). In other embodiments, each analog-to-digital unit **19-722** may apply in parallel at least two gains to the analog values. For example, an analog-to-digital unit may apply Gain1 to received analog pixel data in parallel with application of Gain2 and Gain3 to the analog pixel data. To this end, each instance of analog pixel data **19-704** is amplified utilizing at least two gains.

[0466] In one embodiment, the gains applied to the analog pixel data **19-704**(**0**) at the analog-to-digital unit **19-722**(**0**) may be the same as the gains applied to the analog pixel data **19-704**(**1**) at the analog-to-digital unit **19-722**(**1**). By way of a specific example, the Gain1 applied by both of the analog-to-digital unit **19-722**(**0**) and the analog-to-digital unit **19-722**(**1**) may be a gain of 19−1.0, the Gain2 applied by both of the analog-to-digital unit **19-722**(**0**) and the analog-to-digital unit **19-722**(**1**) may be a gain of 19−2.0, and the Gain3 applied by both of the analog-to-digital unit **19-722**(**0**) and the analog-to-digital unit **19-722**(**1**) may be a gain of 4.0. In another embodiment, one or more of the gains applied to the analog pixel data **19-704**(**0**) at the analog-to-digital unit **19-722**(**0**) may be different from the gains applied to the analog pixel data **19-704**(**1**) at the analog-to-digital unit **19-722**(**1**). For example, the Gain1 applied at the analog-to-digital unit **19-722**(**0**) may be a gain of 19−1.0, and the Gain1 applied at the analog-to-digital unit **19-722**(**1**) may be a gain of 19−2.0. Accordingly, the gains applied at each analog-to-digital unit **19-722** may be selected dependently or independently of the gains applied at other analog-to-digital units **19-722** within system **19-700**.

[0467] In accordance with one embodiment, the at least two gains may be determined using any technically feasible technique based on an exposure of a photographic scene, metering data, user input, detected ambient light, a strobe control, or any combination of the foregoing. For example, a first gain of the at least two gains may be determined such that half of the digital values from an analog storage plane **19-702** are converted to digital values above a specified threshold (e.g., a threshold of 0.5 in a range of 0.0 to 19-1.0) for the dynamic range associated with digital values comprising a first digital image of an image stack **19-732**, which can be characterized as having an "EV0" exposure. Continuing the example, a second gain of the at least two gains may be determined as being twice that of the first gain to generate a second digital image of the image stack **19-732** characterized as having an "EV+1" exposure. Further still, a third gain of the at least two gains may be determined as being half that of the first gain to generate a third digital image of the image stack **19-732** characterized as having an "EV−1" exposure.

[0468] In one embodiment, an analog-to-digital unit **19-722** converts in sequence a first instance of the gain-adjusted analog pixel data to the first digital pixel data **19-723**, a second instance of the gain-adjusted analog pixel data to the second digital pixel data **19-724**, and a third instance of the gain-adjusted analog pixel data to the third digital pixel data **19-725**. For example, an analog-to-digital unit **19-722** may first convert a first instance of the gain-adjusted analog pixel data to first digital pixel data **19-723**, then subsequently convert a second instance of the gain-adjusted analog pixel data to second digital pixel data **19-724**, and then subsequently convert a third instance of the gain-adjusted analog pixel data to third digital pixel data **19-725**. In other embodiments, an analog-to-digital unit **19-722** may perform such conversions in parallel, such that one or more of a first digital pixel data **19-723**, a second digital pixel data **19-724**, and a third digital pixel data **19-725** are generated in parallel.

[0469] Still further, as shown in FIG. **19-4**, each first digital pixel data **19-723** provides a first digital image. Similarly, each second digital pixel data **19-724** provides a second digital image, and each third digital pixel data **19-725** provides a third digital image. Together, each set of digital images produced using the analog values of a single analog storage plane **19-702** comprises an image stack **19-732**. For example, image stack **19-732**(**0**) comprises digital images produced using analog values of the analog storage plane **19-702**(**0**), and image stack **19-732**(**1**) comprises the digital images produced using the analog values of the analog storage plane **19-702**(**1**).

[0470] As illustrated in FIG. **19-4**, all digital images of an image stack **19-732** may be based upon a same analog pixel data **19-704**. However, each digital image of an image stack **19-732** may differ from other digital images in the image stack **19-732** as a function of a difference between the gains used to generate the two digital images. Specifically, a digital image generated using the largest gain of at least two gains may be visually perceived as the brightest or more exposed of the digital images of the image stack **19-732**. Conversely, a digital image generated using the smallest gain of the at least two gains may be visually perceived as the darkest and less exposed than other digital images of the image stack **19-732**. To this end, a first light sensitivity value may be associated with first digital pixel data **19-723**, a second light sensitivity value may be associated with second digital pixel data **19-724**, and a third light sensitivity value may be associated with third digital pixel data **19-725**. Further, because each of the gains may be associated with a different light sensitivity value, a first digital image or first digital signal may be associated with a first light sensitivity value, a second digital image or second digital signal may be associated with a second light sensitivity value, and a third digital image or third digital signal may be associated with a third light sensitivity value.

[0471] It should be noted that while a controlled application of gain to the analog pixel data may greatly aid in HDR image generation, an application of too great of gain may result in a digital image that is visually perceived as being noisy, over-exposed, and/or blown-out. In one embodiment, application of two stops of gain to the analog pixel data may impart visually perceptible noise for darker portions of a photographic scene, and visually imperceptible noise for brighter portions of the photographic scene. In another embodiment, a digital photographic device may be configured to provide an analog storage plane for analog pixel data of a captured photographic scene, and then perform at least two analog-to-digital samplings of the same analog pixel data using an analog-to-digital unit **19-722**. To this end, a digital image may be generated for each sampling of the at least two samplings, where each digital image is obtained at a different exposure despite all the digital images being generated from the same analog sampling of a single optical image focused on an image sensor.

[0472] In one embodiment, an initial exposure parameter may be selected by a user or by a metering algorithm of a digital photographic device. The initial exposure parameter may be selected based on user input or software selecting particular capture variables. Such capture variables may include, for example, ISO, aperture, and shutter speed. A n image sensor may then capture a photographic scene at the initial exposure parameter, and populate a first analog storage plane with a first plurality of analog values corresponding to an optical image focused on the image sensor. Simultaneous, at least in part, with populating the first analog storage plane, a second analog storage plane may be populated with a second plurality of analog values corresponding to the optical image focused on the image sensor. In the context of the foregoing Figures, a first analog storage plane **19-702(0)** may be populated with a plurality of analog values output from a plurality of first analog sampling circuits **19-603(0)** of a pixel array **18-510**, and a second analog storage plane **19-702(1)** may be populated with a plurality of analog values output from a plurality of second analog sampling circuits **19-603**(**1**) of the pixel array **18-510**.

[0473] In other words, in an embodiment where each photosensitive cell includes two analog sampling circuits, then two analog storage planes may be configured such that a first of the analog storage planes stores a first analog value output from one of the analog sampling circuits of a cell, and a second of the analog storage planes stores a second analog value output from the other analog sampling circuit of the same cell. In this configuration, each of the analog storage planes may store at least one analog value received from a pixel of a pixel array or image sensor.

[0474] Further, each of the analog storage planes may receive and store different analog values for a given pixel of the pixel array or image sensor. For example, an analog value received for a given pixel and stored in a first analog storage plane may be output based on a first sample captured during a first exposure time, and a corresponding analog value received for the given pixel and stored in a second analog storage plane may be output based on a second sample captured during a second exposure time that is different than the first exposure time. Accordingly, in one embodiment, substantially all analog values stored in a first analog storage plane may be based on samples obtained during a first exposure time, and substantially all analog values stored in a second analog storage plane may be based on samples obtained during a second exposure time that is different than the first exposure time.

[0475] In the context of the present description, a "single exposure" of a photographic scene at an initial exposure parameter may include simultaneously, at least in part, capturing the photographic scene using two or more sets of analog sampling circuits, where each set of analog sampling circuits may be configured to operate at different exposure times. During capture of the photographic scene using the two or more sets of analog sampling circuits, the photographic scene may be illuminated by ambient light or may be illuminated using a strobe unit. Further, after capturing the photographic scene using the two or more sets of analog sampling circuits, two or more analog storage planes (e.g., one storage plane for each set of analog sampling circuits) may be populated with analog values corresponding to an optical image focused on an image sensor. Next, one or more digital images of a first image stack may be obtained by applying one or more gains to the analog values of a first analog storage plane in accordance with the above systems and methods. Further, one or more digital images of a second image stack may be obtained by applying one or more gains to the analog values of a second analog storage plane in accordance with the above systems and methods.

[0476] To this end, one or more image stacks **19-732** may be generated based on a single exposure of a photographic scene. In one embodiment, each digital image of a particular image stack **19-732** may be generated based on a common exposure time or sample time, but be generated utilizing a unique gain. In such an embodiment, each of the image stacks **19-732** of the single exposure of a photographic scene may be generated based on different sample times.

[0477] In one embodiment, a first digital image of an image stack **19-732** may be obtained utilizing a first gain in accordance with the above systems and methods. For example, if a digital photographic device is configured such that initial exposure parameter includes a selection of ISO 400, the first gain utilized to obtain the first digital image may be mapped to, or otherwise associated with, ISO 400. This first digital image may be referred to as an exposure or image obtained at exposure value 0 (EV 0). Further one more digital images may be obtained utilizing a second gain in accordance with the above systems and methods. For example, the same analog pixel data used to generate the first digital image may be processed utilizing a second gain to generate a second digital image. Still further, one or more digital images may be obtained utilizing a second analog storage plane in accordance with the above systems and methods. For example, second analog pixel data may be used to generate a second digital image, where the second analog pixel data is different from the analog pixel data used to generate the first digital image. Specifically, the analog pixel data used to generate the first digital image may have been captured using a first sample time, and the second analog pixel data may have been captured using a second sample time different than the first sample time. Specifically, the analog pixel data used to generate the first digital image may have been captured during a first exposure time, and the second analog pixel data may have been captured during a second exposure time different than the first exposure time.

[0478] To this end, at least two digital images may be generated utilizing different analog pixel data, and then blended to generate an HDR image. The at least two digital images may be blended by blending a first digital signal and a second digital signal. Where the at least two digital images are generated using different analog pixel data captured during a single exposure of a photographic scene, then there may be approximately, or near, zero interframe time between the at least two digital images. As a result of having zero, or near zero, interframe time between at least two digital images of a same photographic scene, an HDR image may be generated, in one possible embodiment, without motion blur or other artifacts typical of HDR photographs.

[0479] In one embodiment, after selecting a first gain for generating a first digital image of an image stack **19-732**, a second gain may be selected based on the first gain. For example, the second gain may be selected on the basis of it being one stop away from the first gain. More specifically, if the first gain is mapped to or associated with ISO 400, then one stop down from ISO 400 provides a gain associated with ISO 200, and one stop up from ISO 400 provides a gain associated with ISO 800. In such an embodiment, a digital image generated utilizing the gain associated with ISO 200 may be referred to as an exposure or image obtained at exposure value −1 (EV −1), and a digital image generated utilizing the gain associated with ISO 800 may be referred to as an exposure or image obtained at exposure value +1 (EV +1).

[0480] Still further, if a more significant difference in exposures is desired between digital images generated utilizing the same analog signal, then the second gain may be selected on the basis of it being two stops away from the first gain. For example, if the first gain is mapped to or associated with ISO 400, then two stops down from ISO 400 provides a gain associated with ISO 100, and two stops up from ISO 400 provides a gain associated with ISO 1600. In such an embodiment, a digital image generated utilizing the gain associated with ISO 100 may be referred to as an exposure or image obtained at exposure value −2 (EV −2), and a digital image generated utilizing the gain associated with ISO 1600 may be referred to as an exposure or image obtained at exposure value +2 (EV +2).

[0481] In one embodiment, an ISO and exposure of the EV 0 image may be selected according to a preference to generate darker digital images. In such an embodiment, the intention may be to avoid blowing out or overexposing what will be the brightest digital image, which is the digital image generated utilizing the greatest gain. In another embodiment, an EV −1 digital image or EV −2 digital image may be a first generated digital image. Subsequent to generating the EV −1 or EV −2 digital image, an increase in gain at an analog-to-digital unit may be utilized to generate an EV 0 digital image, and then a second increase in gain at the analog-to-digital unit may be utilized to generate an EV +1 or EV +2 digital image. In one embodiment, the initial exposure parameter corresponds to an EV-N digital image and subsequent gains are used to obtain an EV 0 digital image, an EV +M digital image, or any combination thereof, where N and M are values ranging from 0 to −10.

[0482] In one embodiment, three digital images having three different exposures (e.g. an EV −2 digital image, an EV 0 digital image, and an EV +2 digital image) may be generated in parallel by implementing three analog-to-digital units. Each analog-to-digital unit may be configured to convert one or more analog signal values to corresponding digital signal values. Such an implementation may be also capable of simultaneously generating all of an EV −1 digital image, an EV0 digital image, and an EV +1 digital image. Similarly, in other embodiments, any combination of exposures may be generated in parallel from two or more analog-to-digital units, three or more analog-to-digital units, or an arbitrary number of analog-to-digital units. In other embodiments, a set of analog-to-digital units may be configured to each operate on either of two or more different analog storage planes.

[0483] In one embodiment, a combined image **1520** comprises a combination of at least two related digital images. In one embodiment, the combined image **1020** comprises, without limitation, a combined rendering of at least two digital images, such as two or more of the digital images of an image stack **19-732**(**0**) and an image stack **19-732**(**1**) of FIG. **19-4**. In another embodiment, the digital images used to compute the combined image **1520** may be generated by amplifying each of a first analog signal and a second analog signal with at least two different gains, where each analog signal includes optical scene information captured based on an optical image focused on an image sensor. In yet another embodiment, each analog signal may be amplified using the at least two different gains on a pixel-by-pixel, line-by-line, or frame-by-frame basis.

[0484] In other embodiments, in addition to the indication point **1540**-B, there may exist a plurality of additional indication points along the track **1532** between the indication points **1540**-A and **1540**-C. The additional indication points may be associated with additional digital images. For example, a first image stack **19-732** may be generated to include each of a digital image at EV −1 exposure, a digital image at EV 0 exposure, and a digital image at EV +1 exposure. Said image stack **19-732** may be associated with a first analog storage plane captured at a first exposure time, such as the image stack **19-732**(**0**) of FIG. **19-4**. Thus, a first image stack may include a plurality of digital images all associated with a first exposure time, where each digital image is associated with a different ISO. Further, a second image stack **19-732** may also be generated to include each of a digital image at EV −1 exposure, a digital image at EV 0 exposure, and a digital image at EV +1 exposure. However, the second image stack **19-732** may be associated with a second analog storage plane captured at a second exposure time different than the first exposure time, such as the image stack **19-732**(**1**) of FIG. **19-4**. Thus, a second image stack may include a second plurality of digital images all associated with a second exposure time, where each digital image is associated with a different ISO. After analog-to-digital units **19-722**(**0**) and **19-722**(**1**) generate the respective image stacks **19-732**, the digital pixel data output by the analog-to-digital units **19-722**(**0**) and **19-722**(**1**) may be arranged together into a single sequence of digital images of increasing or decreasing exposure. In the context of the instant description, no two digital signals of the two image stacks may be associated with a same ISO+exposure time combination, thus each digital image or instance of digital pixel data may be considered as having a unique effective exposure.

[0485] In the context of the foregoing figures, arranging the digital images or instances of digital pixel data output by the analog-to-digital units **19-722**(**0**) and **19-722**(**1**) into a single sequence of digital images of increasing or decreasing exposure may be performed according to overall exposure. For example, the single sequence of digital images may combine gain and exposure time to determine an effective exposure. The digital pixel data may be rapidly organized to obtain a single sequence of digital images of increasing effective exposure, such as, for example: **19-723**(**0**), **19-723**(**1**), **19-724**(**0**), **19-724**(**1**), **19-725**(**0**), and **19-725**(**1**). Of course, any sorting of the digital images or digital pixel data based on effective exposure level will depend on an order of application of the gains and generation of the digital signals **19-723-725**.

[0486] In one embodiment, exposure times and gains may be selected or predetermined for generating a number of adequately different effective exposures. For example, where three gains are to be applied, then each gain may be selected to be two exposure stops away from a nearest selected gain. Further, where multiple exposure times are to be used, then a first exposure time may be selected to be one exposure stop away from a second exposure time. In such an embodiment, selection of three gains separated two exposure stops, and two exposure times separated by one exposure stop, may ensure generation of six digital images, each having a unique effective exposure.

[0487] With continuing reference to the digital images of multiple image stacks sorted in a sequence of increasing exposure, each of the digital images may then be associated with indication points along the track **1532** of the UI system **1500**. For example, the digital images may be sorted or sequenced along the track **1532** in the order of increasing effective exposure noted previously: **19-723**(**0**), **19-723**(**1**), **19-724**(**0**), **19-724**(**1**), **19-725**(**0**), and **19-725**(**1**). In such an embodiment, the slider control **1530** may then be positioned at any point along the track **1532** that is between two digital images generated based on two different analog storage planes. As a result, two digital images generated based on two different analog storage planes may then be blended to generate a combined image **1520**.

[0488] For example, the slider control **1530** may be positioned at an indication point that may be equally associated with digital pixel data **19-724**(**0**) and digital pixel data **19-724**(**1**). As a result, the digital pixel data **19-724**(**0**), which may include a first digital image generated from a first analog signal captured during a first sample time and amplified utilizing a gain, may be blended with the digital pixel data **19-724**(**1**), which may include a second digital image generated from a second analog signal captured during a second sample time and amplified utilizing the same gain, to generate a combined image **1520**.

[0489] Still further, as another example, the slider control **1530** may be positioned at an indication point that may be equally associated with digital pixel data **19-724**(**1**) and digital pixel data **19-725**(**0**). As a result, the digital pixel data **19-724**(**1**), which may include a first digital image generated from a first analog signal captured during a first sample time and amplified utilizing a first gain, may be blended with the digital pixel data **19-725**(**0**), which may include a second digital image generated from a second analog signal captured during a second sample time and amplified utilizing a different gain, to generate a combined image **1520**.

[0490] Thus, as a result of the slider control **1530** positioning, two or more digital signals may be blended, and the blended digital signals may be generated utilizing analog values from different analog storage planes. As a further benefit of sorting effective exposures along a slider, and then allowing blend operations based on slider control position, each pair of neighboring digital images may include a higher noise digital image and a lower noise digital image. For example, where two neighboring digital signals are amplified utilizing a same gain, the digital signal generated from an analog signal captured with a lower sample time may have less noise. Similarly, where two neighboring digital signals are amplified utilizing different gains, the digital signal generated from an analog signal amplified with a lower gain value may have less noise. Thus, when digital signals are sorted based on effective exposure along a slider, a blend operation of two or more digital signals may serve to reduce the noise apparent in at least one of the digital signals.

[0491] Of course, any two or more effective exposures may be blended based on the indication point of the slider control **1530** to generate a combined image **1520** in the UI system **1500**.

[0492] One advantage of the present invention is that a digital photograph may be selectively generated based on user input using two or more different images generated from a single exposure of a photographic scene. Accordingly, the digital photograph generated based on the user input may have a greater dynamic range than any of the individual images. Further, the generation of an HDR image using two or more different images with zero, or near zero, interframe time allows for the rapid generation of HDR images without motion artifacts.

[0493] Additionally, when there is any motion within a photographic scene, or a capturing device experiences any jitter during capture, any interframe time between exposures may result in a motion blur within a final merged HDR photograph. Such blur can be significantly exaggerated as interframe time increases. This problem renders current HDR photography an ineffective solution for capturing clear images in any circumstance other than a highly static scene.

[0494] Further, traditional techniques for generating a HDR photograph involve significant computational resources, as well as produce artifacts which reduce the image quality of the resulting image. Accordingly, strictly as an option, one or more of the above issues may or may not be addressed utilizing one or more of the techniques disclosed herein.

[0495] Still yet, in various embodiments, one or more of the techniques disclosed herein may be applied to a variety of markets and/or products. For example, although the techniques have been disclosed in reference to a photo capture, they may be applied to televisions, web conferencing (or live streaming capabilities, etc.), security cameras (e.g. increase contrast to determine characteristic, etc.), automobiles (e.g. driver assist systems, in-car infotainment systems, etc.), and/or any other product which includes a camera input.

[0496] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

[0497] FIG. **20-1** illustrates a system **20-100** for capturing flash and ambient illuminated images, in accordance with one possible embodiment. As an option, the system **20-100** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **20-100** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0498] As shown in FIG. **20-1**, the system **20-100** includes a first input **20-102** that is provided to an ambient sample storage node **20-133**(**0**) based on a photodiode **20-101**, and a second input **20-104** provided to a flash sample storage node **20-133**(**1**) based on the photodiode **20-101**. Based on the input **20-102** to the ambient sample storage node **20-133**(**0**) and the input **20-104** to the flash sample storage node **20-133**(**1**), an ambient sample is stored to the ambient sample storage node **20-133**(**0**) sequentially, at least in part, with storage of a flash sample to the flash sample storage node **20-133**(**1**). In one embodiment, simultaneous storage of the ambient sample and the flash sample includes storing the ambient sample and the second sample at least partially sequentially.

[0499] In one embodiment, the input **20-104** may be provided to the flash sample storage node **20-133**(**1**) after the input **20-102** is provided to the ambient sample storage node **20-133**(**0**). In such an embodiment, the process of storing the flash sample may occur after the process of storing the ambient sample. In other words, storing the ambient sample may occur during a first time duration, and storing the flash sample may occur during a second time duration that begins after the first time duration. The second time duration may begin nearly simultaneously with the conclusion of the first time duration.

[0500] While the following discussion describes an image sensor apparatus and method for simultaneously capturing multiple images using one or more photodiodes of an image sensor, any photo-sensing electrical element or photosensor may be used or implemented.

[0501] In one embodiment, the photodiode **20-101** may comprise any semiconductor diode that generates a potential difference, current, or changes its electrical resistance, in response to photon absorption. Accordingly, the photodiode **20-101** may be used to detect or measure a light intensity. Further, the input **20-102** and the input **20-104** received at sample storage nodes **20-133**(**0**) and **20-133**(**1**), respectively, may be based on the light intensity detected or measured by the photodiode **20-101**. In such an embodiment, the ambient sample stored at the ambient sample storage node **20-133**(**0**) may be based on a first exposure time to light at the photodiode **20-101**, and the second sample stored at the flash sample storage node **20-133**(**1**) may be based on a second exposure time to the light at the photodiode **20-101**. The second exposure time may begin concurrently, or near concurrently, with the conclusion of the conclusion of the first exposure time.

[0502] In one embodiment, a rapid rise in scene illumination may occur after completion of the first exposure time, and during the second exposure time while input **20-104** is being received at the flash sample storage node **20-133**(**1**). The rapid rise in scene illumination may be due to activation of a flash or strobe, or any other near instantaneous illumination. As a result of the rapid rise in scene illumination after the first exposure time, the light intensity detected or measured by the photodiode **20-101** during the second exposure time may be greater than the light intensity detected or measured by the photodiode **20-101** during the first exposure time. Accordingly, the second exposure time may be configured or selected based on an anticipated light intensity.

[0503] In one embodiment, the first input **20-102** may include an electrical signal from the photodiode **20-101** that is received at the ambient sample storage node **20-133**(**0**), and the second input **20-104** may include an electrical signal from the photodiode **20-101** that is received at the flash sample storage node **20-133**(**1**). For example, the first input **20-102** may include a current that is received at the ambient sample storage node **20-133**(**0**), and the second input **20-104** may include a current that is received at the flash sample storage node **20-133**(**1**). In another embodiment, the first input **20-102** and the second input **20-104** may be transmitted, at least partially, on a shared electrical interconnect. In other embodiments, the first input **20-102** and the second input **20-104** may be transmitted on different electrical interconnects.

[0504] In some embodiments, the input **20-102** may include a first current, and the input **20-104** may include a second current that is different than the first current. The first current and the second current may each be a function of incident light intensity measured or detected by the photodiode **20-101**. In yet other embodiments, the first input **20-102** may include any input from which the ambient sample storage node **20-133**(**0**) may be operative to store an ambient sample, and the second input **20-104** may include any input from which the flash sample storage node **20-133**(**1**) may be operative to store a flash sample.

[0505] In one embodiment, the first input **20-102** and the second input **20-104** may include an electronic representation of a portion of an optical image that has been focused on an image sensor that includes the photodiode **20-101**. In such an embodiment, the optical image may be focused on the image sensor by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene. In some embodiments, the photodiode **20-101** may be a single photodiode of an array of photodiodes of an image sensor. Such an image sensor may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor. In other embodiments, photodiode **20-101** may include two or more photodiodes.

[0506] In one embodiment, each sample storage node **20-133** includes a charge storing device for storing a sample, and the stored sample may be a function of a light intensity detected at the photodiode **20-101**. For example, each sample storage node **20-133** may include a capacitor for storing a charge as a sample. In such an embodiment, each capacitor stores a charge that corresponds to an accumulated exposure during an exposure time or sample time. For example, current received at each capacitor from an associated photodiode may cause the capacitor, which has been previously charged, to discharge at a rate that is proportional to an incident light intensity detected at the photodiode. The remaining charge of each capacitor may be subsequently output from the capacitor as a value. For example, the remaining charge of each capacitor may be output as an analog value that is a function of the remaining charge on the capacitor.

[0507] To this end, an analog value received from a capacitor may be a function of an accumulated intensity of light detected at an associated photodiode. In some embodiments, each sample storage node **20-133** may include circuitry operable for receiving input based on a photodiode. For example, such circuitry may include one or more transistors. The one or more transistors may be configured for rendering the sample storage node **20-133** responsive to various control signals, such as sample, reset, and row select signals received from one or more controlling devices or components. In other embodiments, each sample storage node **20-133** may include any device for storing any sample or value that is a function of a light intensity detected at the photodiode **20-101**.

[0508] Further, as shown in FIG. **20-1**, the ambient sample storage node **20-133**(**0**) outputs first value **20-106**, and the flash sample storage node **20-133**(**1**) outputs second value **20-108**. In one embodiment, the ambient sample storage node **20-133**(**0**) outputs the first value **20-106** based on the ambient sample stored at the ambient sample storage node **20-133**(**0**), and the flash sample storage node **20-133**(**1**) outputs the second value **20-108** based on the flash sample stored at the flash sample storage node **20-133**(**1**). An ambient sample may include any value stored at an ambient sample storage node **20-133**(**0**) due to input **20-102** from the photodiode **20-101** during an exposure time in which the photodiode **20-101** measures or detects ambient light. A flash sample may include any value stored at a flash storage node **20-133**(**1**) due to input **20-104** from the photodiode **20-101** during an exposure time in which the photodiode **20-101** measures or detects flash or strobe illumination.

[0509] In some embodiments, the ambient sample storage node **20-133**(**0**) outputs the first value **20-106** based on a charge stored at the ambient sample storage node **20-133**(**0**), and the flash sample storage node **20-133**(**1**) outputs the second value **20-108** based on a second charge stored at the flash sample storage node **20-133**(**1**). The first value **20-106** may be output serially with the second value **20-108**, such that one value is output prior to the other value; or the first value **20-106** may be output in parallel with the output of the second value **20-108**. In various embodiments, the first value **20-106** may include a first analog value, and the second value **20-108** may include a second analog value. Each of these values may include a current, which may be output for inclusion in an analog signal that includes at least one analog value associated with each photodiode of a photodiode array. In such embodiments, the first analog value **20-106** may be included in an ambient analog signal, and the second analog value **20-108** may be included in a flash analog signal that is different than the ambient analog signal. In other words, an ambient analog signal may be generated to include an analog value associated with each photodiode of a photodiode array, and a flash analog signal may also be generated to include a different analog value associated with each of the photodiodes of the photodiode array. In such an embodiment, the analog values of the ambient analog signal would be sampled during a first exposure time in which the associated photodiodes were exposed to ambient light, and the analog values of the flash analog signal would be sampled during a second exposure time in which the associated photodiode were exposed to strobe or flash illumination.

[0510] To this end, a single photodiode array may be utilized to generate a plurality of analog signals. The plurality of analog signals may be generated concurrently or in parallel. Further, the plurality of analog signals may each be amplified utilizing two or more gains, and each amplified analog signal may converted to one or more digital signals such that two or more digital signals may be generated, where each digital signal may include a digital image. Accordingly, due to the contemporaneous storage of the ambient sample and the flash sample, a single photodiode array may be utilized to concurrently generate multiple digital signals or digital images, where at least one of the digital signals is associated with an ambient exposure photographic scene, and at least one of the digital signals is associated with a flash or strobe illuminated exposure of the same photographic scene. In such an embodiment, multiple digital signals having different exposure characteristics may be substantially simultaneously generated for a single photographic scene captured at ambient illumination. Such a collection of digital signals or digital images may be referred to as an ambient image stack. Further, multiple digital signals having different exposure characteristics may be substantially simultaneously generated for the single photographic scene captured with strobe or flash illumination. Such a collection of digital signals or digital images may be referred to as a flash image stack.

[0511] In certain embodiments, an analog signal comprises a plurality of distinct analog signals, and a signal amplifier comprises a corresponding set of distinct signal amplifier circuits. For example, each pixel within a row of pixels of an image sensor may have an associated distinct analog signal within an analog signal, and each distinct analog signal may have a corresponding distinct signal amplifier circuit. Further, two or more amplified analog signals may each include gain-adjusted analog pixel data representative of a common analog value from at least one pixel of an image sensor. For example, for a given pixel of an image sensor, a given analog value may be output in an analog signal, and then, after signal amplification operations, the given analog value is represented by a first amplified value in a first amplified analog signal, and by a second amplified value in a second amplified analog signal. Analog pixel data may be analog signal values associated with one or more given pixels.

[0512] In various embodiments, the digital images of the ambient image stack and the flash image stack may be combined or blended to generate one or more new blended images having a greater dynamic range than any of the individual images. Further, the digital images of the ambient image stack and the flash image stack may be combined or blended for controlling a flash contribution in the one or more new blended images.

[0513] FIG. **20-2** illustrates a method **20-200** for capturing flash and ambient illuminated images, in accordance with one embodiment. As an option, the method **20-200** may be carried out in the context of any of the Figures disclosed herein. Of course, however, the method **20-200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0514] As shown in operation **20-202**, an ambient sample is stored based on an electrical signal from a photodiode of an image sensor. Further, sequentially, at least in part, with the storage of the ambient sample, a flash sample is stored based on the electrical signal from the photodiode of the image sensor at operation **20-204**. As noted above, the photodiode of the image sensor may comprise any semiconductor diode that generates a potential difference, or changes its electrical resistance, in response to photon absorption. Accordingly, the photodiode may be used to detect or measure light intensity, and the electrical signal from the photodiode may include a photodiode current that varies as a function of the light intensity.

[0515] In some embodiments, each sample may include an electronic representation of a portion of an optical image that has been focused on an image sensor that includes the photodiode. In such an embodiment, the optical image may be focused on the image sensor by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene. The photodiode may be a single photodiode of an array of photodiodes of the image sensor. Such an image sensor may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor

[0516] In the context of one embodiment, each of the samples may be stored by storing energy. For example, each of the samples may include a charged stored on a capacitor. In such an embodiment, the ambient sample may include a first charge stored at a first capacitor, and the flash sample may include a second charge stored at a second capacitor. In one embodiment, the ambient sample may be different than the flash sample. For example, the ambient sample may include a first charge stored at a first capacitor, and the flash sample may include a second charge stored at a second capacitor that is different than the first charge.

[0517] In one embodiment, the ambient sample may be different than the flash sample due to being sampled at different sample times. For example, the ambient sample may be stored by charging or discharging a first capacitor during a first sample time, and the flash sample may be stored by charging or discharging a second capacitor during a second sample time, where the first capacitor and the second capacitor may be substantially identical and charged or discharged at a substantially identical rate for a given photodiode current. The second sample time may be contemporaneously, or near contemporaneously, with a conclusion of the first sample time, such that the second capacitor may be charged or discharged after the charging or discharging of the first capacitor has completed.

[0518] In another embodiment, the ambient sample may be different than the flash sample due to, at least partially, different storage characteristics. For example, the ambient sample may be stored by charging or discharging a first capacitor for a period of time, and the flash sample may be stored by charging or discharging a second capacitor for the same period of time, where the first capacitor and the second capacitor may have different storage characteristics and/or be charged or discharged at different rates. More specifically, the first capacitor may have a different capacitance than the second capacitor.

[0519] In another embodiment, the ambient sample may be different than the flash sample due to a flash or strobe illumination that occurs during the second exposure time, and that provides different illumination characteristics than the ambient illumination of the first exposure time. For example, the ambient sample may be stored by charging or discharging a first capacitor for a period of time of ambient illumination, and the flash sample may be stored by charging or discharging a second capacitor for a period of time of flash illumination. Due to the differences in illumination between the first exposure time and the second exposure time, the second capacitor may be charged or discharged faster than the first capacitor due to the increased light intensity associated with the flash illumination of the second exposure time.

[0520] Additionally, as shown at operation **20-206**, after storage of the ambient sample and the flash sample, a first value is output based on the ambient sample, and a second value is output based on the flash sample, for generating at least one image. In the context of one embodiment, the first value and the second value are transmitted or output in sequence. For example, the first value may be transmitted prior to the second value. In another embodiment, the first value and the second value may be transmitted in parallel.

[0521] In one embodiment, each output value may comprise an analog value. For example, each output value may include a current representative of the associated stored sample, such as an ambient sample or a flash sample. More specifically, the first value may include a current value representative of the stored ambient sample, and the second value may include a current value representative of the stored flash sample. In one embodiment, the first value is output for inclusion in an ambient analog signal, and the second value is output for inclusion in a flash analog signal different than the ambient analog signal. Further, each value may be output in a manner such that it is combined with other values output based on other stored samples, where the other stored samples are stored responsive to other electrical signals received from other photodiodes of an image sensor. For example, the first value may be combined in an ambient analog signal with values output based on other ambient samples, where the other ambient samples were stored based on electrical signals received from photodiodes that neighbor the photodiode from which the electrical signal utilized for storing the ambient sample was received. Similarly, the second value may be combined in a flash analog signal with values output based on other flash samples, where the other flash samples were stored based on electrical signals received from the same photodiodes that neighbor the photodiode from which the electrical signal utilized for storing the flash sample was received.

[0522] Finally, at operation **20-208**, at least one of the first value and the second value are amplified utilizing two or more gains. In one embodiment, where each output value comprises an analog value, amplifying at least one of the first value and the second value may result in at least two amplified analog values. In another embodiment, where the first value is output for inclusion in an ambient analog signal, and the second value is output for inclusion in a flash analog signal different than the ambient analog signal, one of the ambient analog signal or the flash analog signal may be amplified utilizing two or more gains each. For example, an ambient analog signal that includes the first value may be amplified with a first gain and a second gain, such that the first value is amplified with the first gain and the second gain. Amplifying the ambient analog signal with the first gain may result in a first amplified ambient analog signal, and amplifying the ambient analog signal with the second gain may result in a second amplified ambient analog signal. Of course, more than two analog signals may be amplified using two or more gains. In one embodiment, each amplified analog signal may be converted to a digital signal comprising a digital image.

[0523] To this end, an array of photodiodes may be utilized to generate an ambient analog signal based on a set of ambient samples captured at a first exposure time or sample time and illuminated with ambient light, and a flash analog signal based on a set of flash samples captured at a second exposure time or sample time and illuminated with flash or strobe illumination, where the set of ambient samples and the set of flash samples may be two different sets of samples of the same photographic scene. Further, each analog signal may include an analog value generated based on each photodiode of each pixel of an image sensor. Each analog value may be representative of a light intensity measured at the photodiode associated with the analog value. Accordingly, an analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values, and analog pixel data may be analog signal values associated with one or more given pixels. Still further, each analog signal may undergo subsequent processing, such as amplification, which may facilitate conversion of the analog signal into one or more digital signals, each including digital pixel data, which may each comprise a digital image.

[0524] The embodiments disclosed herein may advantageously enable a camera module to sample images comprising an image stack with lower (e.g. at or near zero, etc.) inter-sample time (e.g. interframe, etc.) than conventional techniques. In certain embodiments, images comprising an analog image stack or a flash image stack are effectively sampled or captured simultaneously, or near simultaneously, which may reduce inter-sample time to zero. In other embodiments, the camera module may sample images in coordination with the strobe unit to reduce inter-sample time between an image sampled without strobe illumination and an image sampled with strobe illumination.

[0525] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.

[0526] In one embodiment, the first exposure time and the second exposure time do not overlap in time. For example, a controller may be configured to control the second exposure time such that it begins contemporaneously, or near contemporaneously, with a conclusion of the first exposure time. In such an embodiment, the sample signal **19-618**(**1**) may be activated as the sample signal **19-618**(**0**) is deactivated.

[0527] As a benefit of having two different exposure conditions, in situations where a photodiode **19-602** is exposed to a sufficient threshold of incident light **19-601**, a first capacitor **19-604**(**0**) may provide an analog value suitable for generating a digital image, and a second capacitor **19-604**(**1**) of the same cell **19-600** may provide a “blown out” or over exposed image portion due to excessive flash illumination. Thus, for each cell **19-600**, a first capacitor **19-604** may more effectively capture darker image content than another capacitor **19-604** of the same cell **19-600**. This may be useful, for example, in situations where strobe or flash illumination over-exposes foreground objects in a digital image of a photographic scene, or under-exposes background objects in the digital image of the photographic scene. In such an example, an image captured during another exposure time utilizing ambient illumination may help correct any over-exposed or under-exposed objects. Similarly, in situations where ambient light is unable to sufficiently illuminate particular elements of a photographic scene, and these elements appear dark or difficult to see in an associated digital image, an image captured during another exposure time utilizing strobe or flash illumination may help correct any under-exposed portions of the image.

[0528] In various embodiments, capacitor **19-604**(**0**) may be substantially identical to capacitor **19-604**(**1**). For example, the capacitors **19-604**(**0**) and **19-604**(**1**) may have substantially identical capacitance values. In one embodiment, a sample signal **19-618** of one of the analog sampling circuits may be activated for a longer or shorter period of time than a sample signal **19-618** is activated for any other analog sampling circuits **19-603**.

[0529] As noted above, the sample signal **19-618**(**0**) of the first analog sampling circuit **19-603**(**0**) may be activated for a first exposure time, and a sample signal **19-618**(**1**) of the second analog sampling circuit **19-603**(**1**) may be activated for a second exposure time. In one embodiment, the first exposure time and/or the second exposure time may be determined based on an exposure setting selected by a user, by software, or by some combination of user and software. For example, the first exposure time may be selected based on a 1/60 second shutter time selected by a user of a camera. In response, the second exposure time may be selected based on the first exposure time. In one embodiment, the user's selected 1/60 second shutter time may be selected for an ambient image, and a metering algorithm may then evaluate the photographic scene to determine an optimal second exposure time for a flash or strobe capture. The second exposure time for the flash or strobe capture may be selected based on incident light metered during the evaluation of the photographic scene. Of course, in other embodiments, a user selection may be used to select the second exposure time, and then the first exposure time for an ambient capture may be selected according to the selected second exposure time. In yet other embodiments, the first exposure time may be selected independent of the second exposure time.

[0530] In other embodiments, the capacitors **19-604(0)** and **19-604(1)** may have different capacitance values. In one embodiment, the capacitors **19-604(0)** and **19-604(1)** may have different capacitance values for the purpose of rendering one of the analog sampling circuits **19-603** more or less sensitive to the current I_PD from the photodiode **19-602** than other analog sampling circuits **19-603** of the same cell **19-600**. For example, a capacitor **19-604** with a significantly larger capacitance than other capacitors **19-604** of the same cell **19-600** may be less likely to fully discharge when capturing photographic scenes having significant amounts of incident light **19-601**. In such embodiments, any difference in stored voltages or samples between the capacitors **19-604(0)** and **19-604(1)** may be a function of the different capacitance values, in conjunction with different activation times of the sample signals **19-618** and different incident light measurements during the respective exposure times.

[0531] In one embodiment, the photosensitive cell **19-600** may be configured such that the first analog sampling circuit **19-603(0)** and the second analog sampling circuit **19-603(1)** share at least one shared component. In various embodiments, the at least one shared component may include a photodiode **19-602** of an image sensor. In other embodiments, the at least one shared component may include a reset, such that the first analog sampling circuit **19-603(0)** and the second analog sampling circuit **19-603(1)** may be reset concurrently utilizing the shared reset. In the context of FIG. **19-3**, the photosensitive cell **19-600** may include a shared reset between the analog sampling circuits **19-603(0)** and **19-603(1)**. For example, reset **19-616(0)** may be coupled to reset **19-616(1)**, and both may be asserted together such that the reset **19-616(0)** is the same signal as the reset **19-616(1)**, which may be used to simultaneously reset both of the first analog sampling circuit **19-603(0)** and the second analog sampling circuit **19-603(1)**. After reset, the first analog sampling circuit **19-603(0)** and the second analog sampling circuit **19-603(1)** may be asserted to sample independently.

[0532] To this end, the photosensitive cell **19-600** may be utilized to simultaneously store both of an ambient sample and a flash sample based on the incident light **19-601**. Specifically, the ambient sample may be captured and stored on a first capacitor during a first exposure time, and the flash sample may be captured and stored on a second capacitor during a second exposure time. Further, during this second exposure time, a strobe may be activated for temporarily increasing illumination of a photographic scene, and increasing the incident light measured at one or more photodiodes of an image sensor during the second exposure time.

[0533] In one embodiment, a unique instance of analog pixel data **18-621** may include, as an ordered set of individual analog values, all analog values output from all corresponding analog sampling circuits or sample storage nodes. For example, in the context of the foregoing figures, each cell of cells **18-542-18-545** of a plurality of pixels **18-540** of a pixel array **18-510** may include both a first analog sampling circuit **18-603(0)** and a second analog sampling circuit **18-603(1)**. Thus, the pixel array **18-510** may include a plurality of first analog sampling circuits **18-603(0)** and also include a plurality of second analog sampling circuits **18-603(1)**. In other words, the pixel array **18-510** may include a first analog sampling circuit **18-603(0)** for each cell, and also include a second analog sampling circuit **18-603(1)** for each cell. In an embodiment, a first instance of analog pixel data **18-621** may be received containing a discrete analog value from each analog sampling circuit of a plurality of first analog sampling circuits **18-603(0)**, and a second instance of analog pixel data **18-621** may be received containing a discrete analog value from each analog sampling circuit of a plurality of second analog sampling circuits **18-603(1)**. Thus, in embodiments where cells of a pixel array include two or more analog sampling circuits, the pixel array may output two or more discrete analog signals, where each analog signal includes a unique instance of analog pixel data **18-621**.

[0534] Further, each of the first analog sampling circuits **19-603**(**0**) may sample a photodiode current during a first exposure time, during which a photographic scene is illuminated with ambient light; and each of the second sampling circuits **19-603**(**1**) may sample the photodiode current during a second exposure time, during which the photographic scene is illuminated with a strobe or flash. Accordingly, a first analog signal, or ambient analog signal, may include analog values representative of the photographic scene when illuminated with ambient light; and a second analog signal, or flash analog signal, may include analog values representative of the photographic scene when illuminated with the strobe or flash.

[0535] In some embodiments, only a subset of the cells of a pixel array may include two or more analog sampling circuits. For example, not every cell may include both a first analog sampling circuit **19-603**(**0**) and a second analog sampling circuit **19-603**(**1**).

[0536] FIG. **20-3** illustrates a system **20-700** for converting analog pixel data of an analog signal to digital pixel data, in accordance with an embodiment. As an option, the system **20-700** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system **20-700** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0537] The system **20-700** is shown in FIG. **20-3** to include a first analog storage plane **20-702**(**0**), a first analog-to-digital unit **20-722**(**0**), and an ambient digital image stack **20-732**(**0**), and is shown to further include a second analog storage plane **20-702**(**1**), a second analog-to-digital unit **20-722**(**1**), and a flash digital image stack **20-732**(**1**). Accordingly, the system **20-700** is shown to include at least two analog storage planes **20-702**(**0**) and **20-702**(**1**). As illustrated in FIG. **20-3**, a plurality of analog values are each depicted as a “V” within each of the analog storage planes **20-702**, and corresponding digital values are each depicted as a “D” within digital images of each of the image stacks **20-732**. In one embodiment, all of the analog values of the first analog storage plane **20-702**(**0**) are captured during a first exposure time, during which a photographic scene was illuminated with ambient light; and all of the analog values of the second analog storage plane **20-702**(**1**) are captured during a second exposure time, during which the photographic scene was illuminated using a strobe or flash.

[0538] In the context of certain embodiments, each analog storage plane **20-702** may comprise any collection of one or more analog values. In some embodiments, each analog storage plane **20-702** may comprise at least one analog pixel value for each pixel of a row or line of a pixel array. Still yet, in another embodiment, each analog storage plane **20-702** may comprise at least one analog pixel value for each pixel of an entirety of a pixel array, which may be referred to as a frame. For example, each analog storage plane **20-702** may comprise an analog pixel value, or more generally, an analog value for each cell of each pixel of every line or row of a pixel array.

[0539] Further, the analog values of each analog storage plane **20-702** are output as analog pixel data **20-704** to a corresponding analog-to-digital unit **20-722**. For example, the analog values of analog storage plane **20-702**(**0**) are output as analog pixel data **20-704**(**0**) to analog-to-digital unit **20-722**(**0**), and the analog values of analog storage plane **20-702**(**1**) are output as analog pixel data **20-704**(**1**) to analog-to-digital unit **20-722**(**1**). In one embodiment, each analog-to-digital unit **20-722** may be substantially identical to the analog-to-digital unit **18-622** described within the context of FIG. **18-4**. For example, each analog-to-digital unit **20-722** may comprise at least one amplifier and at least one analog-to-digital converter, where the amplifier is operative to receive a gain value and utilize the gain value to gain-adjust analog pixel data received at the analog-to-digital unit **20-722**. Further, in such an embodiment, the amplifier may transmit gain-adjusted analog pixel data to an analog-to-digital converter, which then generates digital pixel data from the gain-adjusted analog pixel data. To this end, an analog-to-digital conversion may be performed on the contents of each of two or more different analog storage planes **20-702**.

[0540] In the context of the system **20-700** of FIG. **20-3**, each analog-to-digital unit **20-722** receives corresponding analog pixel data **20-704**, and applies at least two different gains to the received analog pixel data **20-704** to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data. For example, the analog-to-digital unit **20-722**(**0**) receives analog pixel data **20-704**(**0**), and applies at least two different gains to the analog pixel data **20-704**(**0**) to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **20-704**(**0**); and the analog-to-digital unit **20-722**(**1**) receives analog pixel data **20-704**(**1**), and applies at least two different gains to the analog pixel data **20-704**(**1**) to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **20-704**(**1**).

[0541] Further, each analog-to-digital unit **20-722** converts each generated gain-adjusted analog pixel data to digital pixel data, and then outputs at least two digital outputs. In one embodiment, each analog-to-digital unit **20-722** provides a different digital output corresponding to each gain applied to the received analog pixel data **20-704**. With respect to FIG. **20-3** specifically, the analog-to-digital unit **20-722**(**0**) is shown to generate a first digital signal comprising first digital pixel data **20-723**(**0**) corresponding to a first gain (Gain1), a second digital signal comprising second digital pixel data **20-724**(**0**) corresponding to a second gain (Gain2), and a third digital signal comprising third digital pixel data **20-725**(**0**) corresponding to a third gain (Gain3). Similarly, the analog-to-digital unit **20-722**(**1**) is shown to generate a first digital signal comprising first digital pixel data **20-723**(**1**) corresponding to a first gain (Gain1), a second digital signal comprising second digital pixel data **20-724**(**1**) corresponding to a second gain (Gain2), and a third digital signal comprising third digital pixel data **20-725**(**1**) corresponding to a third gain (Gain3). Each instance of each digital pixel data may comprise a digital image, such that each digital signal comprises a digital image.

[0542] Accordingly, as a result of the analog-to-digital unit **20-722**(**0**) applying each of Gain1, Gain2, and Gain3 to the analog pixel data **20-704**(**0**), and thereby generating first digital pixel data **20-723**(**0**), second digital pixel data **20-724**(**0**), and third digital pixel data **20-725**(**0**), the analog-to-digital unit **20-722**(**0**) generates a stack of digital images, also referred to as an ambient image stack **20-732**(**0**). Similarly, as a result of the analog-to-digital unit **20-722**(**1**) applying each of Gain1, Gain2, and Gain3 to the analog pixel data **20-704**(**1**), and thereby generating first digital pixel data **20-723**(**1**), second digital pixel data **20-724**(**1**), and third digital pixel data **20-725**(**1**), the analog-to-digital unit **20-722**(**1**) generates a second stack of digital images, also referred to as a flash image stack **20-732**(**1**). Each of the digital images of the ambient image stack **20-732**(**0**) may be a digital image of the photographic scene captured with ambient illumination during a first exposure time. Each of the digital images of the flash image stack **20-732**(**1**) may be a digital image of the photographic scene captured with strobe or flash illumination during a second exposure time.

[0543] In one embodiment, each analog-to-digital unit **20-722** applies in sequence at least two gains to the analog values. For example, within the context of FIG. **20-3**, the analog-to-digital unit **20-722**(**0**) first applies Gain1 to the analog pixel data **20-704**(**0**), then subsequently applies Gain2 to the same analog pixel data **20-704**(**0**), and then subsequently applies Gain3 to the same analog pixel data **20-704**(**0**). In other embodiments, each analog-to-digital unit **20-722** may apply in parallel at least two gains to the analog values. For example, an analog-to-digital unit may apply Gain1 to received analog pixel data in parallel with application of Gain2 and Gain3 to the analog pixel data. To this end, each instance of analog pixel data **20-704** is amplified utilizing at least two gains.

[0544] In one embodiment, the gains applied to the analog pixel data **20-704**(**0**) at the analog-to-digital unit **20-722**(**0**) may be the same as the gains applied to the analog pixel data **20-704**(**1**) at the analog-to-digital unit **20-722**(**1**). By way of a specific example, the Gain1 applied by both of the analog-to-digital unit **20-722**(**0**) and the analog-to-digital unit **20-722**(**1**) may be a gain of 1.0, the Gain2 applied by both of the analog-to-digital unit **20-722**(**0**) and the analog-to-digital unit **20-722**(**1**) may be a gain of 2.0, and the Gain3 applied by both of the analog-to-digital unit **20-722**(**0**) and the analog-to-digital unit **20-722**(**1**) may be a gain of 4.0. In another embodiment, one or more of the gains applied to the analog pixel data **20-704**(**0**) at the analog-to-digital unit **20-722**(**0**) may be different from the gains applied to the analog pixel data **20-704**(**1**) at the analog-to-digital unit **20-722**(**1**). For example, the Gain1 applied at the analog-to-digital unit **20-722**(**0**) may be a gain of 1.0, and the Gain1 applied at the analog-to-digital unit **20-722**(**1**) may be a gain of 2.0. Accordingly, the gains applied at each analog-to-digital unit **20-722** may be selected dependently or independently of the gains applied at other analog-to-digital units **20-722** within system **20-700**.

[0545] In accordance with one embodiment, the at least two gains may be determined using any technically feasible technique based on an exposure of a photographic scene, metering data, user input, detected ambient light, a strobe control, or any combination of the foregoing. For example, a first gain of the at least two gains may be determined such that half of the digital values from an analog storage plane **20-702** are converted to digital values above a specified threshold (e.g., a threshold of 0.5 in a range of 0.0 to 1.0) for the dynamic range associated with digital values comprising a first digital image of an image stack **20-732**, which can be characterized as having an "EV0" exposure. Continuing the example, a second gain of the at least two gains may be determined as being twice that of the first gain to generate a second digital image of the image stack **20-732** characterized as having an "EV +1" exposure. Further still, a third gain of the at least two gains may be determined as being half that of the first gain to generate a third digital image of the image stack **20-732** characterized as having an "EV −1" exposure.

[0546] In one embodiment, an analog-to-digital unit **20-722** converts in sequence a first instance of the gain-adjusted analog pixel data to the first digital pixel data **20-723**, a second instance of the gain-adjusted analog pixel data to the second digital pixel data **20-724**, and a third instance of the gain-adjusted analog pixel data to the third digital pixel data **20-725**. For example, an analog-to-digital unit **20-722** may first convert a first instance of the gain-adjusted analog pixel data to first digital pixel data **20-723**, then subsequently convert a second instance of the gain-adjusted analog pixel data to second digital pixel data **20-724**, and then subsequently convert a third instance of the gain-adjusted analog pixel data to third digital pixel data **20-725**. In other embodiments, an analog-to-digital unit **20-722** may perform such conversions in parallel, such that one or more of a first digital pixel data **20-723**, a second digital pixel data **20-724**, and a third digital pixel data **20-725** are generated in parallel.

[0547] Still further, as shown in FIG. **20-3**, each first digital pixel data **20-723** provides a first digital image. Similarly, each second digital pixel data **20-724** provides a second digital image, and each third digital pixel data **20-725** provides a third digital image. Together, each set of digital images produced using the analog values of a single analog storage plane **20-702** comprises an image stack **20-732**. For example, ambient image stack **20-732**(**0**) comprises digital images produced using analog values of the analog storage plane **20-702**(**0**), and flash image stack **20-732**(**1**) comprises the digital images produced using the analog values of the analog storage plane **20-702**(**1**). As noted previously, each of the digital images of the ambient image stack **20-732**(**0**) may be a digital image of the photographic scene captured with ambient illumination during a first exposure time. Similarly, each of the digital images of the flash image stack **20-732**(**1**) may be a digital image of the photographic scene captured with strobe or flash illumination during a second exposure time.

[0548] As illustrated in FIG. **20-3**, all digital images of an image stack **20-732** may be based upon a same analog pixel data **20-704**. However, each digital image of an image stack **20-732** may differ from other digital images in the image stack **20-732** as a function of a difference between the gains used to generate the two digital images. Specifically, a digital image generated using the largest gain of at least two gains may be visually perceived as the brightest or more exposed of the digital images of the image stack **20-732**. Conversely, a digital image generated using the smallest gain of the at least two gains may be visually perceived as the darkest and less exposed than other digital images of the image stack **20-732**. To this end, a first light sensitivity value may be associated with first digital pixel data **20-723**, a second light sensitivity value may be associated with second digital pixel data **20-724**, and a third light sensitivity value may be associated with third digital pixel data **20-725**. Further, because each of the gains may be associated with a different light sensitivity value, a first digital image or first digital signal may be associated with a first light sensitivity value, a second digital image or second digital signal may be associated with a second light sensitivity value, and a third digital image or third digital signal may be associated with a third light sensitivity value. In one embodiment, one or more digital images of an image stack may be blended, resulting in a blended image associated with a blended light sensitivity.

[0549] It should be noted that while a controlled application of gain to the analog pixel data may greatly aid in HDR image generation, an application of too great of gain may result in a digital image that is visually perceived as being noisy, over-exposed, and/or blown-out. In one embodiment, application of two stops of gain to the analog pixel data may impart visually perceptible noise for darker portions of a photographic scene, and visually imperceptible noise for brighter portions of the photographic scene. In another embodiment, a digital photographic device may be configured to provide an analog storage plane for analog pixel data of a captured photographic scene, and then perform at least two analog-to-digital samplings of the same analog pixel data using an analog-to-digital unit **20-722**. To this end, a digital image may be generated for each sampling of the at least two samplings, where each digital image is obtained at a different exposure despite all the digital images being generated from the same analog sampling of a single optical image focused on an image sensor.

[0550] In one embodiment, an initial exposure parameter may be selected by a user or by a metering algorithm of a digital photographic device. The initial exposure parameter may be selected based on user input or software selecting particular capture variables. Such capture variables may include, for example, ISO, aperture, and shutter speed. A n image sensor may then capture a photographic scene at the initial exposure parameter during a first exposure time, and populate a first analog storage plane with a first plurality of analog values corresponding to an optical image focused on the image sensor. Next, during a second exposure time, a second analog storage plane may be populated with a second plurality of analog values corresponding to the optical image focused on the image sensor. During the second exposure time, a strobe or flash unit may be utilized to illuminate at least a portion of the photographic scene. In the context of the foregoing Figures, a first analog storage plane **20-702(0)** comprising a plurality of first analog sampling circuits **19-603(0)** may be populated with a plurality of analog values associated with an ambient capture, and a second analog storage plane **20-702(1)** comprising a plurality of second analog sampling circuits **19-603(1)** may be populated with a plurality of analog values associated with a flash or strobe capture.

[0551] In other words, in an embodiment where each photosensitive cell includes two analog sampling circuits, then two analog storage planes may be configured such that a first of the analog storage planes stores a first analog value output from one of the analog sampling circuits of a cell, and a second of the analog storage planes stores a second analog value output from the other analog sampling circuit of the same cell.

[0552] Further, each of the analog storage planes may receive and store different analog values for a given pixel of the pixel array or image sensor. For example, an analog value received for a given pixel and stored in a first analog storage plane may be output based on an ambient sample captured during a first exposure time, and a corresponding analog value received for the given pixel and stored in a second analog storage plane may be output based on a flash sample captured during a second exposure time that is different than the first exposure time. Accordingly, in one embodiment, substantially all analog values stored in a first analog storage plane may be based on samples obtained during a first exposure time, and substantially all analog values stored in a second analog storage plane may be based on samples obtained during a second exposure time that is different than the first exposure time.

[0553] In the context of the present description, a "single exposure" of a photographic scene may include simultaneously, at least in part, storing analog values representative of the photographic scene using two or more sets of analog sampling circuits, where each set of analog sampling circuits may be configured to operate at different exposure times. During capture of the photographic scene using the two or more sets of analog sampling circuits, the photographic scene may be illuminated by ambient light during a first exposure time, and by a flash or strobe unit during a second exposure time. Further, after capturing the photographic scene using the two or more sets of analog sampling circuits, two or more analog storage planes (e.g., one storage plane for each set of analog sampling circuits) may be populated with analog values corresponding to an optical image focused on an image sensor. Next, one or more digital images of an ambient image stack may be obtained by applying one or more gains to the analog values of the first analog storage plane captured during the first exposure time, in accordance with the above systems and methods. Further, one or more digital images of a flash image stack may be obtained by applying one or more gains to the analog values of the second analog storage plane captured during the second exposure time, in accordance with the above systems and methods.

[0554] To this end, one or more image stacks **20-732** may be generated based on a single exposure of a photographic scene.

[0555] In one embodiment, a first digital image of an image stack **20-732** may be obtained utilizing a first gain in accordance with the above systems and methods. For example, if a digital photographic device is configured such that initial exposure parameter includes a selection of ISO 400, the first gain utilized to obtain the first digital image may be mapped to, or otherwise associated with, ISO 400. This first digital image may be referred to as an exposure or image obtained at exposure value 0 (EV 0). Further one more digital images may be obtained utilizing a second gain in accordance with the above systems and methods. For example, the same analog pixel data used to generate the first digital image may be processed utilizing a second gain to generate a second digital image. Still further, one or more digital images may be obtained utilizing a second analog storage plane in accordance with the above systems and methods. For example, second analog pixel data may be used to generate a second digital image, where the second analog pixel data is different from the analog pixel data used to generate the first digital image. Specifically, the analog pixel data used to generate the first digital image may have been captured during a first exposure time, and the second analog pixel data may have been captured during a second exposure time different than the first exposure time.

[0556] To this end, at least two digital images may be generated utilizing different analog pixel data, and then blended to generate an HDR image. The at least two digital images may be blended by blending a first digital signal and a second digital signal. Where the at least two digital images are generated using different analog pixel data captured during a single exposure of a photographic scene, then there may be approximately, or near, zero interframe time between the at least two digital images. As a result of having zero, or near zero, interframe time between at least two digital images of a same photographic scene, an HDR image may be generated, in one possible embodiment, without motion blur or other artifacts typical of HDR photographs.

[0557] In one embodiment, after selecting a first gain for generating a first digital image of an image stack **20-732**, a second gain may be selected based on the first gain. For example, the second gain may be selected on the basis of it being one stop away from the first gain. More specifically, if the first gain is mapped to or associated with ISO 400, then one stop down from ISO 400 provides a gain associated with ISO 200, and one stop up from ISO 400 provides a gain associated with ISO 800. In such an embodiment, a digital image generated utilizing the gain associated with ISO 200 may be referred to as an exposure or image obtained at exposure value −1 (EV −1), and a digital image generated utilizing the gain associated with ISO 800 may be referred to as an exposure or image obtained at exposure value +1 (EV +1).

[0558] Still further, if a more significant difference in exposures is desired between digital images generated utilizing the same analog signal, then the second gain may be selected on the basis of it being two stops away from the first gain. For example, if the first gain is mapped to or associated with ISO 400, then two stops down from ISO 400 provides a gain associated with ISO 100, and two stops up from ISO 400 provides a gain associated with ISO 1600. In such an embodiment, a digital image generated utilizing the gain associated with ISO 100 may be referred to as an exposure or image obtained at exposure value −2 (EV −2), and a digital image generated utilizing the gain associated with ISO 1600 may be referred to as an exposure or image obtained at exposure value +2 (EV +2).

[0559] In one embodiment, an ISO and exposure of the EV 0 image may be selected according to a preference to generate darker digital images. In such an embodiment, the intention may be to avoid blowing out or overexposing what will be the brightest digital image, which is the digital image generated utilizing the greatest gain. In another embodiment, an EV −1 digital image or EV −2 digital image may be a first generated digital image. Subsequent to generating the EV −1 or EV −2 digital image, an increase in gain at an analog-to-digital unit may be utilized to generate an EV0 digital image, and then a second increase in gain at the analog-to-digital unit may be utilized to generate an EV +1 or EV +2 digital image. In one embodiment, the initial exposure parameter corresponds to an EV-N digital image and subsequent gains are used to obtain an EV 0 digital image, an EV +M digital image, or any combination thereof, where N and M are values ranging from 0 to −10.

[0560] In one embodiment, three digital images having three different exposures (e.g. an EV −2 digital image, an EV 0 digital image, and an EV +2 digital image) may be generated in parallel by implementing three analog-to-digital units. Each analog-to-digital unit may be configured to convert one or more analog signal values to corresponding digital signal values. Such an implementation may be also capable of simultaneously generating all of an EV −1 digital image, an EV0 digital image, and an EV +1 digital image. Similarly, in other embodiments, any combination of exposures may be generated in parallel from two or more analog-to-digital units, three or more analog-to-digital units, or an arbitrary number of analog-to-digital units. In other embodiments, a set of analog-to-digital units may be configured to each operate on either of two or more different analog storage planes.

[0561] In some embodiments, a set of gains may be selected for application to the analog pixel data **18-621** based on whether the analog pixel data is associated with an ambient capture or a flash capture. For example, if the analog pixel data **18-621** comprises a plurality of values from an analog storage plane associated with ambient sample storage, a first set of gains may be selected for amplifying the values of the analog storage plane associated with the ambient sample storage. Further, a second set of gains may be selected for amplifying values of an analog storage plane associated with the flash sample storage.

[0562] A plurality of first analog sampling circuits **19-603**(**0**) may comprise the analog storage plane used for the ambient sample storage, and a plurality of second analog sampling circuits **19-603**(**1**) may comprise the analog storage plane used for the flash sample storage. Either set of gains may be preselected based on exposure settings. For example, a first set of gains may be preselected for exposure settings associated with a flash capture, and a second set of gains may be preselected for exposure settings associated with an ambient capture. Each set of gains may be preselected based on any feasible exposure settings, such as, for example, ISO, aperture, shutter speed, white balance, and exposure. One set of gains may include gain values that are greater than each of their counterparts in the other set of gains. For example, a first set of gains selected for application to each ambient sample may include gain values of 0.5, 1.0, and 2.0, and a second set of gains selected for application to each flash sample may include gain values of 1.0, 2.0, and 4.0.

[0563] FIG. **20-4**A illustrates a user interface (UI) system **20-1000** for generating a combined image **20-1020**, according to one embodiment. As an option, the UI system **20-1000** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the UI system **20-1000** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0564] In one embodiment, a combined image **20-1020** comprises a combination of at least two related digital images. For example the combined image **20-1020** may comprise, without limitation, a combined rendering of at least two digital images, such as two or more of the digital images of an ambient image stack **20-732**(**0**) and a flash image stack **20-732**(**1**) of FIG. **20-3**. In another embodiment, the digital images used to compute the combined image **20-1020** may be generated by amplifying each of an ambient analog signal and a flash analog signal with at least two different gains, where each analog signal includes optical scene information captured based on an optical image focused on an image sensor. In yet another embodiment, each analog signal may be amplified using the at least two different gains on a pixel-by-pixel, line-by-line, or frame-by-frame basis.

[0565] In one embodiment, the UI system **20-1000** presents a display image **20-1010** that includes, without limitation, a combined image **20-1020**, and a control region **20-1025**, which in FIG. **20-4**A is shown to include a slider control **20-1030** configured to move along track **20-1032**, and two or more indication points **20-1040**, which may each include a visual marker displayed within display image **20-1010**.

[0566] In one embodiment, the UI system **20-1000** is generated by an adjustment tool executing within a processor complex **310** of a digital photographic system **300**, and the display image **20-1010** is displayed on display unit **312**. In one embodiment, at least two digital images comprise source images for generating the combined image **20-1020**. The at least two digital images may reside within NV memory **316**, volatile memory **318**, memory subsystem **362**, or any combination thereof. In another embodiment, the UI system **20-1000** is generated by an adjustment tool executing within a computer system, such as a laptop computer or a desktop computer. The at least two digital images may be transmitted to the computer system or may be generated by an attached camera device. In yet another embodiment, the UI system **20-1000** may be generated by a cloud-based server computer system, which may download the at least two digital images to a client browser, which may execute combining operations described below. In another embodiment, the UI system **20-1000** is generated by a cloud-based server computer system, which receives the at least two digital images from a digital photographic system in a mobile device, and which may execute the combining operations described below in conjunction with generating combined image **20-1020**.

[0567] The slider control **20-1030** may be configured to move between two end points corresponding to indication points **20-1040**-A and **20-1040**-C. One or more indication points, such as indication point **20-1040**-B may be positioned between the two end points. Of course, in other embodiment, the control region **20-1025** may include other configurations of indication points **20-1040** between the two end points. For example, the control region **20-1025** may include more or less than one indication point.

[0568] Each indication point **20-1040** may be associated with a specific rendering of a combined image **20-1020**, or a specific combination of two or more digital images. For example, the indication point **20-1040**-A may be associated with a first digital image generated from an ambient analog signal captured during a first exposure time, and amplified utilizing a first gain; and the indication point **20-1040**-C may be associated with a second digital image generated from a flash analog signal captured during a second exposure time, and amplified utilizing a second gain. Both the first digital image and the second digital image may be from a single exposure, as described hereinabove. Further, the first digital image may include an ambient capture of the single exposure, and the second digital image may include a flash capture of the single exposure. In one embodiment, the first gain and the second gain may be the same gain. In another embodiment, when the slider control **20-1030** is positioned directly over the indication point **20-1040**-A, only the first digital image may be displayed as the combined image **20-1020** in the display image **20-1010**, and similarly when the slider control **20-1030** is positioned directly over the indication point **20-1040**-C, only the second digital image may be displayed as the combined image **20-1020** in the display image **20-1010**.

[0569] In one embodiment, indication point **20-1040**-B may be associated with a blending of the first digital image and the second digital image. Further, the first digital image may be an ambient digital image, and the second digital image may be a flash digital image. Thus, when the slider control **20-1030** is positioned at the indication point **20-1040**-B, the combined image **20-1020** may be a blend of the ambient digital image and the flash digital image. In one embodiment, blending of the ambient digital image and the flash digital image may comprise alpha blending, brightness blending, dynamic range blending, and/or tone mapping or other non-linear blending and mapping operations. In another embodiment, any blending of the first digital image and the second digital image may provide a new image that has a greater dynamic range or other visual characteristics that are different than either of the first image and the second image alone. In one embodiment, a blending of the first digital image and the second digital image may allow for control of a flash contribution within the combined image. Thus, a blending of the first digital image and the second digital image may provide a new computed image that may be displayed as combined image **20-1020** or used to generate combined image **20-1020**. To this end, a first digital signal and a second digital signal may be combined, resulting in at least a portion of a combined image. Further, one of the first digital signal and the second digital signal may be further combined with at least a portion of another digital image or digital signal. In one embodiment, the other digital image may include another combined image, which may include an HDR image.

[0570] In one embodiment, when the slider control **20-1030** is positioned at the indication point **20-1040**-A, the first digital image is displayed as the combined image **20-1020**, and when the slider control **20-1030** is positioned at the indication point **20-1040**-C, the second digital image is displayed as the combined image **20-1020**; furthermore, when slider control **20-1030** is positioned at indication point **20-1040**-B, a blended image is displayed as the combined image **20-1020**. In such an embodiment, when the slider control **20-1030** is positioned between the indication point **20-1040**-A and the indication point **20-1040**-C, a mix (e.g. blend) weight may be calculated for the first digital image and the second digital image. For the first digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **20-1030** is at indication point **20-1040**-C and a value of 1.0 when slider control **20-1030** is at indication point **20-1040**-A, with a range of mix weight values between 0.0 and 1.0 located between the indication points **20-1040**-C and **20-1040**-A, respectively. For the second digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **20-1030** is at indication point **20-1040**-A and a value of 1.0 when slider control **20-1030** is at indication point **20-1040**-C, with a range of mix weight values between 0.0 and 1.0 located between the indication points **20-1040**-A and **20-1040**-C, respectively.

[0571] In another embodiment, the indication point **20-1040**-A may be associated with a first combination of images, and the indication point **20-1040**-C may be associated with a second combination of images. Each combination of images may include an independent blend of images. For example, the indication point **20-1040**-A may be associated with a blending of the digital images of ambient image stack **20-732**(**0**) of FIG. **20-3**, and the indication point **20-1040**-C may be associated with a blending of the digital images of flash image stack **20-732**(**1**). In other words, the indication point **20-1040**-A may be associated with a blended ambient digital image or blended ambient digital signal, and the indication point **20-1040**-C may be associated with a blended flash digital image or blended flash digital signal. In such an embodiment, when the slider control **20-1030** is positioned at the indication point **20-1040**-A, the blended ambient digital image is displayed as the combined image **20-1020**, and when the slider control **20-1030** is positioned at the indication point **20-1040**-C, the blended flash digital image is displayed as the combined image **20-1020**. Each of the blended ambient digital image and the blended flash digital image may be associated with unique light sensitivities.

[0572] Further, when slider control **20-1030** is positioned at indication point **20-1040**-B, the blended ambient digital image may be blended with the blended flash digital image to generate a new blended image. The new blended image may be associated with yet another unique light sensitivity, and may offer a balance of proper background exposure due to the blending of ambient images, with a properly lit foreground subject due to the blending of flash images. In such an embodiment, when the slider control **20-1030** is positioned between the indication point **20-1040**-A and the indication point **20-1040**-C, a mix (e.g. blend) weight may be calculated for the blended ambient digital image and the blended flash digital image. For the blended ambient digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **20-1030** is at indication point **20-1040**-C and a value of 1.0 when slider control **20-1030** is at indication point **20-1040**-A, with a range of mix weight values between 0.0 and 1.0 located between the indication points **20-1040**-C and **20-1040**-A, respectively. For the blended flash digital image, the mix weight may be calculated as having a value of 0.0 when the slider control **20-1030** is at indication point **20-1040**-A and a value of 1.0 when slider control **20-1030** is at indication point **20-1040**-C, with a range of mix weight values between 0.0 and 1.0 located between the indication points **20-1040**-A and **20-1040**-C, respectively.
[0573] FIG. **20-4**B illustrates a user interface (UI) system **20-1050** for generating a combined image **20-1020**, according to one embodiment. As an option, the UI system **20-1050** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the UI system **20-1050** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0574] As shown in FIG. **20-4**B, the UI system **20-1050** may be substantially identical to the UI system **20-1000** of FIG. **20-4**A, with exception of the control region **20-1025** of UI system **20-1000** and control region **20-1026** of UI system **20-1050**. The control region **20-1026** of UI system **20-1050** is shown to include six indication points **20-1040**-U, **20-1040**-V, **20-1040**-W, **20-1040**-X, **20-1040**-Y, and **20-1040**-Z. The indication points **20-1040**-U and **20-1040**-Z may be representative of end points, similar to the indication points **20-1040**-A and **20-1040**-C, respectively, of UI system **20-1000**. Further, the control region **20-1026** of UI system **20-1050** is shown to include a plurality of indication points **20-1040**—such as indication points **20-1040**-V, **20-1040**-W, **20-1040**-X, and **20-1040**-Y-disposed between the two end points along track **20-1032**. Each of the indication points may be associated with one or more digital images of image stacks **20-732**.
[0575] For example, an ambient image stack **20-732** may be generated to include each of an ambient digital image at EV −1 exposure, an ambient digital image at EV 0 exposure, and an ambient digital image at EV +1 exposure. Said ambient image stack **20-732** may be associated with a first analog storage plane captured at a first exposure time, such as the ambient image stack **20-732**(**0**) of FIG. **20-3**. Thus, an ambient image stack may include a plurality of digital images all associated with a first exposure time during an ambient capture, where each digital image is associated with a different ISO or light sensitivity. Further, a flash image stack **20-732** may also be generated to include each of a flash digital image at EV −1 exposure, a flash digital image at EV 0 exposure, and a flash digital image at EV +1 exposure. However, the flash image stack **20-732** may be associated with a second analog storage plane captured at a second exposure time during which a strobe or flash was activated, such as the flash image stack **20-732**(**1**) of FIG. **20-3**. Thus, a flash image stack may include a second plurality of digital images all associated with a second exposure time during which a strobe or flash was activated, where each flash digital image is associated with a different ISO or light sensitivity.
[0576] After analog-to-digital units **20-722**(**0**) and **20-722**(**1**) generate the respective image stacks **20-732**, the digital pixel data output by the analog-to-digital units **20-722**(**0**) and **20-722**(**1**) may be arranged together into a single sequence of digital images of increasing or decreasing exposure. In one embodiment, no two digital signals of the two image stacks may be associated with a same ISO+exposure time combination, such that each digital image or instance of digital pixel data may

be considered as having a unique effective exposure.

[0577] In one embodiment, and in the context of the foregoing figures, each of the indication points **20-1040**-U, **20-1040**-V, and **20-1040**-W may be associated with digital images of an image stack **20-732**, and each of the indication points **20-1040**-X, **20-1040**-Y, and **20-1040**-Z may be associated with digital images of another image stack **20-732**. For example, each the indication points **20-1040**-U, **20-1040**-V, and **20-1040**-W may be associated with a different ambient digital image or ambient digital signal. Similarly, each of the indication points **20-1040**-X, **20-1040**-Y, and **20-1040**-Z may be associated with a different flash digital image or flash digital signal. In such an embodiment, as the slider **20-1030** is moved from left to right along the track **20-1032**, exposure and flash contribution of the combined image **20-1020** may appear to be adjusted or changed. Of course, when the slider **20-1030** is between two indication points along the track **20-1032**, the combined image **20-1032** may be a combination of any two or more images of the two image stacks **20-732**.

[0578] In another embodiment, the digital images or instances of digital pixel data output by the analog-to-digital units **20-722(0)** and **20-722(1)** may be arranged into a single sequence of digital images of increasing or decreasing exposure. In such an embodiment, the sequence may alternate between ambient and flash digital images. For example, for each of the digital images, gain and exposure time may be combined to determine an effective exposure of the digital image. The digital pixel data may be rapidly organized to obtain a single sequence of digital images of increasing effective exposure, such as, for example: **20-723(0)**, **20-723(1)**, **20-724(0)**, **20-724(1)**, **20-725(0)**, and **20-725(1)**. In such an organization, the sequence of digital images may alternate between flash digital images and ambient digital images. Of course, any sorting of the digital images or digital pixel data based on effective exposure level will depend on an order of application of the gains and generation of the digital signals **20-723-20-725**.

[0579] In one embodiment, exposure times and gains may be selected or predetermined for generating a number of adequately different effective exposures. For example, where three gains are to be applied, then each gain may be selected to be two exposure stops away from a nearest selected gain. Further, a first exposure time may be selected to be one exposure stop away from a second exposure time. In such an embodiment, selection of three gains separated by two exposure stops, and two exposure times separated by one exposure stop, may ensure generation of six digital images, each having a unique effective exposure.

[0580] In another embodiment, exposure times and gains may be selected or predetermined for generating corresponding images of similar exposures between the ambient image stack and the flash image stack. For example, a first digital image of an ambient image stack may be generated utilizing an exposure time and gain combination that corresponds to an exposure time and gain combination utilized to generate a first digital image of a flash image stack. This may be done so that the first digital image of the ambient image stack has a similar effective exposure to that of the first digital image of the flash image stack, which may assist in adjusting a flash contribution in a combined image generated by blending the two digital images.

[0581] With continuing reference to the digital images of multiple image stacks sorted in a sequence of increasing exposure, each of the digital images may then be associated with indication points along the track **20-1032** of the UI system **20-1050**. For example, the digital images may be sorted or sequenced along the track **20-1032** in the order of increasing effective exposure noted previously (**20-723(0)**, **20-723(1)**, **20-724(0)**, **20-724(1)**, **20-725(0)**, and **20-725(1)**) at indication points **20-1040**-U, **20-1040**-V, **20-1040**-W, **20-1040**-X, **20-1040**-Y, and **20-1040**-Z, respectively.

[0582] In such an embodiment, the slider control **20-1030** may then be positioned at any point along the track **20-1032** that is between two digital images generated based on two different analog storage planes, where each analog storage plane is associated with a different scene illumination. As a result, a digital image generated based on an analog storage plane associated with ambient illumination may then be blended with a digital image generated based on an analog storage plane associated with flash illumination to generate a combined image **20-1020**. In this way, one or more images captured with ambient illumination may be blended with one or more images captured with flash illumination.

[0583] For example, the slider control **20-1030** may be positioned at an indication point that may be equally associated with digital pixel data **20-724**(**0**) and digital pixel data **20-724**(**1**). As a result, the digital pixel data **20-724**(**0**), which may include a first digital image generated from an ambient analog signal captured during a first exposure time with ambient illumination and amplified utilizing a gain, may be blended with the digital pixel data **20-724**(**1**), which may include a second digital image generated from a flash analog signal captured during a second exposure time with flash illumination and amplified utilizing the same gain, to generate a combined image **20-1020**.

[0584] Still further, as another example, the slider control **20-1030** may be positioned at an indication point that may be equally associated with digital pixel data **20-724**(**1**) and digital pixel data **20-725**(**0**). As a result, the digital pixel data **20-724**(**1**), which may include a first digital image generated from an ambient analog signal captured during a first exposure time with ambient illumination and amplified utilizing a first gain, may be blended with the digital pixel data **20-725**(**0**), which may include a second digital image generated from a flash analog signal captured during a second exposure time with flash illumination and amplified utilizing a different gain, to generate a combined image **20-1020**.

[0585] Thus, as a result of the slider control **20-1030** positioning, two or more digital signals may be blended, and the blended digital signals may be generated utilizing analog values from different analog storage planes. As a further benefit of sorting effective exposures along a slider, and then allowing blend operations based on slider control position, each pair of neighboring digital images may include a higher noise digital image and a lower noise digital image. For example, where two neighboring digital signals are amplified utilizing a same gain, the digital signal generated from an analog signal captured with a lower exposure time may have less noise. Similarly, where two neighboring digital signals are amplified utilizing different gains, the digital signal generated from an analog signal amplified with a lower gain value may have less noise. Thus, when digital signals are sorted based on effective exposure along a slider, a blend operation of two or more digital signals may serve to reduce the noise apparent in at least one of the digital signals.

[0586] Of course, any two or more effective exposures may be blended based on the indication point of the slider control **20-1030** to generate a combined image **20-1020** in the UI system **20-1050**.

[0587] In one embodiment, a mix operation may be applied to a first digital image and a second digital image based upon at least one mix weight value associated with at least one of the first digital image and the second digital image. In one embodiment, a mix weight of 1.0 gives complete mix weight to a digital image associated with the 1.0 mix weight. In this way, a user may blend between the first digital image and the second digital image. To this end, a first digital signal and a second digital signal may be blended in response to user input. For example, sliding indicia may be displayed, and a first digital signal and a second digital signal may be blended in response to the sliding indicia being manipulated by a user.

[0588] A system of mix weights and mix operations provides a UI tool for viewing a first digital image, a second digital image, and a blended image as a gradual progression from the first digital image to the second digital image. In one embodiment, a user may save a combined image **20-1020** corresponding to an arbitrary position of the slider control **20-1030**. The adjustment tool implementing the UI system **20-1000** may receive a command to save the combined image **20-1020** via any technically feasible gesture or technique. For example, the adjustment tool may be configured to save the combined image **20-1020** when a user gestures within the area occupied by combined image **20-1020**. Alternatively, the adjustment tool may save the combined image **20-1020** when a user presses, but does not otherwise move the slider control **20-1030**. In another implementation, the adjustment tool may save the combined image **20-1020** when a user gestures, such as by pressing a UI element (not shown), such as a save button, dedicated to receive a save command.

[0589] To this end, a slider control may be used to determine a contribution of two or more digital images to generate a final computed image, such as combined image **20-1020**. Persons skilled in the art will recognize that the above system of mix weights and mix operations may be generalized to include two or more indication points, associated with two or more related images. Such related images may comprise, without limitation, any number of digital images that have been generated from two or more analog storage planes, and which may have zero, or near zero, interframe time.

[0590] Furthermore, a different continuous position UI control, such as a rotating knob, may be implemented rather than the slider **20-1030**.

[0591] FIG. **20-4**C illustrates user interface (UI) systems displaying combined images **20-1070-20-1072** with differing levels of strobe exposure, according to one embodiment. As an option, the UI systems of FIG. **20-4**C may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the UI systems be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0592] As shown in FIG. **20-4**C, a blended image may be blended from two or more images based on a position of slider control **20-1030**. As shown, the slider control **20-1030** is configured to select one or more source images for input to a blending operation, where the source images are associated with increasing strobe intensity as the slider control **20-1030** moves from left to right.

[0593] For example, based on the position of slider control **20-1030** in control region **20-1074**, first blended image **20-1070** may be generated utilizing one or more source images captured without strobe or flash illumination. As a specific example, the first blended image **20-1070** may be generated utilizing one or more images captured using only ambient illumination. The one or more images captured using only ambient illumination may comprise an image stack **20-732**, such as the ambient image stack **20-732**(**0**). As shown, the first blended image **20-1070** includes an under-exposed subject **20-1062**. Further, based on the position of slider control **20-1030** in control region **20-1076**, third blended image **20-1072** may be generated utilizing one or more source images captured using strobe or flash illumination. The one or more source images associated with the position of slider control **20-1030** in the control region **20-1076** may comprise an image stack **20-732**, such as the flash image stack **20-732**(**1**). As shown, the third blended image **20-1072** includes an over-exposed subject **20-1082**

[0594] By manipulating the slider control **20-1030**, a user may be able to adjust the contribution of the source images used to generate the blended image. Or, in other words, the user may be able to adjust the blending of one or more images. For example, the user may be able to adjust or increase a flash contribution from the one or more source images captured using strobe or flash illumination. A s illustrated in FIG. **20-4**C, when a user positions the slider control **20-1030** along a track away from track end points, as shown in control region **20-1075**, a flash contribution from the one or more source images captured using strobe or flash illumination may be blended with the one or more source images captured using ambient illumination. This may result in the generation of second blended image **20-1071**, which includes a properly exposed subject **20-1081**. To this end, by blending digital images captured in ambient lighting conditions with digital images of the same photographic scene captured with strobe or flash illumination, novel digital images may be generated. Further, a flash contribution of the digital images captured with strobe or flash illumination may be adjustable by a user to ensure that both foreground subjects and background objects are properly exposed.

[0595] A determination of appropriate strobe intensity may be subjective, and embodiments disclosed herein advantageously enable a user to subjectively select a final combined image having a desired strobe intensity after a digital image has been captured. In practice, a user is able to capture what is apparently a single photograph by asserting a single shutter-release. The single shutter-release may cause capture of a set of ambient samples to a first analog storage plane during a first exposure time, and capture of a set of flash samples to a second analog storage plane during a second exposure time that immediately follows the first exposure time. The ambient samples may comprise an ambient analog signal that is then used to generate multiple digital images of an ambient image stack. Further, the flash samples may comprise a flash analog signal that is then used to generate multiple digital images of a flash image stack. By blending two or more images of the ambient image stack and the flash image stack, the user may thereby identify a final combined image with desired strobe intensity. Further, both the ambient image stack and the flash image stack may be stored, such that the user can select the final combined image at a later time.

[0596] In other embodiments, two or more slider controls may be presented in a UI system. For example, in one embodiment, a first slider control may be associated with digital images of an ambient image stack, and a second slider control may be associated with digital images of a flash image stack. By manipulating the slider controls independently, a user may control a blending of ambient digital images independently from blending of flash digital images. Such an embodiment may allow a user to first select a blending of images from the ambient image stack that provides a preferred exposure of background objects. Next, the user may then select a flash contribution. For example, the user may select a blending of images from the flash image stack that provides a preferred exposure of foreground objects. Thus, by allowing for independent selection of ambient contribution and flash contribution, a final blended or combined image may include properly exposed foreground objects as well as properly exposed background objects.

[0597] In another embodiment, a desired exposure for one or more given regions of a blended image may be identified by a user selecting another region of the blended image. For example, the other region selected by the user may be currently displayed at a proper exposure within a UI system while the one or more given regions are currently under-exposed or over-exposed. In response to the user's selection of the other region, a blending of source images from an ambient image stack and a flash image stack may be identified to provide the proper exposure at the one or more given regions of the blended image. The blended image may then be updated to reflect the identified blending of source images that provides the proper exposure at the one or more given regions.

[0598] In another embodiment, images of a given image stack may be blended before performing any blending operations with images of a different image stack. For example, two or more ambient digital images or ambient digital signals, each with a unique light sensitivity, may be blended to generate a blended ambient digital image with a blended ambient light sensitivity. Further, the blended ambient digital image may then be subsequently blended with one or more flash digital images or flash digital signals. The blending with the one or more flash digital images may be in response to user input. In another embodiment, two or more flash digital images may be blended to generate a blended flash digital image with a blended flash light sensitivity, and the blended flash digital image may then be blended with the blended ambient digital image.

[0599] As another example, two or more flash digital images or flash digital signals, each with a unique light sensitivity, may be blended to generate a blended flash digital image with a blended flash light sensitivity. Further, the blended flash digital image may then be subsequently blended with one or more ambient digital images or ambient digital signals. The blending with the one or more ambient digital images may be in response to user input. In another embodiment, two or more ambient digital images may be blended to generate a blended ambient digital image with a blended ambient light sensitivity, and the blended ambient digital image may then be blended with the blended flash digital image.

[0600] In one embodiment, the ambient image stack may include digital images at different effective exposures than the digital images of the flash image stack. This may be due to application of different gain values for generating each of the ambient image stack and the flash image stack. For example, a particular gain value may be selected for application to an ambient analog signal, but not for application to a corresponding flash analog signal.

[0601] As shown in FIG. **18-8**, a wireless mobile device **18-376**(**0**) generates at least two digital images. In one embodiment, the at least two digital images may be generated by amplifying analog values of two or more analog storage planes, where each generated digital image may correspond to digital output of an applied gain. In one embodiment, a first digital image may include an EV −1 exposure of a photographic scene, and a second digital image may include an EV +1 exposure of the photographic scene. In another embodiment, the at least two digital images may include an EV −2 exposure of a photographic scene, an EV 0 exposure of the photographic scene, and an EV +2 exposure of the photographic scene. In yet another embodiment, the at least two digital images may comprise one or more image stacks. For example, the at least two digital images may comprise an ambient image stack and/or a flash image stack.
[0602] With respect to FIG. **18-8**, user manipulation of the slider control may adjust a flash contribution of one or more source images captured with strobe or flash illumination.
[0603] One advantage of the present invention is that a digital photograph may be selectively generated based on user input using two or more different images generated from a single exposure of a photographic scene. Accordingly, the digital photograph generated based on the user input may have a greater dynamic range than any of the individual images. Additionally, a user may selectively adjust a flash contribution of the different images to the generated digital photograph. Further, the generation of an HDR image using two or more different images with zero, or near zero, interframe time allows for the rapid generation of HDR images without motion artifacts.
[0604] Additionally, when there is any motion within a photographic scene, or a capturing device experiences any jitter during capture, any interframe time between exposures may result in a motion blur within a final merged HDR photograph. Such blur can be significantly exaggerated as interframe time increases. This problem renders current HDR photography an ineffective solution for capturing clear images in any circumstance other than a highly static scene. Further, traditional techniques for generating a HDR photograph involve significant computational resources, as well as produce artifacts which reduce the image quality of the resulting image. Accordingly, strictly as an option, one or more of the above issues may or may not be addressed utilizing one or more of the techniques disclosed herein.
[0605] Still yet, in various embodiments, one or more of the techniques disclosed herein may be applied to a variety of markets and/or products. For example, although the techniques have been disclosed in reference to a photo capture, they may be applied to televisions, web conferencing (or live streaming capabilities, etc.), security cameras (e.g. increase contrast to determine characteristic, etc.), automobiles (e.g. driver assist systems, in-car infotainment systems, etc.), and/or any other product which includes a camera input.
[0606] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.
[0607] FIG. **21-1** illustrates a system **21-100** for obtaining low-noise, high-speed captures of a photographic scene, in accordance with one embodiment. As an option, the system **21-100** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **21-100** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0608] As shown in FIG. **21-1**, the system **21-100** includes a first pixel **21-105**, a second pixel **21-107**, a first sample storage node **21-121**, and a second sample storage node **21-123**. Further, the first pixel **21-105** is shown to include a first cell **21-101**, and the second pixel **21-107** is shown to include a second cell **21-103**. In one embodiment, each pixel may include one or more cells. For example, in some embodiments, each pixel may include four cells. Further, each of the cells may include a photodiode, photosensor, or any photo-sensing electrical element. A photodiode may

comprise any semiconductor diode that generates a potential difference, current, or changes its electrical resistance, in response to photon absorption. Accordingly, a photodiode may be used to detect or measure a light intensity.

[0609] Referring again to FIG. **21-1**, the first cell **21-101** and the first sample storage node **21-121** are in communication via interconnect **21-111**, the second cell **21-103** and the second sample storage node **21-123** are in communication via interconnect **21-113**, and the first cell **21-101** and the second cell **21-103** are in communication via interconnect **21-112**.

[0610] Each of the interconnects **21-111-21-113** may carry an electrical signal from one or more cells to a sample storage node. For example, the interconnect **21-111** may carry an electrical signal from the cell **21-101** to the first sample storage node **21-121**. The interconnect **21-113** may carry an electrical signal from the cell **21-103** to the second sample storage node **21-123**. Further, the interconnect **21-112** may carry an electrical signal from the cell **21-103** to the first sample storage node **21-121**, or may carry an electrical signal from the cell **21-101** to the second sample storage node **21-123**. In such embodiments, the interconnect **21-112** may enable a communicative coupling between the first cell **21-101** and the second cell **21-103**. Further, in some embodiments, the interconnect **21-112** may be operable to be selectively enabled or disabled. In such embodiments, the interconnect **21-112** may be selectively enabled or disable using one or more transistors and/or control signals.

[0611] In one embodiment, each electrical signal carried by the interconnects **21-111-113** may include a photodiode current. For example, each of the cells **21-101** and **21-103** may include a photodiode. Each of the photodiodes of the cells **21-101** and **21-103** may generate a photodiode current which is communicated from the cells **21-101** and **21-103** via the interconnects **21-111-113** to one or more of the sample storage nodes **21-121** and **21-123**. In configurations where the interconnect **21-112** is disabled, the interconnect **21-113** may communicate a photodiode current from the cell **21-103** to the second sample storage node **21-123**, and, similarly, the interconnect **21-111** may communicate a photodiode current from the cell **21-101** to the first sample storage node **21-121**. However, in configurations where the interconnect **21-112** is enabled, both the cell **21-101** and the cell **21-103** may communicate a photodiode current to the first sample storage node **21-121** and the second sample storage node **21-123**.

[0612] Of course, each sample storage node may be operative to receive any electrical signal from one or more communicatively coupled cells, and then store a sample based upon the received electrical signal. In some embodiments, each sample storage node may be configured to store two or more samples. For example, the first sample storage node **21-121** may store a first sample based on a photodiode current from the cell **21-101**, and may separately store a second sample based on, at least in part, a photodiode current from the cell **21-103**.

[0613] In one embodiment, each sample storage node includes a charge storing device for storing a sample, and the sample stored at a given storage node may be a function of a light intensity detected at one or more associated photodiodes. For example, the first sample storage node **21-121** may store a sample as a function of a received photodiode current, which is generated based on a light intensity detected at a photodiode of the cell **21-101**. Further, the second sample storage node **21-123** may store a sample as a function of a received photodiode current, which is generated based on a light intensity detected at a photodiode of the cell **21-103**. As yet another example, when the interconnect **21-112** is enabled, the first sample storage node **21-121** may receive a photodiode current from each of the cells **21-101** and **21-103**, and the first sample storage node **21-121** may thereby store a sample as a function of both the light intensity detected at the photodiode of the cell **21-101** and the light intensity detected at the photodiode of the cell **21-103**.

[0614] In one embodiment, each sample storage node may include a capacitor for storing a charge as a sample. In such an embodiment, each capacitor stores a charge that corresponds to an accumulated exposure during an exposure time or sample time. For example, current received at each capacitor from one or more associated photodiodes may cause the capacitor, which has been previously charged, to discharge at a rate that is proportional to incident light intensity detected at the one or more photodiodes. The remaining charge of each capacitor may be referred to as a value or analog value, and may be subsequently output from the capacitor. For example, the remaining charge of each capacitor may be output as an analog value that is a function of the remaining charge on the capacitor. In one embodiment, via the interconnect **21-112**, the cell **21-101** may be communicatively coupled to one or more capacitors of the first sample storage node **21-121**, and the cell **21-103** may also be communicatively coupled to one or more capacitors of the first sample storage node **21-121**.

[0615] In some embodiments, each sample storage node may include circuitry operable for receiving input based on one or more photodiodes. For example, such circuitry may include one or more transistors. The one or more transistors may be configured for rendering the sample storage node responsive to various control signals, such as sample, reset, and row select signals received from one or more controlling devices or components. In other embodiments, each sample storage node may include any device for storing any sample or value that is a function of a light intensity detected at one or more associated photodiode. In some embodiments, the interconnect **21-112** may be selectively enabled or disabled using one or more associated transistors. Accordingly, the cell **21-101** and the cell **21-103** may be in communication utilizing a communicative coupling that includes at least one transistor. In embodiments where each of the pixels **21-105** and **21-107** include additional cells (not shown), the additional cells may not be communicatively coupled to the cells **21-101** and **21-103** via the interconnect **21-112**.

[0616] In various embodiments, the pixels **21-105** and **21-107** may be two pixels of an array of pixels of an image sensor. Each value stored at a sample storage node may include an electronic representation of a portion of an optical image that has been focused on the image sensor that includes the pixels **21-105** and **21-107**. In such an embodiment, the optical image may be focused on the image sensor by a lens. The electronic representation of the optical image may comprise spatial color intensity information, which may include different color intensity samples (e.g. red, green, and blue light, etc.). In other embodiments, the spatial color intensity information may also include samples for white light. In one embodiment, the optical image may be an optical image of a photographic scene. Such an image sensor may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor.

[0617] FIG. **21-2** illustrates a system **21-200** for obtaining low-noise, high-speed captures of a photographic scene, in accordance with another embodiment. As an option, the system **21-200** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **21-200** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0618] As shown in FIG. **21-2**, the system **21-200** includes a plurality of pixels **21-240**. Specifically, the system **21-200** is shown to include pixels **21-240(0)**, **21-240(1)**, **21-240(2)**, and **21-240(3)**. Each of the pixels **21-240** may be substantially identical with respect to composition and configuration. Further, each of the pixels **21-240** may be a single pixel of an array of pixels comprising an image sensor. To this end, each of the pixels **21-240** may comprise hardware that renders the pixel operable to detect or measure various wavelengths of light, and convert the measured light into one or more electrical signals for rendering or generating one or more digital images. Each of the pixels **21-240** may be substantially identical to the pixel **21-105** or the pixel **21-107** of FIG. **21-1**.

[0619] Further, each of the pixels **21-240** is shown to include a cell **21-242**, a cell **21-243**, a cell **21-244** and a cell **21-245**. In one embodiment, each of the cells **21-242-245** includes a photodiode operative to detect and measure one or more peak wavelengths of light. For example, each of the cells **21-242** may be operative to detect and measure red light, each of the cells **21-243** and **21-244** may be operative to detect and measure green light, and each of the cells **21-245** may be operative to detect and measure blue light. In other embodiments, a photodiode may be configured to detect wavelengths of light other than only red, green, or blue. For example, a photodiode may be configured to detect white, cyan, magenta, yellow, or non-visible light such as infrared or ultraviolet light. Any communicatively coupled cells may be configured to detect a same peak wavelength of light.

[0620] In various embodiments, each of the cells **21-242-21-245** may generate an electrical signal in response to detecting and measuring its associated one or more peak wavelengths of light. In one embodiment, each electrical signal may include a photodiode current. A given cell may generate a photodiode current which is sampled by a sample storage node for a selected sample time or exposure time, and the sample storage node may store an analog value based on the sampling of the photodiode current. Of course, as noted previously, each sample storage node may be capable of concurrently storing more than one analog value.

[0621] As shown in FIG. **21-2**, each of the cells **21-242** are communicatively coupled via an interconnect **21-250**. In one embodiment, the interconnect **21-250** may be enabled or disabled using one or more control signals. When the interconnect **21-250** is enabled, the interconnect may carry a combined electrical signal. The combined electrical signal may comprise a combination of electrical signals output from each of the cells **21-242**. For example, the combined electrical signal may comprise a combined photodiode current, where the combined photodiode current includes photodiode current received from photodiodes of each of the cells **21-242**. Thus, enabling the interconnect **21-250** may serve to increase a combined photodiode current generated based on one or more peak wavelengths of light. In some embodiments, the combined photodiode current may be used to more rapidly store an analog value at a sample storage node than if a photodiode current generated by only a single cell was used to store the analog value. To this end, the interconnect **21-250** may be enabled to render the pixels **21-240** of an image sensor more sensitive to incident light. Increasing the sensitivity of an image sensor may allow for more rapid capture of digital images in low light conditions, capture of digital images with reduced noise, and/or capture of brighter or better exposed digital images in a given exposure time.

[0622] The embodiments disclosed herein may advantageously enable a camera module to sample images to have less noise, less blur, and greater exposure in low-light conditions than conventional techniques. In certain embodiments, images may be effectively sampled or captured simultaneously, which may reduce inter-sample time to, or near, zero. In other embodiments, the camera module may sample images in coordination with the strobe unit to reduce inter-sample time between an image sampled without strobe illumination and an image sampled with strobe illumination.

[0623] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.

[0624] FIG. **21-3**A illustrates a circuit diagram for a photosensitive cell **21-600**, in accordance with one possible embodiment. As an option, the cell **21-600** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the cell **21-600** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0625] As shown in FIG. **21-3**A, a photosensitive cell **21-600** includes a photodiode **21-602** coupled to a first analog sampling circuit **21-603**(**0**) and a second analog sampling circuit **21-603**(**1**). The photodiode **21-602** may be implemented as a photodiode of a cell **21-101** described within the context of FIG. **21-1**, or any of the photodiodes **18-562** of FIG. **18-3**E. In one embodiment, a unique instance of photosensitive cell **21-600** may be implemented as any of cells **21-242-21-245** within the context of FIG. **21-2**, or any of cells **18-542-18-545** within the context of

FIGS. **18-3**A-**18-5**E. Further, the first analog sampling circuit **21-603**(**0**) and the second analog sampling circuit **21-603**(**1**) may separately, or in combination, comprise a sample storage node, such as one of the sample storage nodes **21-121** or **21-123** of FIG. **21-1**.

[0626] As shown, the photosensitive cell **21-600** comprises two analog sampling circuits **21-603**, and a photodiode **21-602**. The two analog sampling circuits **21-603** include a first analog sampling circuit **21-603**(**0**) which is coupled to a second analog sampling circuit **21-603**(**1**). As shown in FIG. **21-3**A, the first analog sampling circuit **21-603**(**0**) comprises transistors **21-606**(**0**), **21-610**(**0**), **21-612**(**0**), **21-614**(**0**), and a capacitor **21-604**(**0**); and the second analog sampling circuit **21-603**(**1**) comprises transistors **21-606**(**1**), **21-610**(**1**), **21-612**(**1**), **21-614**(**1**), and a capacitor **21-604**(**1**). In one embodiment, each of the transistors **21-606**, **21-610**, **21-612**, and **21-614** may be a field-effect transistor.

[0627] The photodiode **21-602** may be operable to measure or detect incident light **21-601** of a photographic scene. In one embodiment, the incident light **21-601** may include ambient light of the photographic scene. In another embodiment, the incident light **21-601** may include light from a strobe unit utilized to illuminate the photographic scene. Of course, the incident light **21-601** may include any light received at and measured by the photodiode **21-602**. Further still, and as discussed above, the incident light **21-601** may be concentrated on the photodiode **21-602** by a microlens, and the photodiode **21-602** may be one photodiode of a photodiode array that is configured to include a plurality of photodiodes arranged on a two-dimensional plane.

[0628] In one embodiment, the analog sampling circuits **21-603** may be substantially identical. For example, the first analog sampling circuit **21-603**(**0**) and the second analog sampling circuit **21-603**(**1**) may each include corresponding transistors, capacitors, and interconnects configured in a substantially identical manner. Of course, in other embodiments, the first analog sampling circuit **21-603**(**0**) and the second analog sampling circuit **21-603**(**1**) may include circuitry, transistors, capacitors, interconnects and/or any other components or component parameters (e.g. capacitance value of each capacitor **21-604**) which may be specific to just one of the analog sampling circuits **21-603**.

[0629] In one embodiment, each capacitor **21-604** may include one node of a capacitor comprising gate capacitance for a transistor **21-610** and diffusion capacitance for transistors **21-606** and **21-614**. The capacitor **21-604** may also be coupled to additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any other technically feasible capacitor structures.

[0630] The cell **21-600** is further shown to include an interconnect **21-644** between the analog sampling circuit **21-603**(**0**) and the analog sampling circuit **21-603**(**1**). The interconnect **21-644** includes a transistor **21-641**, which comprises a gate **21-640** and a source **21-642**. A drain of the transistor **21-641** is coupled to each of the analog sampling circuit **21-603**(**0**) and the analog sampling circuit **21-603**(**1**). When the gate **21-640** is turned off, the cell **21-600** may operate in isolation. When operating in isolation, the cell **21-600** may operate in a manner whereby the photodiode **21-602** is sampled by one or both of the analog sampling circuits **21-603** of the cell **21-600**. For example, the photodiode **21-602** may be sampled by the analog sampling circuit **21-603**(**0**) and the analog sampling circuit **21-603**(**1**) in a concurrent manner, or the photodiode **21-602** may be sampled by the analog sampling circuit **21-603**(**0**) and the analog sampling circuit **21-603**(**1**) in a sequential manner. In alternative embodiments, the drain terminal of transistor **21-641** is coupled to interconnect **21-644** and the source terminal of transistor **21-641** is coupled to the sampling circuits **21-603** and the photodiode **21-602**.

[0631] With respect to analog sampling circuit **21-603**(**0**), when reset **21-616**(**0**) is active (low), transistor **21-614**(**0**) provides a path from voltage source V2 to capacitor **21-604**(**0**), causing capacitor **21-604**(**0**) to charge to the potential of V2. When sample signal **21-618**(**0**) is active, transistor **21-606**(**0**) provides a path for capacitor **21-604**(**0**) to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **21-602** in response to the incident light **21-**

601. In this way, photodiode current I_PD is integrated for a first exposure time when the sample signal **21-618**(**0**) is active, resulting in a corresponding first voltage on the capacitor **21-604**(**0**). This first voltage on the capacitor **21-604**(**0**) may also be referred to as a first sample. When row select **21-634**(**0**) is active, transistor **21-612**(**0**) provides a path for a first output current from V1 to output **21-608**(**0**). The first output current is generated by transistor **21-610**(**0**) in response to the first voltage on the capacitor **21-604**(**0**). When the row select **21-634**(**0**) is active, the output current at the output **21-608**(**0**) may therefore be proportional to the integrated intensity of the incident light **21-601** during the first exposure time.

[0632] With respect to analog sampling circuit **21-603**(**1**), when reset **21-616**(**1**) is active (low), transistor **21-614**(**1**) provides a path from voltage source V2 to capacitor **21-604**(**1**), causing capacitor **21-604**(**1**) to charge to the potential of V2. When sample signal **21-618**(**1**) is active, transistor **21-606**(**1**) provides a path for capacitor **21-604**(**1**) to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **21-602** in response to the incident light **21-601**. In this way, photodiode current I_PD is integrated for a second exposure time when the sample signal **21-618**(**1**) is active, resulting in a corresponding second voltage on the capacitor **21-604**(**1**). This second voltage on the capacitor **21-604**(**1**) may also be referred to as a second sample. When row select **21-634**(**1**) is active, transistor **21-612**(**1**) provides a path for a second output current from V1 to output **21-608**(**1**). The second output current is generated by transistor **21-610**(**1**) in response to the second voltage on the capacitor **21-604**(**1**). When the row select **21-634**(**1**) is active, the output current at the output **21-608**(**1**) may therefore be proportional to the integrated intensity of the incident light **21-601** during the second exposure time.

[0633] As noted above, when the cell **21-600** is operating in an isolation mode, the photodiode current I_PD of the photodiode **21-602** may be sampled by one of the analog sampling circuits **21-603** of the cell **21-600**; or may be sampled by both of the analog sampling circuits **21-603** of the cell **21-600**, either concurrently or sequentially. When both the sample signal **21-618**(**0**) and the sample signal **21-618**(**1**) are activated simultaneously, the photodiode current I_PD of the photodiode **21-602** may be sampled by both analog sampling circuits **21-603** concurrently, such that the first exposure time and the second exposure time are, at least partially, overlapping.

[0634] When the sample signal **21-618**(**0**) and the sample signal **21-618**(**1**) are activated sequentially, the photodiode current I_PD of the photodiode **21-602** may be sampled by the analog sampling circuits **21-603** sequentially, such that the first exposure time and the second exposure time do not overlap.

[0635] In various embodiments, when the gate **21-640** is turned on, the cell **21-600** may be thereby communicatively coupled to one or more other instances of cell **21-600** of other pixels via the interconnect **21-644**. In one embodiment, when two or more cells **21-600** are coupled together, the two or more corresponding instances of photodiode **21-602** may collectively provide a shared photodiode current on the interconnect **21-644**. In such an embodiment, one or more analog sampling circuits **21-603** of the two instances of cell **21-600** may sample the shared photodiode current. For example, in one embodiment, a single sample signal **21-618**(**0**) may be activated such that a single analog sampling circuit **21-603** samples the shared photodiode current. In another embodiment two instances of a sample signal **21-618**(**0**), each associated with a different cell **21-600**, may be activated to sample the shared photodiode current, such that two analog sampling circuits **21-603** of two different cells **21-600** sample the shared photodiode current. In yet another embodiment, both of a sample signal **21-618**(**0**) and **21-618**(**1**) of a single cell **21-600** may be activated to sample the shared photodiode current, such that two analog sampling circuits **21-603**(**0**) and **21-603**(**1**) of one of the cells **21-600** sample the shared photodiode current, and neither of the analog sampling circuits **21-603** of the other cell **21-600** sample the shared photodiode current.

[0636] In a specific example, two instances of cell **21-600** may be coupled via the interconnect **21-644**. Each instance of the cell **21-600** may include a photodiode **21-602** and two analog sampling circuits **21-603**. In such an example, the two photodiodes **21-602** may be configured to provide a shared photodiode current to one, two, three, or all four of the analog sampling circuits **21-603** via the interconnect **21-644**. If the two photodiodes **21-602** detect substantially identical quantities of light, then the shared photodiode current may be twice the magnitude that any single photodiode current would be from a single one of the photodiodes **21-602**. Thus, this shared photodiode current may otherwise be referred to as a 2× photodiode current. If only one analog sampling circuit **21-603** is activated to sample the 2× photodiode current, the analog sampling circuit **21-603** may effectively sample the 2× photodiode current twice as fast for a given exposure level as the analog sampling circuit **21-603** would sample a photodiode current received from a single photodiode **21-602**. Further, if only one analog sampling circuit **21-603** is activated to sample the 2× photodiode current, the analog sampling circuit **21-603** may be able to obtain a sample twice as bright as the analog sampling circuit **21-603** would obtain by sampling a photodiode current received from a single photodiode **21-602** for a same exposure time. However, in such an embodiment, because only a single analog sampling circuit **21-603** of the two cells **21-600** actively samples the 2× photodiode current, one of the cells **21-600** does not store any analog value representative of the 2× photodiode current. Accordingly, when a 2× photodiode current is sampled by only a subset of corresponding analog sampling circuits **21-603**, image resolution may be reduced in order to increase a sampling speed or sampling sensitivity.

[0637] In one embodiment, communicatively coupled cells **21-600** may be located in a same row of pixels of an image sensor. In such an embodiment, sampling with only a subset of communicatively coupled analog sampling circuits **21-603** may reduce an effective horizontal resolution of the image sensor by ½. In another embodiment, communicatively coupled cells **21-600** may be located in a same column of pixels of an image sensor. In such an embodiment, sampling with only a subset of communicatively coupled analog sampling circuits **21-603** may reduce an effective vertical resolution of the image sensor by ½.

[0638] In another embodiment, an analog sampling circuit **21-603** of each of the two cells **21-600** may be simultaneously activated to concurrently sample the 2× photodiode current. In such an embodiment, because the 2× photodiode current is shared by two analog sampling circuits **21-603**, sampling speed and sampling sensitivity may not be improved in comparison to a single analog sampling circuit **21-603** sampling a photodiode current of a single photodiode **21-602**. However, by sharing the 2× photodiode current over the interconnect **21-644** between the two cells **21-600**, and then sampling the 2× photodiode current using an analog sampling circuit **21-603** in each of the cells **21-600**, the analog values sampled by each of the analog sampling circuits **21-603** may be effectively averaged, thereby reducing the effects of any noise present in a photodiode current output by either of the coupled photodiodes **21-602**.

[0639] In yet another example, two instances of cell **21-600** may be coupled via the interconnect **21-644**. Each instance of the cell **21-600** may include a photodiode **21-602** and two analog sampling circuits **21-603**. In such an example, the two photodiodes **21-602** may be configured to provide a shared photodiode current to one, two, three, or all four of the analog sampling circuits **21-603** via the interconnect **21-644**. If the two photodiodes **21-602** detect substantially identical quantities of light, then the shared photodiode current may be twice the magnitude that any single photodiode current would be from a single one of the photodiodes **21-602**. Thus, this shared photodiode current may otherwise be referred to as a 2× photodiode current. Two analog sampling circuits **21-603** of one of the cells **21-600** may be simultaneously activated to concurrently sample the 2× photodiode current in a manner similar to that described hereinabove with respect to the analog sampling circuits **21-603(0)** and **21-603(1)** sampling the photodiode current I_PD of the photodiode **21-602** in isolation. In such an embodiment, two analog storage planes may be populated with analog values at a rate that is 2× faster than if the analog sampling circuits **21-603(0)** and **21-603(1)** received a photodiode current from a single photodiode **21-602**.

[0640] In another embodiment including two instances of cell **21-600** coupled via interconnect **21-**

644 for sharing a 2× photodiode current, such that four analog sampling circuits **21-603** may be simultaneously activated for a single exposure. In such an embodiment, the four analog sampling circuits **21-603** may concurrently sample the 2× photodiode current in a manner similar to that described hereinabove with respect to the analog sampling circuits **21-603(0)** and **21-603(1)** sampling the photodiode current I_PD of the photodiode **21-602** in isolation. In such an embodiment, the four analog sampling circuits **21-603** may be disabled sequentially, such that each of the four analog sampling circuits **21-603** stores a unique analog value representative of the 2× photodiode current. Thereafter, each analog value may be output in a different analog signal, and each analog signal may be amplified and converted to a digital signal comprising a digital image.

[0641] Thus, in addition to the 2× photodiode current serving to reduce noise in any final digital image, four different digital images may be generated for the single exposure, each with a different effective exposure and light sensitivity. These four digital images may comprise, and be processed as, an image stack. In other embodiments, the four analog sampling circuits **21-603** may be activated and deactivated together for sampling the 2× photodiode current, such that each of the analog sampling circuits **21-603** store a substantially identical analog value. In yet other embodiments, the four analog sampling circuits **21-603** may be activated and deactivated in a sequence for sampling the 2× photodiode current, such that no two analog sampling circuits **21-603** are actively sampling at any given moment.

[0642] Of course, while the above examples and embodiments have been described for simplicity in the context of two instances of a cell **21-600** being communicatively coupled via interconnect **21-644**, more than two instances of a cell **21-600** may be communicatively coupled via the interconnect **21-644**. For example, four instances of a cell **21-600** may be communicatively coupled via an interconnect **21-644**. In such an example, eight different analog sampling circuits **21-603** may be addressable, in any sequence or combination, for sampling a 4× photodiode current shared between the four instances of cell **21-600**. Thus, as an option, a single analog sampling circuit **21-603** may be able to sample the 4× photodiode current at a rate 4× faster than the analog sampling circuit **21-603** would be able to sample a photodiode current received from a single photodiode **21-602**.

[0643] For example, an analog value stored by sampling a 4× photodiode current at a 1/120 second exposure time may be substantially identical to an analog value stored by sampling a 1× photodiode current at a 1/30 second exposure time. By reducing an exposure time required to sample a given analog value under a given illumination, blur may be reduced within a final digital image. Thus, sampling a shared photodiode current may effectively increase the ISO, or light sensitivity, at which a given photographic scene is sampled without increasing the noise associated with applying a greater gain.

[0644] As another option, the single analog sampling circuit **21-603** may be able to obtain, for a given exposure time, a sample 4× brighter than a sample obtained by sampling a photodiode current received from a single photodiode. Sampling a 4× photodiode current may allow for much more rapid sampling of a photographic scene, which may serve to reduce any blur present in a final digital image, to more quickly capture a photographic scene (e.g., ¼ exposure time), to increase the brightness or exposure of a final digital image, or any combination of the foregoing. Of course, sampling a 4× photodiode current with a single analog sampling circuit **21-603** may result in an analog storage plane having ¼ the resolution of an analog storage plane in which each cell **21-600** generates a sample. In another embodiment, where four instances of a cell **21-600** may be communicatively coupled via an interconnect **21-644**, up to eight separate exposures may be captured by sequentially sampling the 4× photodiode current with each of the eight analog sampling circuits **21-603**. In one embodiment, each cell includes one or more analog sampling circuits **21-603**.

[0645] FIG. **21-3**B illustrates a circuit diagram for a photosensitive cell **21-660**, in accordance with one possible embodiment. As an option, the cell **21-660** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the cell **21-660** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0646] As shown, the photosensitive cell **21-660** comprises a photodiode **21-602** that is substantially identical to the photodiode **21-602** of cell **21-600**, a first analog sampling circuit **21-603**(**0**) that is substantially identical to the first analog sampling circuit **21-603**(**0**) of cell **21-600**, a second analog sampling circuit **21-603**(**1**) that is substantially identical to the second analog sampling circuit **21-603**(**1**) of cell **21-600**, and an interconnect **21-654**. The interconnect **21-654** is shown to comprise three transistors **21-651-653**, and a source **21-650**. Each of the transistors **21-651**, **21-652**, and **21-653**, include a gate **21-656**, **21-657**, and **21-658**, respectively. The cell **21-660** may operate in substantially the same manner as the cell **21-600** of FIG. **21-3**A, however the cell **21-660** includes only two pass gates from photodiodes **21-602** of other cells **21-660** coupled via the interconnect **21-654**, whereas the cell **21-600** includes three pass gates from the photodiodes **21-602** of other cells **21-600** coupled via the interconnect **21-644**.

[0647] FIG. **21-3**C illustrates a circuit diagram for a system **21-690** including plurality of communicatively coupled photosensitive cells **21-694**, in accordance with one possible embodiment. As an option, the system **21-690** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the system **21-690** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0648] As illustrated in FIG. **21-3**C, the system **21-690** is shown to include four pixels **21-692**, where each of the pixels **21-692** includes a respective cell **21-694**, and a set of related cells **21-694** are communicatively coupled via interconnect **21-698**. Each of the pixels **21-692** may be implemented as a pixel **21-240** of FIG. **21-2**, each of the cells **21-694** may be implemented as a cell **21-242** of FIG. **21-2**, and the interconnect **21-698** may be implemented as the interconnect **21-250** of FIG. **21-2**. Further, the interconnect **21-698** is shown to include multiple instances of a source **21-696**, and multiple instances of a gate **21-691**. Also, each cell **21-694** may include an analog sampling circuit **21-603** coupled to a photodiode **21-602** for measuring or detecting incident light **21-601**. The analog sampling circuit **21-603** may be substantially identical to either of the analog sampling circuits **21-603**(**0**) and **21-603**(**1**) disclosed in the context of FIG. **21-3**A.

[0649] When all instances of the gate **21-691** are turned on, each of the cells **21-694** may be thereby communicatively coupled to each of the other cells **21-694** of the other pixels **21-692** via the interconnect **21-698**. As a result, a shared photodiode current may be generated. As shown in FIG. **21-3**C, each of the cells **21-694**(**1**), **21-694**(**2**), and **21-694**(**3**) output a substantially similar photodiode current I_PD on the interconnect **21-698**. The photodiode current I_PD generated by each of the cells **21-694**(**1**), **21-694**(**2**), and **21-694**(**3**) may be generated by the respective photodiodes **21-602**(**1**), **21-602**(**2**), and **21-602**(**3**). The photodiode current from the cells **21-694**(**1**), **21-694**(**2**), and **21-694**(**3**) may combine on the interconnect **21-698** to form a combined photodiode current of 3*I_PD, or a 3× photodiode current.

[0650] When sample signal **21-618** of analog sampling circuit **21-603** is asserted, the 3× photodiode combines with the photodiode current I_PD of photodiode **21-602**(**0**), and a 4× photodiode current may be sampled by the analog sampling circuit **21-603**. Thus, a sample may be stored to capacitor **21-604** of analog sampling circuit **21-603** of cell **21-694**(**0**) at a rate 4× faster than if the single photodiode **21-602**(**0**) generated the photodiode current I_PD sampled by the analog sampling circuit **21-603**. As an option, the 4× photodiode current may be sampled for a same given exposure time that a 1× photodiode current would be sampled for, which may significantly increase or decrease a value of the analog value stored in the analog sampling circuit **21-603**. For example, an analog value stored from sampling the 4× photodiode current for the given exposure time may be associated with a final digital pixel value that is effectively 4× brighter than an analog value stored from sampling a 1× photodiode current for the given exposure time.

[0651] When all instances of the gate **21-691** are turned off, each of the cells **21-694** may be uncoupled from the other cells **21-694** of the other pixels **21-692**. When the cells **21-694** are uncoupled, each of the cells **21-694** may operate in isolation as discussed previously, for example with respect to FIG. **21-3**A. For example, when operating in isolation, analog sampling circuit **21-603** may only sample, under the control of sample signal **21-618**, a photodiode current I_PD from a respective photodiode **21-602**(**0**).

[0652] In one embodiment, pixels **21-692** within an image sensor each include a cell **21-694** configured to be sensitive to red light (a "red cell"), a cell **21-694** configured to be sensitive to green light (a "green cell"), and a cell **21-694** configured to be sensitive to blue light (a "blue cell"). Furthermore, sets of two or more pixels **21-692** may be configured as described above in FIGS. **21-6**A-**6**C to switch into a photodiode current sharing mode, whereby red cells within each set of pixels share photodiode current, green cells within each set of pixels share photodiode current, and blue cells within each set of pixels share photodiode current. In certain embodiments, the pixels **21-692** also each include a cell **21-694** configured to be sensitive to white light (a "white cell"), whereby each white cell may operate independently with respect to photodiode current while the red cells, green cells, and blue cells operate in a shared photodiode current mode. All other manufacturing parameters being equal, each white cell may be more sensitive (e.g., three times more sensitive) to incident light than any of the red cells, green cells, or blue cells, and, consequently, a white cell may require less exposure time or gain to generate a comparable intensity signal level. In such an embodiment, the resolution of color information (from the red cells, green cells, and blue cells) may be reduced to gain greater sensitivity and better noise performance, while the resolution of pure intensity information (from the white cells) may be kept at full sensor resolution without significantly sacrificing sensitivity or noise performance with respect to intensity information. For example, a 4K pixel by 4K pixel image sensor may be configured to operate as a 2K pixel by 2K pixel image sensor with respect to color, thereby improving color sensitivity by a factor of 4×, while, at the same time, being able to simultaneously capture a 4K pixel by 4K pixel intensity plane from the white cells. In such a configuration, the quarter resolution color information provided by the red cells, green cells, and blue cells may be fused with full resolution intensity information provided by the white cells. To this end, a full 4K by 4K resolution color image may be generated by the image sensor, with better overall sensitivity and noise performance than a comparable conventional image sensor.

[0653] FIG. **21-4** illustrates implementations of different analog storage planes, in accordance with another embodiment. As an option, the analog storage planes of FIG. **21-4** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the analog storage planes of FIG. **21-4** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0654] FIG. **21-4** is illustrated to include a first analog storage plane **21-802** and a second analog storage plane **21-842**. A plurality of analog values are each depicted as a "V" within the analog storage planes **21-802** and **21-842**. In the context of certain embodiments, each analog storage plane may comprise any collection of one or more analog values. In some embodiments, an analog storage plane may be capable of storing at least one analog pixel value for each pixel of a row or line of a pixel array. In one embodiment, an analog storage plane may cable of storing an analog value for each cell of each pixel of a plurality of pixels of a pixel array. Still yet, in another embodiment, an analog storage plane may be capable of storing at least one analog pixel value for each pixel of an entirety of a pixel array, which may be referred to as a frame. For example, an analog storage plane may be capable of storing an analog value for each cell of each pixel of every line or row of a pixel array.

[0655] In one embodiment, the analog storage plane **21-842** may be representative of a portion of an image sensor in which an analog sampling circuit of each cell has been activated to sample a corresponding photodiode current. In other words, for a given region of an image sensor, all cells include an analog sampling circuit that samples a corresponding photodiode current, and stores an analog value as a result of the sampling operation. As a result, the analog storage plane **21-842** includes a greater analog value density **21-846** than an analog value density **21-806** of the analog storage plane **21-802**.

[0656] In one embodiment, the analog storage plane **21-802** may be representative of a portion of an image sensor in which only one-quarter of the cells include analog sampling circuits activated to sample a corresponding photodiode current. In other words, for a given region of an image sensor, only one-quarter of the cells include an analog sampling circuit that samples a corresponding photodiode current, and stores an analog value as a result of the sampling operation. The analog value density **21-806** of the analog storage plane **21-802** may result from a configuration, as discussed above, wherein four neighboring cells are communicatively coupled via an interconnect such that a 4× photodiode current is sampled by a single analog sampling circuit of one of the four cells, and the remaining analog sampling circuits of the other three cells are not activated to sample.

[0657] FIG. **21-5** illustrates a system **21-900** for converting analog pixel data of an analog signal to digital pixel data, in accordance with another embodiment. As an option, the system **21-900** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the system **21-900** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0658] The system **21-900** is shown in FIG. **21-5** to include a first analog storage plane **21-802**, an analog-to-digital unit **21-922**, a first digital image **21-912**, a second analog storage plane **21-842**, and a second digital image **21-952**. As illustrated in FIG. **21-5**, a plurality of analog values are each depicted as a “V” within each of the analog storage planes **21-802** and **21-842**, and corresponding digital values are each depicted as a “D” within digital images **21-912** and **21-952**, respectively.

[0659] As noted above, each analog storage plane **21-802** and **21-842** may comprise any collection of one or more analog values. In one embodiment, a given analog storage plane may comprise an analog value for each analog storage circuit **21-603** that receives an active sample signal **21-618**, and thereby samples a photodiode current, during an associated exposure time.

[0660] In some embodiments, an analog storage plane may include analog values for only a subset of all the analog storage circuits **21-603** of an image sensor. This may occur, for example, when analog storage circuits **21-603** of only odd or even rows of pixels are activated to sample during a given exposure time. Similarly, this may occur when analog storage circuits **21-603** of only odd or even columns of pixels are activated to sample during a given exposure. As another example, this may occur when two or more photosensitive cells are communicatively coupled, such as by an interconnect **21-644**, in a manner that distributes a shared photodiode current, such as a 2× or 4× photodiode current, between the communicatively coupled cells. In such an embodiment, only a subset of analog sampling circuits **21-603** of the communicatively coupled cells may be activated by a sample signal **21-618** to sample the shared photodiode current during a given exposure time. Any analog sampling circuits **21-603** activated by a sample signal **21-618** during the given exposure time may sample the shared photodiode current, and store an analog value to the analog storage plane associated with the exposure time. However, the analog storage plane associated with the exposure time would not include any analog values associated with the analog sampling circuits **21-603** that are not activated by a sample signal **21-618** during the exposure time.

[0661] Thus, an analog value density of a given analog storage plane may depend on a subset of analog sampling circuits **21-603** activated to sample photodiode current during a given exposure associated with the analog storage plane. Specifically, a greater analog value density may be obtained, such as for the more dense analog storage plane **21-842**, when a sample signal **21-618** is activated for an analog sampling circuit **21-603** in each of a plurality of neighboring cells of an image sensor during a given exposure time. Conversely, a decreased analog value density may be obtained, such as for the less dense analog storage plane **21-802**, when a sample signal **21-618** is activated for only a subset of neighboring cells of an image sensor during a given exposure time.

[0662] Returning now to FIG. **21-5**, the analog values of the less dense analog storage plane **21-802** are output as analog pixel data **21-904** to the analog-to-digital unit **21-922**. Further, the analog values of the more dense analog storage plane **21-842** are separately output as analog pixel data **21-944** to the analog-to-digital unit **21-922**. In one embodiment, the analog-to-digital unit **21-922** may be substantially identical to the analog-to-digital unit **18-622** described within the context of FIG. **18-4**. For example, the analog-to-digital unit **21-922** may comprise at least one amplifier and at least one analog-to-digital converter, where the amplifier is operative to receive a gain value and utilize the gain value to gain-adjust analog pixel data received at the analog-to-digital unit **21-922**. Further, in such an embodiment, the amplifier may transmit gain-adjusted analog pixel data to an analog-to-digital converter, which then generates digital pixel data from the gain-adjusted analog pixel data. To this end, an analog-to-digital conversion may be performed on the contents of each of two or more different analog storage planes **21-802** and **21-842**.

[0663] In one embodiment, the analog-to-digital unit **21-922** applies at least two different gains to each instance of received analog pixel data. For example, the analog-to-digital unit **21-922** may receive analog pixel data **21-904**, and apply at least two different gains to the analog pixel data **21-904** to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **21-904**; and the analog-to-digital unit **21-922** may receive analog pixel data **21-944**, and then apply at least two different gains to the analog pixel data **21-944** to generate at least a first gain-adjusted analog pixel data and a second gain-adjusted analog pixel data based on the analog pixel data **21-944**.

[0664] Further, the analog-to-digital unit **21-922** may convert each instance of gain-adjusted analog pixel data to digital pixel data, and then output a corresponding digital signal. With respect to FIG. **21-5** specifically, the analog-to-digital unit **21-922** is shown to generate a first digital signal comprising first digital pixel data **21-906** corresponding to application of Gain1 to analog pixel data **21-904**; and a second digital signal comprising second digital pixel data **21-946** corresponding to application of Gain1 to analog pixel data **21-944**. Each instance of digital pixel data may comprise a digital image, such that the first digital pixel data **21-906** comprises a digital image **21-912**, and the second digital pixel data **21-946** comprises a digital image **21-952**. In other words, a first digital image **21-912** may be generated based on the analog values of the less dense analog storage plane **21-802**, and a second digital image **21-952** may be generated based on the analog values of the more dense analog storage plane **21-842**.

[0665] Of course, in other embodiments, the analog-to-digital unit **21-922** may apply a plurality of gains to each instance of analog pixel data, to thereby generate an image stack based on each analog storage plane **21-802** and **21-842**. Each image stack may be manipulated as set forth in those applications, or as set forth below.

[0666] In some embodiments, the digital image **21-952** may have a greater resolution than the digital image **21-912**. In other words, a greater number of pixels may comprise digital image **21-952** than a number of pixels that comprise digital image **21-912**. This may be because the digital image **21-912** was generated from the less dense analog storage plane **21-802** that included, in one example, only one-quarter the number of sampled analog values of more dense analog storage plane **21-842**. In other embodiments, the digital image **21-952** may have the same resolution as the digital image **21-912**. In such an embodiment, a plurality of digital pixel data values may be generated to make up for the reduced number of sampled analog values in the less dense analog storage plane **21-802**. For example, the plurality of digital pixel data values may be generated by interpolation to increase the resolution of the digital image **21-912**.

[0667] In one embodiment, the digital image **21-912** generated from the less dense analog storage plane **21-802** may be used to improve the digital image **21-952** generated from the more dense analog storage plane **21-842**. As a specific non-limiting example, each of the less dense analog storage plane **21-802** and the more dense analog storage plane **21-842** may storage analog values for a single exposure of a photographic scene. In the context of the present description, a “single exposure” of a photographic scene may include simultaneously, at least in part, capturing the photographic scene using two or more sets of analog sampling circuits, where each set of analog sampling circuits may be configured to operate at different exposure times. Further, the single exposure may be further broken up into multiple discrete exposure times or samples times, where the exposure times or samples times may occur sequentially, partially simultaneously, or in some combination of sequentially and partially simultaneously.

[0668] During capture of the single exposure of the photographic scene using the two or more sets of analog sampling circuits, some cells of the capturing image sensor may be communicatively coupled to one or more other cells. For example, cells of an image sensor may be communicatively coupled as shown in FIG. **21-2**, such that each cell is coupled to three other cells associated with a same peak wavelength of light. Therefore, during the single exposure, each of the communicatively coupled cells may receive a 4× photodiode current.

[0669] During a first sample time of the single exposure, a first analog sampling circuit in each of the four cells may receive an active sample signal, which causes the first analog sampling circuit in each of the four cells to sample the 4× photodiode current for the first sample time. The more dense analog storage plane **21-842** may be representative of the analog values stored during such a sample operation. Further, a second analog sampling circuit in each of the four cells may be controlled to separately sample the 4× photodiode current. As one option, during a second sample time after the first sample time, only a single second analog sampling circuit of the four coupled cells may receive an active sample signal, which causes the single analog sampling circuit to sample the 4× photodiode current for the second sample time. The less dense analog storage plane **21-802** may be representative of the analog values stored during such a sample operation.

[0670] As a result, analog values stored during the second sample time of the single exposure are sampled with an increased sensitivity, but a decreased resolution, in comparison to the analog values stored during the first sample time. In situations involving a low-light photographic scene, the increased light sensitivity associated with the second sample time may generate a better exposed and/or less noisy digital image, such as the digital image **21-912**. However, the digital image **21-952** may have a desired final image resolution or image size. Thus, in some embodiments, the digital image **21-912** may be blended or mixed or combined with digital image **21-952** to reduce the noise and improve the exposure of the digital image **21-952**. For example, a digital image with one-half vertical or one-half horizontal resolution may be blended with a digital image at full resolution. In another embodiment any combination of digital images at one-half vertical resolution, one-half horizontal resolution, and full resolution may be blended.

[0671] In some embodiments, a first exposure time (or first sample time) and a second exposure time (or second sample time) are each captured using an ambient illumination of the photographic scene. In other embodiments, the first exposure time (or first sample time) and the second exposure time (or second sample time) are each captured using a flash or strobe illumination of the photographic scene. In yet other embodiments, the first exposure time (or first sample time) may be captured using an ambient illumination of the photographic scene, and the second exposure time (or second sample time) may be captured using a flash or strobe illumination of the photographic scene.

[0672] In embodiments in which the first exposure time is captured using an ambient illumination, and the second exposure time is captured using flash or strobe illumination, analog values stored during the first exposure time may be stored to an analog storage plane at a higher density than the analog values stored during the second exposure time. This may effectively increase the ISO or sensitivity of the capture of the photographic scene at ambient illumination. Subsequently, the photographic scene may then be captured at full resolution using the strobe or flash illumination. The lower resolution ambient capture and the full resolution strobe or flash capture may then be merged to create a combined image that includes detail not found in either of the individual captures.

[0673] One advantage of the present invention is that a digital photograph may be selectively generated based on user input using two or more different images generated from a single exposure of a photographic scene. Accordingly, the digital photograph generated based on the user input may have a greater dynamic range than any of the individual images. Further, the generation of an HDR image using two or more different images with zero, or near zero, interframe time allows for the rapid generation of HDR images without motion artifacts.

[0674] When there is any motion within a photographic scene, or a capturing device experiences any jitter during capture, any interframe time between exposures may result in a motion blur within a final merged HDR photograph. Such blur can be significantly exaggerated as interframe time increases. This problem renders current HDR photography an ineffective solution for capturing clear images in any circumstance other than a highly static scene. Further, traditional techniques for generating a HDR photograph involve significant computational resources, as well as produce artifacts which reduce the image quality of the resulting image. Accordingly, strictly as an option, one or more of the above issues may or may not be addressed utilizing one or more of the techniques disclosed herein.

[0675] Still yet, in various embodiments, one or more of the techniques disclosed herein may be applied to a variety of markets and/or products. For example, although the techniques have been disclosed in reference to a photo capture, they may be applied to televisions, web conferencing (or live streaming capabilities, etc.), security cameras (e.g. increase contrast to determine characteristic, etc.), automobiles (e.g. driver assist systems, in-car infotainment systems, etc.), and/or any other product which includes a camera input.

[0676] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

[0677] FIG. **22-1**A illustrates a first data flow process **22-200** for generating a blended image **22-280** based on at least an ambient image **22-220** and a strobe image **22-210**, according to one embodiment of the present invention. A strobe image **22-210** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is actively emitting strobe illumination **22-150**. Ambient image **22-220** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is inactive and substantially not emitting strobe illumination **22-150**.

[0678] In one embodiment, ambient image **22-220** is generated according to a prevailing ambient white balance for a scene being photographed. The prevailing ambient white balance may be computed using the well-known gray world model, an illuminator matching model, or any other technically feasible technique. Strobe image **22-210** should be generated according to an expected white balance for strobe illumination **22-150**, emitted by strobe unit **22-136**. Blend operation **22-270**, discussed in greater detail below, blends strobe image **22-210** and ambient image **22-220** to generate a blended image **22-280** via preferential selection of image data from strobe image **22-210** in regions of greater intensity compared to corresponding regions of ambient image **22-220**.

[0679] In one embodiment, data flow process **22-200** is performed by processor complex **22-110** within digital photographic system **22-100**, and blend operation **22-270** is performed by at least one GPU core **22-172**, one CPU core **22-170**, or any combination thereof.

[0680] FIG. **22-1**B illustrates a second data flow process **22-202** for generating a blended image **22-280** based on at least an ambient image **22-220** and a strobe image **22-210**, according to one embodiment of the present invention. Strobe image **22-210** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is actively emitting strobe illumination **22-150**. Ambient image **22-220** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is inactive and substantially not emitting strobe illumination **22-150**.

[0681] In one embodiment, ambient image **22-220** is generated according to a prevailing ambient white balance for a scene being photographed. The prevailing ambient white balance may be computed using the well-known gray world model, an illuminator matching model, or any other technically feasible technique. In certain embodiments, strobe image **22-210** is generated according to the prevailing ambient white balance. In an alternative embodiment ambient image **22-220** is generated according to a prevailing ambient white balance, and strobe image **22-210** is generated according to an expected white balance for strobe illumination **22-150**, emitted by strobe unit **22-136**. In other embodiments, ambient image **22-220** and strobe image **22-210** comprise raw image data, having no white balance operation applied to either. Blended image **22-280** may be subjected to arbitrary white balance operations, as is common practice with raw image data, while advantageously retaining color consistency between regions dominated by ambient illumination and regions dominated by strobe illumination.

[0682] As a consequence of color balance differences between ambient illumination, which may dominate certain portions of strobe image **22-210** and strobe illumination **22-150**, which may dominate other portions of strobe image **22-210**, strobe image **22-210** may include color information in certain regions that is discordant with color information for the same regions in ambient image **22-220**. Frame analysis operation **22-240** and color correction operation **22-250** together serve to reconcile discordant color information within strobe image **22-210**. Frame analysis operation **22-240** generates color correction data **22-242**, described in greater detail below, for adjusting color within strobe image **22-210** to converge spatial color characteristics of strobe image **22-210** to corresponding spatial color characteristics of ambient image **22-220**. Color correction operation **22-250** receives color correction data **22-242** and performs spatial color adjustments to generate corrected strobe image data **22-252** from strobe image **22-210**. Blend operation **22-270**, discussed in greater detail below, blends corrected strobe image data **22-252** with ambient image **22-220** to generate blended image **22-280**. Color correction data **22-242** may be generated to completion prior to color correction operation **22-250** being performed. Alternatively, certain portions of color correction data **22-242**, such as spatial correction factors, may be generated as needed.

[0683] In one embodiment, data flow process **22-202** is performed by processor complex **22-110** within digital photographic system **22-100**. In certain implementations, blend operation **22-270** and color correction operation **22-250** are performed by at least one GPU core **22-172**, at least one CPU core **22-170**, or a combination thereof. Portions of frame analysis operation **22-240** may be performed by at least one GPU core **22-172**, one CPU core **22-170**, or any combination thereof. Frame analysis operation **22-240** and color correction operation **22-250** are discussed in greater detail below.

[0684] FIG. **22-1**C illustrates a third data flow process **22-204** for generating a blended image **22-280** based on at least an ambient image **22-220** and a strobe image **22-210**, according to one embodiment of the present invention. Strobe image **22-210** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is actively emitting strobe illumination **22-150**. Ambient image **22-220** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is inactive and substantially not emitting strobe illumination **22-150**.

[0685] In one embodiment, ambient image **22-220** is generated according to a prevailing ambient white balance for a scene being photographed. The prevailing ambient white balance may be computed using the well-known gray world model, an illuminator matching model, or any other technically feasible technique. Strobe image **22-210** should be generated according to an expected white balance for strobe illumination **22-150**, emitted by strobe unit **22-136**.

[0686] In certain common settings, camera unit **22-130** is packed into a hand-held device, which may be subject to a degree of involuntary random movement or “shake” while being held in a user's hand. In these settings, when the hand-held device sequentially samples two images, such as strobe image **22-210** and ambient image **22-220**, the effect of shake may cause misalignment between the two images. The two images should be aligned prior to blend operation **22-270**, discussed in greater detail below. Alignment operation **22-230** generates an aligned strobe image **22-232** from strobe image **22-210** and an aligned ambient image **22-234** from ambient image **22-220**. Alignment operation **22-230** may implement any technically feasible technique for aligning images or sub-regions.

[0687] In one embodiment, alignment operation **22-230** comprises an operation to detect point pairs between strobe image **22-210** and ambient image **22-220**, an operation to estimate an affine or related transform needed to substantially align the point pairs. Alignment may then be achieved by executing an operation to resample strobe image **22-210** according to the affine transform thereby aligning strobe image **22-210** to ambient image **22-220**, or by executing an operation to resample ambient image **22-220** according to the affine transform thereby aligning ambient image **22-220** to strobe image **22-210**. Aligned images typically overlap substantially with each other, but may also have non-overlapping regions. Image information may be discarded from non-overlapping regions during an alignment operation. Such discarded image information should be limited to relatively narrow boundary regions. In certain embodiments, resampled images are normalized to their original size via a scaling operation performed by one or more GPU cores **22-172**.

[0688] In one embodiment, the point pairs are detected using a technique known in the art as a Harris affine detector. The operation to estimate an affine transform may compute a substantially optimal affine transform between the detected point pairs, comprising pairs of reference points and offset points. In one implementation, estimating the affine transform comprises computing a transform solution that minimizes a sum of distances between each reference point and each offset point subjected to the transform. Persons skilled in the art will recognize that these and other techniques may be implemented for performing the alignment operation **22-230** without departing the scope and spirit of the present invention.

[0689] In one embodiment, data flow process **22-204** is performed by processor complex **22-110** within digital photographic system **22-100**. In certain implementations, blend operation **22-270** and resampling operations are performed by at least one GPU core.

[0690] FIG. **22-1**D illustrates a fourth data flow process **22-206** for generating a blended image **22-280** based on at least an ambient image **22-220** and a strobe image **22-210**, according to one embodiment of the present invention. Strobe image **22-210** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is actively emitting strobe illumination **22-150**. Ambient image **22-220** comprises a digital photograph sampled by camera unit **22-130** while strobe unit **22-136** is inactive and substantially not emitting strobe illumination **22-150**.

[0691] In one embodiment, ambient image **22-220** is generated according to a prevailing ambient white balance for a scene being photographed. The prevailing ambient white balance may be computed using the well-known gray world model, an illuminator matching model, or any other technically feasible technique. In certain embodiments, strobe image **22-210** is generated according to the prevailing ambient white balance. In an alternative embodiment ambient image **22-220** is generated according to a prevailing ambient white balance, and strobe image **22-210** is generated according to an expected white balance for strobe illumination **22-150**, emitted by strobe unit **22-136**. In other embodiments, ambient image **22-220** and strobe image **22-210** comprise raw image data, having no white balance operation applied to either. Blended image **22-280** may be subjected to arbitrary white balance operations, as is common practice with raw image data, while advantageously retaining color consistency between regions dominated by ambient illumination and regions dominated by strobe illumination.

[0692] Alignment operation **22-230**, discussed previously in FIG. **22-1**C, generates an aligned strobe image **22-232** from strobe image **22-210** and an aligned ambient image **22-234** from ambient image **22-220**. Alignment operation **22-230** may implement any technically feasible technique for aligning images.

[0693] Frame analysis operation **22-240** and color correction operation **22-250**, both discussed

previously in FIG. **22-1**B, operate together to generate corrected strobe image data **22-252** from aligned strobe image **22-232**. Blend operation **22-270**, discussed in greater detail below, blends corrected strobe image data **22-252** with ambient image **22-220** to generate blended image **22-280**.
[0694] Color correction data **22-242** may be generated to completion prior to color correction operation **22-250** being performed. Alternatively, certain portions of color correction data **22-242**, such as spatial correction factors, may be generated as needed. In one embodiment, data flow process **22-206** is performed by processor complex **22-110** within digital photographic system **22-100**.
[0695] While frame analysis operation **22-240** is shown operating on aligned strobe image **22-232** and aligned ambient image **22-234**, certain global correction factors may be computed from strobe image **22-210** and ambient image **22-220**. For example, in one embodiment, a frame level color correction factor, discussed below, may be computed from strobe image **22-210** and ambient image **22-220**. In such an embodiment the frame level color correction may be advantageously computed in parallel with alignment operation **22-230**, reducing overall time required to generate blended image **22-280**.
[0696] In certain embodiments, strobe image **22-210** and ambient image **22-220** are partitioned into two or more tiles and color correction operation **22-250**, blend operation **22-270**, and resampling operations comprising alignment operation **22-230** are performed on a per tile basis before being combined into blended image **22-280**. Persons skilled in the art will recognize that tiling may advantageously enable finer grain scheduling of computational tasks among CPU cores **22-170** and GPU cores **22-172**. Furthermore, tiling enables GPU cores **22-172** to advantageously operate on images having higher resolution in one or more dimensions than native two-dimensional surface support may allow for the GPU cores. For example, certain generations of GPU core are only configured to operate on 2048 by 2048 pixel images, but popular mobile devices include camera resolution of more than 2048 in one dimension and less than 2048 in another dimension. In such a system, two tiles may be used to partition strobe image **22-210** and ambient image **22-220** into two tiles each, thereby enabling a GPU having a resolution limitation of 2048 by 2048 to operate on the images. In one embodiment, a first tile of blended image **22-280** is computed to completion before a second tile for blended image **22-280** is computed, thereby reducing peak system memory required by processor complex **22-110**.
[0697] FIG. **22-2**A illustrates image blend operation **22-270**, according to one embodiment of the present invention. A strobe image **22-310** and an ambient image **22-320** of the same horizontal resolution (H-res) and vertical resolution (V-res) are combined via blend function **22-330** to generate blended image **22-280** having the same horizontal resolution and vertical resolution. In alternative embodiments, strobe image **22-310** or ambient image **22-320**, or both images may be scaled to an arbitrary resolution defined by blended image **22-280** for processing by blend function **22-330**. Blend function **22-330** is described in greater detail below in FIGS. **22-2**B-**22-2**D.
[0698] As shown, strobe pixel **22-312** and ambient pixel **22-322** are blended by blend function **22-330** to generate blended pixel **22-332**, stored in blended image **22-280**. Strobe pixel **22-312**, ambient pixel **22-322**, and blended pixel **22-332** are located in substantially identical locations in each respective image.
[0699] In one embodiment, strobe image **22-310** corresponds to strobe image **22-210** of FIG. **22-1**A and ambient image **22-320** corresponds to ambient image **22-220**. In another embodiment, strobe image **22-310** corresponds to corrected strobe image data **22-252** of FIG. **22-1**B and ambient image **22-320** corresponds to ambient image **22-220**. In yet another embodiment, strobe image **22-310** corresponds to aligned strobe image **22-232** of FIG. **22-1**C and ambient image **22-320** corresponds to aligned ambient image **22-234**. In still yet another embodiment, strobe image **22-310** corresponds to corrected strobe image data **22-252** of FIG. **22-1**D, and ambient image **22-320** corresponds to aligned ambient image **22-234**.
[0700] Blend operation **22-270** may be performed by one or more CPU cores **22-170**, one or more

GPU cores **22-172**, or any combination thereof. In one embodiment, blend function **22-330** is associated with a fragment shader, configured to execute within one or more GPU cores **22-172**.
[0701] FIG. **22-2**B illustrates blend function **22-330** of FIG. **22-2**A for blending pixels associated with a strobe image and an ambient image, according to one embodiment of the present invention. As shown, a strobe pixel **22-312** from strobe image **22-310** and an ambient pixel **22-322** from ambient image **22-320** are blended to generate a blended pixel **22-332** associated with blended image **22-280**.
[0702] Strobe intensity **22-314** is calculated for strobe pixel **22-312** by intensity function **22-340**. Similarly, ambient intensity **22-324** is calculated by intensity function **22-340** for ambient pixel **22-322**. In one embodiment, intensity function **22-340** implements Equation 22-1, where Cr, Cg, Cb are contribution constants and Red, Green, and Blue represent color intensity values for an associated pixel:

$$\text{Intensity}=Cr*\text{Red}+Cg*\text{Green}+Cb*\text{Blue} \qquad \text{(Eq. 22-1)}$$

[0703] A sum of the contribution constants should be equal to a maximum range value for Intensity. For example, if Intensity is defined to range from 0.0 to 1.0, then Cr+Cg+Cb=1.0. In one embodiment Cr=Cg=Cb=⅓.
[0704] Blend value function **22-342** receives strobe intensity **22-314** and ambient intensity **22-324** and generates a blend value **22-344**. Blend value function **22-342** is described in greater detail in FIGS. **22-2**D and **22-2**C. In one embodiment, blend value **22-344** controls a linear mix operation **22-346** between strobe pixel **22-312** and ambient pixel **22-322** to generate blended pixel **22-332**. Linear mix operation **22-346** receives Red, Green, and Blue values for strobe pixel **22-312** and ambient pixel **22-322**. Linear mix operation **22-346** receives blend value **22-344**, which determines how much strobe pixel **22-312** versus how much ambient pixel **22-322** will be represented in blended pixel **22-332**. In one embodiment, linear mix operation **22-346** is defined by Equation 22-2, where Out corresponds to blended pixel **22-332**, Blend corresponds to blend value **22-344**, “A” corresponds to a color vector comprising ambient pixel **22-322**, and “B” corresponds to a color vector comprising strobe pixel **22-312**.

$$\text{Out}=(\text{Blend}*B)+(1.0-\text{Blend})*A \qquad \text{(Eq. 22-2)}$$

[0705] When blend value **22-344** is equal to 1.0, blended pixel **22-332** is entirely determined by strobe pixel **22-312**. When blend value **22-344** is equal to 0.0, blended pixel **22-332** is entirely determined by ambient pixel **22-322**. When blend value **22-344** is equal to 0.5, blended pixel **22-332** represents a per component average between strobe pixel **22-312** and ambient pixel **22-322**.
[0706] FIG. **22-2**C illustrates a blend surface **22-302** for blending two pixels, according to one embodiment of the present invention. In one embodiment, blend surface **22-302** defines blend value function **22-342** of FIG. **22-2**B. Blend surface **22-302** comprises a strobe dominant region **22-352** and an ambient dominant region **22-350** within a coordinate system defined by an axis for each of ambient intensity **22-324**, strobe intensity **22-314**, and blend value **22-344**. Blend surface **22-302** is defined within a volume where ambient intensity **22-324**, strobe intensity **22-314**, and blend value **22-344** may range from 0.0 to 1.0. Persons skilled in the art will recognize that a range of 0.0 to 1.0 is arbitrary and other numeric ranges may be implemented without departing the scope and spirit of the present invention.
[0707] When ambient intensity **22-324** is larger than strobe intensity **22-314**, blend value **22-344** may be defined by ambient dominant region **22-350**. Otherwise, when strobe intensity **22-314** is larger than ambient intensity **22-324**, blend value **22-344** may be defined by strobe dominant region **22-352**. Diagonal **22-351** delineates a boundary between ambient dominant region **22-350** and strobe dominant region **22-352**, where ambient intensity **22-324** is equal to strobe intensity **22-314**. As shown, a discontinuity of blend value **22-344** in blend surface **22-302** is implemented along diagonal **22-351**, separating ambient dominant region **22-350** and strobe dominant region **22-

352.
[0708] For simplicity, a particular blend value **22-344** for blend surface **22-302** will be described herein as having a height above a plane that intersects three points including points at (1,0,0), (0,1,0), and the origin (0,0,0). In one embodiment, ambient dominant region **22-350** has a height **22-359** at the origin and strobe dominant region **22-352** has a height **22-358** above height **22-359**. Similarly, ambient dominant region **22-350** has a height **22-357** above the plane at location (1,1), and strobe dominant region **22-352** has a height **22-356** above height **22-357** at location (1,1). Ambient dominant region **22-350** has a height **22-355** at location (1,0) and strobe dominant region **22-352** has a height of 354 at location (0,1).
[0709] In one embodiment, height **22-355** is greater than 0.0, and height **22-354** is less than 1.0. Furthermore, height **22-357** and height **22-359** are greater than 0.0 and height **22-356** and height **22-358** are each greater than 0.25. In certain embodiments, height **22-355** is not equal to height **22-359** or height **22-357**. Furthermore, height **22-354** is not equal to the sum of height **22-356** and height **22-357**, nor is height **22-354** equal to the sum of height **22-358** and height **22-359**.
[0710] The height of a particular point within blend surface **22-302** defines blend value **22-344**, which then determines how much strobe pixel **22-312** and ambient pixel **22-322** each contribute to blended pixel **22-332**. For example, at location (0,1), where ambient intensity is 0.0 and strobe intensity is 1.0, the height of blend surface **22-302** is given as height **22-354**, which sets blend value **22-344** to a value for height **22-354**. This value is used as blend value **22-344** in mix operation **22-346** to mix strobe pixel **22-312** and ambient pixel **22-322**. At (0,1), strobe pixel **22-312** dominates the value of blended pixel **22-332**, with a remaining, small portion of blended pixel **22-322** contributed by ambient pixel **22-322**. Similarly, at (1,0), ambient pixel **22-322** dominates the value of blended pixel **22-332**, with a remaining, small portion of blended pixel **22-322** contributed by strobe pixel **22-312**.
[0711] Ambient dominant region **22-350** and strobe dominant region **22-352** are illustrated herein as being planar sections for simplicity. However, as shown in FIG. **22-2**D, certain curvature may be added, for example, to provide smoother transitions, such as along at least portions of diagonal **22-351**, where strobe pixel **22-312** and ambient pixel **22-322** have similar intensity. A gradient, such as a table top or a wall in a given scene, may include a number of pixels that cluster along diagonal **22-351**. These pixels may look more natural if the height difference between ambient dominant region **22-350** and strobe dominant region **22-352** along diagonal **22-351** is reduced compared to a planar section. A discontinuity along diagonal **22-351** is generally needed to distinguish pixels that should be strobe dominant versus pixels that should be ambient dominant. A given quantization of strobe intensity **22-314** and ambient intensity **22-324** may require a certain bias along diagonal **22-351**, so that either ambient dominant region **22-350** or strobe dominant region **22-352** comprises a larger area within the plane than the other.
[0712] FIG. **22-2**D illustrates a blend surface **22-304** for blending two pixels, according to another embodiment of the present invention. Blend surface **22-304** comprises a strobe dominant region **22-352** and an ambient dominant region **22-350** within a coordinate system defined by an axis for each of ambient intensity **22-324**, strobe intensity **22-314**, and blend value **22-344**. Blend surface **22-304** is defined within a volume substantially identical to blend surface **22-302** of FIG. **22-2**C.
[0713] As shown, upward curvature at locations (0,0) and (1,1) is added to ambient dominant region **22-350**, and downward curvature at locations (0,0) and (1,1) is added to strobe dominant region **22-352**. As a consequence, a smoother transition may be observed within blended image **22-280** for very bright and very dark regions, where color may be less stable and may diverge between strobe image **22-310** and ambient image **22-320**. Upward curvature may be added to ambient dominant region **22-350** along diagonal **22-351** and corresponding downward curvature may be added to strobe dominant region **22-352** along diagonal **22-351**.
[0714] In certain embodiments, downward curvature may be added to ambient dominant region **22-350** at (1,0), or along a portion of the axis for ambient intensity **22-324**. Such downward curvature

may have the effect of shifting the weight of mix operation **22-346** to favor ambient pixel **22-322** when a corresponding strobe pixel **22-312** has very low intensity.

[0715] In one embodiment, a blend surface, such as blend surface **22-302** or blend surface **22-304**, is pre-computed and stored as a texture map that is established as an input to a fragment shader configured to implement blend operation **22-270**. A surface function that describes a blend surface having an ambient dominant region **22-350** and a strobe dominant region **22-352** is implemented to generate and store the texture map. The surface function may be implemented on a CPU core **22-170** of FIG. **22-1**A or a GPU core **22-172**, or a combination thereof. The fragment shader executing on a GPU core may use the texture map as a lookup table implementation of blend value function **22-342**. In alternative embodiments, the fragment shader implements the surface function and computes a blend value **22-344** as needed for each combination of a strobe intensity **22-314** and an ambient intensity **22-324**. One exemplary surface function that may be used to compute a blend value **22-344** (blendValue) given an ambient intensity **22-324** (ambient) and a strobe intensity **22-314** (strobe) is illustrated below as pseudo-code in Table 22-1. A constant "e" is set to a value that is relatively small, such as a fraction of a quantization step for ambient or strobe intensity, to avoid dividing by zero. Height **22-355** corresponds to constant 0.125 divided by 3.0.

TABLE-US-00001 TABLE 22-1 fDivA = strobe/(ambient + e); fDivB = (1.0 − ambient) / ((1.0 − strobe) + (1.0 − ambient) + e) temp = (fDivA >= 1.0) ? 1.0 : 0.125; blendValue = (temp + 2.0 * fDivB) / 3.0;

[0716] In certain embodiments, the blend surface is dynamically configured based on image properties associated with a given strobe image **22-310** and corresponding ambient image **22-320**. Dynamic configuration of the blend surface may include, without limitation, altering one or more of heights **22-354** through **359**, altering curvature associated with one or more of heights **22-354** through **359**, altering curvature along diagonal **22-351** for ambient dominant region **22-350**, altering curvature along diagonal **22-351** for strobe dominant region **22-352**, or any combination thereof.

[0717] One embodiment of dynamic configuration of a blend surface involves adjusting heights associated with the surface discontinuity along diagonal **22-351**. Certain images disproportionately include gradient regions having strobe pixels **22-312** and ambient pixels **22-322** of similar or identical intensity. Regions comprising such pixels may generally appear more natural as the surface discontinuity along diagonal **22-351** is reduced. Such images may be detected using a heat-map of ambient intensity **22-324** and strobe intensity **22-314** pairs within a surface defined by ambient intensity **22-324** and strobe intensity **22-314**. Clustering along diagonal **22-351** within the heat-map indicates a large incidence of strobe pixels **22-312** and ambient pixels **22-322** having similar intensity within an associated scene. In one embodiment, clustering along diagonal **22-351** within the heat-map indicates that the blend surface should be dynamically configured to reduce the height of the discontinuity along diagonal **22-351**. Reducing the height of the discontinuity along diagonal **22-351** may be implemented via adding downward curvature to strobe dominant region **22-352** along diagonal **22-351**, adding upward curvature to ambient dominant region **22-350** along diagonal **22-351**, reducing height **22-358**, reducing height **22-356**, or any combination thereof. Any technically feasible technique may be implemented to adjust curvature and height values without departing the scope and spirit of the present invention. Furthermore, any region of blend surfaces **22-302**, **22-304** may be dynamically adjusted in response to image characteristics without departing the scope of the present invention.

[0718] In one embodiment, dynamic configuration of the blend surface comprises mixing blend values from two or more pre-computed lookup tables implemented as texture maps. For example, a first blend surface may reflect a relatively large discontinuity and relatively large values for heights **22-356** and **22-358**, while a second blend surface may reflect a relatively small discontinuity and relatively small values for height **22-356** and **22-358**. Here, blend surface **22-304** may be dynamically configured as a weighted sum of blend values from the first blend surface and the second blend surface. Weighting may be determined based on certain image characteristics, such as clustering of strobe intensity **22-314** and ambient intensity **22-324** pairs in certain regions within the surface defined by strobe intensity **22-314** and ambient intensity **22-324**, or certain histogram attributes for strobe image **22-210** and ambient image **22-220**. In one embodiment, dynamic configuration of one or more aspects of the blend surface, such as discontinuity height, may be adjusted according to direct user input, such as via a UI tool.

[0719] FIG. **22-2**E illustrates an image blend operation for blending a strobe image with an ambient image to generate a blended image, according to one embodiment of the present invention. A strobe image **22-310** and an ambient image **22-320** of the same horizontal resolution and vertical resolution are combined via mix operation **22-346** to generate blended image **22-280** having the same resolution horizontal resolution and vertical resolution. In alternative embodiments, strobe image **22-310** or ambient image **22-320**, or both images may be scaled to an arbitrary resolution defined by blended image **22-280** for processing by mix operation **22-346**.

[0720] In certain settings, strobe image **22-310** and ambient image **22-320** include a region of pixels having similar intensity per pixel but different color per pixel. Differences in color may be attributed to differences in white balance for each image and different illumination contribution for each image. Because the intensity among adjacent pixels is similar, pixels within the region will cluster along diagonal **22-351** of FIGS. **22-2**D and **22-2**C, resulting in a distinctly unnatural speckling effect as adjacent pixels are weighted according to either strobe dominant region **22-352** or ambient dominant region **22-350**. To soften this speckling effect and produce a natural appearance within these regions, blend values may be blurred, effectively reducing the discontinuity between strobe dominant region **22-352** and ambient dominant region **22-350**. As is well-known in the art, blurring may be implemented by combining two or more individual samples.

[0721] In one embodiment, a blend buffer **22-315** comprises blend values **22-345**, which are computed from a set of two or more blend samples. Each blend sample is computed according to blend function **22-330**, described previously in FIGS. **22-2**B-**22-2**D. In one embodiment, blend buffer **22-315** is first populated with blend samples, computed according to blend function **22-330**. The blend samples are then blurred to compute each blend value **22-345**, which is stored to blend buffer **22-315**. In other embodiments, a first blend buffer is populated with blend samples computed according to blend function **22-330**, and two or more blend samples from the first blend buffer are blurred together to generate blend each value **22-345**, which is stored in blend buffer **22-315**. In yet other embodiments, two or more blend samples from the first blend buffer are blurred together to generate each blend value **22-345** as needed. In still another embodiment, two or more pairs of strobe pixels **22-312** and ambient pixels **22-322** are combined to generate each blend value **22-345** as needed. Therefore, in certain embodiments, blend buffer **22-315** comprises an allocated buffer in memory, while in other embodiments blend buffer **22-315** comprises an illustrative abstraction with no corresponding allocation in memory.

[0722] As shown, strobe pixel **22-312** and ambient pixel **22-322** are mixed based on blend value **22-345** to generate blended pixel **22-332**, stored in blended image **22-280**. Strobe pixel **22-312**, ambient pixel **22-322**, and blended pixel **22-332** are located in substantially identical locations in each respective image.

[0723] In one embodiment, strobe image **22-310** corresponds to strobe image **22-210** and ambient image **22-320** corresponds to ambient image **22-220**. In other embodiments, strobe image **22-310** corresponds to aligned strobe image **22-232** and ambient image **22-320** corresponds to aligned ambient image **22-234**. In one embodiment, mix operation **22-346** is associated with a fragment shader, configured to execute within one or more GPU cores **22-172**.

[0724] As discussed previously in FIGS. **22-1**B and **22-1**D, strobe image **22-210** may need to be processed to correct color that is divergent from color in corresponding ambient image **22-220**. Strobe image **22-210** may include frame-level divergence, spatially localized divergence, or a combination thereof. FIGS. **22-3**A and **22-3**B describe techniques implemented in frame analysis

operation **22-240** for computing color correction data **22-242**. In certain embodiments, color correction data **22-242** comprises frame-level characterization data for correcting overall color divergence, and patch-level correction data for correcting localized color divergence. FIGS. **22-4**A and **22-4**B discuss techniques for implementing color correction operation **22-250**, based on color correction data **22-242**.
[0725] FIG. **22-3**A illustrates a patch-level analysis process **22-400** for generating a patch correction array **22-450**, according to one embodiment of the present invention. Patch-level analysis provides local color correction information for correcting a region of a source strobe image to be consistent in overall color balance with an associated region of a source ambient image. A patch corresponds to a region of one or more pixels within an associated source image. A strobe patch **22-412** comprises representative color information for a region of one or more pixels within strobe patch array **22-410**, and an associated ambient patch **22-422** comprises representative color information for a region of one or more pixels at a corresponding location within ambient patch array **22-420**.
[0726] In one embodiment, strobe patch array **22-410** and ambient patch array **22-420** are processed on a per patch basis by patch-level correction estimator **22-430** to generate patch correction array **22-450**. Strobe patch array **22-410** and ambient patch array **22-420** each comprise a two-dimensional array of patches, each having the same horizontal patch resolution and the same vertical patch resolution. In alternative embodiments, strobe patch array **22-410** and ambient patch array **22-420** may each have an arbitrary resolution and each may be sampled according to a horizontal and vertical resolution for patch correction array **22-450**.
[0727] In one embodiment, patch data associated with strobe patch array **22-410** and ambient patch array **22-420** may be pre-computed and stored for substantially entire corresponding source images. Alternatively, patch data associated with strobe patch array **22-410** and ambient patch array **22-420** may be computed as needed, without allocating buffer space for strobe patch array **22-410** or ambient patch array **22-420**.
[0728] In data flow process **22-202** of FIG. **22-1**B, the source strobe image comprises strobe image **22-210**, while in data flow process **22-206** of FIG. **22-1**D, the source strobe image comprises aligned strobe image **22-232**. Similarly, ambient patch array **22-420** comprises a set of patches generated from a source ambient image. In data flow process **22-202**, the source ambient image comprises ambient image **22-220**, while in data flow process **22-206**, the source ambient image comprises aligned ambient image **22-234**.
[0729] In one embodiment, representative color information for each patch within strobe patch array **22-410** is generated by averaging color for a four-by-four region of pixels from the source strobe image at a corresponding location, and representative color information for each patch within ambient patch array **22-420** is generated by averaging color for a four-by-four region of pixels from the ambient source image at a corresponding location. An average color may comprise red, green and blue components. Each four-by-four region may be non-overlapping or overlapping with respect to other four-by-four regions. In other embodiments, arbitrary regions may be implemented. Patch-level correction estimator **22-430** generates patch correction **22-432** from strobe patch **22-412** and a corresponding ambient patch **22-422**. In certain embodiments, patch correction **22-432** is saved to patch correction array **22-450** at a corresponding location. In one embodiment, patch correction **22-432** includes correction factors for red, green, and blue, computed according to the pseudo-code of Table 22-2, below.
TABLE-US-00002 TABLE 22-2 ratio.r = (ambient.r) / (strobe.r); ratio.g = (ambient.g) / (strobe.g); ratio.b = (ambient.b) / (strobe.b); maxRatio = max(ratio.r, max(ratio.g, ratio.b)); correct.r = (ratio.r / maxRatio); correct.g = (ratio.g / maxRatio); correct.b = (ratio.b / maxRatio);
[0730] Here, “strobe.r” refers to a red component for strobe patch **22-412**, “strobe.g” refers to a green component for strobe patch **22-412**, and “strobe.b” refers to a blue component for strobe patch **22-412**. Similarly, “ambient.r,” “ambient.g,” and “ambient.b” refer respectively to red, green,

and blue components of ambient patch **22-422**. A maximum ratio of ambient to strobe components is computed as "maxRatio," which is then used to generate correction factors, including "correct.r" for a red channel, "correct.g" for a green channel, and "correct.b" for a blue channel. Correction factors correct.r, correct.g, and correct.b together comprise patch correction **22-432**. These correction factors, when applied fully in color correction operation **22-250**, cause pixels associated with strobe patch **22-412** to be corrected to reflect a color balance that is generally consistent with ambient patch **22-422**.

[0731] In one alternative embodiment, each patch correction **22-432** comprises a slope and an offset factor for each one of at least red, green, and blue components. Here, components of source ambient image pixels bounded by a patch are treated as function input values and corresponding components of source strobe image pixels are treated as function outputs for a curve fitting procedure that estimates slope and offset parameters for the function. For example, red components of source ambient image pixels associated with a given patch may be treated as "X" values and corresponding red pixel components of source strobe image pixels may be treated as "Y" values, to form (X, Y) points that may be processed according to a least-squares linear fit procedure, thereby generating a slope parameter and an offset parameter for the red component of the patch. Slope and offset parameters for green and blue components may be computed similarly. Slope and offset parameters for a component describe a line equation for the component. Each patch correction **22-432** includes slope and offset parameters for at least red, green, and blue components. Conceptually, pixels within an associated strobe patch may be color corrected by evaluating line equations for red, green, and blue components.

[0732] In a different alternative embodiment, each patch correction **22-432** comprises three parameters describing a quadratic function for each one of at least red, green, and blue components. Here, components of source strobe image pixels bounded by a patch are fit against corresponding components of source ambient image pixels to generate quadratic parameters for color correction. Conceptually, pixels within an associated strobe patch may be color corrected by evaluating quadratic equations for red, green, and blue components.

[0733] FIG. **22-3**B illustrates a frame-level analysis process **22-402** for generating frame-level characterization data **22-492**, according to one embodiment of the present invention. Frame-level correction estimator **22-490** reads strobe data **22-472** comprising pixels from strobe image data **22-470** and ambient data **22-482** comprising pixels from ambient image data **22-480** to generate frame-level characterization data **22-492**.

[0734] In certain embodiments, strobe data **22-472** comprises pixels from strobe image **22-210** of FIG. **22-1**A and ambient data **22-482** comprises pixels from ambient image **22-220**. In other embodiments, strobe data **22-472** comprises pixels from aligned strobe image **22-232** of FIG. **22-1**C, and ambient data **22-482** comprises pixels from aligned ambient image **22-234**. In yet other embodiments, strobe data **22-472** comprises patches representing average color from strobe patch array **22-410**, and ambient data **22-482** comprises patches representing average color from ambient patch array **22-420**.

[0735] In one embodiment, frame-level characterization data **22-492** includes at least frame-level color correction factors for red correction, green correction, and blue correction. Frame-level color correction factors may be computed according to the pseudo-code of Table 22-3.

TABLE-US-00003 TABLE 22-3 ratioSum.r = (ambientSum.r) / (strobeSum.r); ratioSum.g = (ambientSum.g) / (strobeSum.g); ratioSum.b = (ambientSum.b) / (strobeSum.b); maxSumRatio = max(ratioSum.r, max(ratioSum.g, ratioSum.b)); correctFrame.r = (ratioSum.r / maxSumRatio); correctFrame.g = (ratioSum.g / maxSumRatio); correctFrame.b = (ratioSum.b / maxSumRatio);

[0736] Here, "strobeSum.r" refers to a sum of red components taken over strobe image data **22-470**, "strobeSum.g" refers to a sum of green components taken over strobe image data **22-470**, and "strobeSum.b" refers to a sum of blue components taken over strobe image data **22-470**. Similarly, "ambientSum.r," "ambientSum.g," and "ambientSum.b" each refer to a sum of components taken over ambient image data **22-480** for respective red, green, and blue components. A maximum ratio of ambient to strobe sums is computed as "maxSumRatio," which is then used to generate frame-level color correction factors, including "correctFrame.r" for a red channel, "correctFrame.g" for a green channel, and "correctFrame.b" for a blue channel. These frame-level color correction factors, when applied fully and exclusively in color correction operation **22-250**, cause overall color balance of strobe image **22-210** to be corrected to reflect a color balance that is generally consistent with that of ambient image **22-220**.

[0737] While overall color balance for strobe image **22-210** may be corrected to reflect overall color balance of ambient image **22-220**, a resulting color corrected rendering of strobe image **22-210** based only on frame-level color correction factors may not have a natural appearance and will likely include local regions with divergent color with respect to ambient image **22-220**. Therefore, as described below in FIG. **22-4**A, patch-level correction may be used in conjunction with frame-level correction to generate a color corrected strobe image.

[0738] In one embodiment, frame-level characterization data **22-492** also includes at least a histogram characterization of strobe image data **22-470** and a histogram characterization of ambient image data **22-480**. Histogram characterization may include identifying a low threshold intensity associated with a certain low percentile of pixels, a median threshold intensity associated with a fiftieth percentile of pixels, and a high threshold intensity associated with a high threshold percentile of pixels. In one embodiment, the low threshold intensity is associated with an approximately fifteenth percentile of pixels and a high threshold intensity is associated with an approximately eighty-fifth percentile of pixels, so that approximately fifteen percent of pixels within an associated image have a lower intensity than a calculated low threshold intensity and approximately eighty-five percent of pixels have a lower intensity than a calculated high threshold intensity.

[0739] In certain embodiments, frame-level characterization data **22-492** also includes at least a heat-map, described previously. The heat-map may be computed using individual pixels or patches representing regions of pixels. In one embodiment, the heat-map is normalized using a logarithm operator, configured to normalize a particular heat-map location against a logarithm of a total number of points contributing to the heat-map. Alternatively, frame-level characterization data **22-492** includes a factor that summarizes at least one characteristic of the heat-map, such as a diagonal clustering factor to quantify clustering along diagonal **22-351** of FIGS. **22-2**C and **22-2**D. This diagonal clustering factor may be used to dynamically configure a given blend surface.

[0740] While frame-level and patch-level correction coefficients have been discussed representing two different spatial extents, persons skilled in the art will recognize that more than two levels of spatial extent may be implemented without departing the scope and spirit of the present invention.

[0741] FIG. **22-4**A illustrates a data flow process **22-500** for correcting strobe pixel color, according to one embodiment of the present invention. A strobe pixel **22-520** is processed to generate a color corrected strobe pixel **22-512**. In one embodiment, strobe pixel **22-520** comprises a pixel associated with strobe image **22-210** of FIG. **22-1**B, ambient pixel **22-522** comprises a pixel associated with ambient image **22-220**, and color corrected strobe pixel **22-512** comprises a pixel associated with corrected strobe image data **22-252**. In an alternative embodiment, strobe pixel **22-520** comprises a pixel associated with aligned strobe image **22-232** of FIG. **22-1**D, ambient pixel **22-522** comprises a pixel associated with aligned ambient image **22-234**, and color corrected strobe pixel **22-512** comprises a pixel associated with corrected strobe image data **22-252**. Color corrected strobe pixel **22-512** may correspond to strobe pixel **22-312** in FIG. **22-2**A, and serve as an input to blend function **22-330**.

[0742] In one embodiment, patch-level correction factors **22-525** comprise one or more sets of correction factors for red, green, and blue associated with patch correction **22-432** of FIG. **22-3**A, frame-level correction factors **22-527** comprise frame-level correction factors for red, green, and blue associated with frame-level characterization data **22-492** of FIG. **22-3**B, and frame-level histogram factors **22-529** comprise at least a low threshold intensity and a median threshold intensity for both an ambient histogram and a strobe histogram associated with frame-level characterization data **22-492**.

[0743] A pixel-level trust estimator **22-502** computes a pixel-level trust factor **22-503** from strobe pixel **22-520** and ambient pixel **22-522**. In one embodiment, pixel-level trust factor **22-503** is computed according to the pseudo-code of Table 22-4, where strobe pixel **22-520** corresponds to strobePixel, ambient pixel **22-522** corresponds to ambientPixel, and pixel-level trust factor **22-503** corresponds to pixelTrust. Here, ambientPixel and strobePixel may comprise a vector variable, such as a well known vec3 or vec4 vector variable.

TABLE-US-00004 TABLE 22-4 ambientIntensity = intensity (ambientPixel); strobeIntensity = intensity (strobePixel); stepInput = ambientIntensity * strobeIntensity; pixelTrust = smoothstep (lowEdge, highEdge, stepInput);

[0744] Here, an intensity function may implement Equation 22-1 to compute ambientIntensity and strobel ntensity, corresponding respectively to an intensity value for ambientPixel and an intensity value for strobePixel. While the same intensity function is shown computing both ambientintensity and strobelntensity, certain embodiments may compute each intensity value using a different intensity function. A product operator may be used to compute stepinput, based on ambientIntensity and strobel ntensity. The well-known smoothstep function implements a relatively smoothly transition from 0.0 to 1.0 as stepinput passes through lowEdge and then through highEdge. In one embodiment, lowEge=0.25 and highEdge=0.66.

[0745] A patch-level correction estimator **22-504** computes patch-level correction factors **22-505** by sampling patch-level correction factors **22-525**. In one embodiment, patch-level correction estimator **22-504** implements bilinear sampling over four sets of patch-level color correction samples to generate sampled patch-level correction factors **22-505**. In an alternative embodiment, patch-level correction estimator **22-504** implements distance weighted sampling over four or more sets of patch-level color correction samples to generate sampled patch-level correction factors **22-505**. In another alternative embodiment, a set of sampled patch-level correction factors **22-505** is computed using pixels within a region centered about strobe pixel **22-520**. Persons skilled in the art will recognize that any technically feasible technique for sampling one or more patch-level correction factors to generate sampled patch-level correction factors **22-505** is within the scope and spirit of the present invention.

[0746] In one embodiment, each one of patch-level correction factors **22-525** comprises a red, green, and blue color channel correction factor. In a different embodiment, each one of the patch-level correction factors **22-525** comprises a set of line equation parameters for red, green, and blue color channels. Each set of line equation parameters may include a slope and an offset. In another embodiment, each one of the patch-level correction factors **22-525** comprises a set of quadratic curve parameters for red, green, and blue color channels. Each set of quadratic curve parameters may include a square term coefficient, a linear term coefficient, and a constant.

[0747] In one embodiment, frame-level correction adjuster **22-506** computes adjusted frame-level correction factors **22-507** (adjCorrectFrame) from the frame-level correction factors for red, green, and blue according to the pseudo-code of Table 22-5. Here, a mix operator may function according to Equation 22-2, where variable A corresponds to 1.0, variable B corresponds to a correctFrame color value, and frameT rust may be computed according to an embodiment described below in conjunction with the pseudo-code of Table 22-5. As discussed previously, correctFrame comprises frame-level correction factors. Parameter frameTrust quantifies how trustworthy a particular pair of ambient image and strobe image may be for performing frame-level color correction.

TABLE-US-00005 TABLE 22-5 adjCorrectFrame.r = mix(1.0, correctFrame.r, frameTrust); adjCorrectFrame.g = mix(1.0, correctFrame.g, frameTrust); adjCorrectFrame.b = mix(1.0, correctFrame.b, frameTrust);

[0748] When frameT rust approaches zero (correction factors not trustworthy), the adjusted frame-level correction factors **22-507** converge to 1.0, which yields no frame-level color correction. When frameT rust is 1.0 (completely trustworthy), the adjusted frame-level correction factors **22-507** converge to values calculated previously in Table 22-3. The pseudo-code of Table 22-5 illustrates one technique for calculating frameT rust.

TABLE-US-00006 TABLE 22-5 strobeExp = (WSL*SL + WSM*SM + WSH*SH) / (WSL + WSM + WSH); ambientExp = (WAL*SL + WAM*SM + WAH*SH) / (WAL + WAM + WAH); frameTrustStrobe = smoothstep (SLE, SHE, strobeExp); frameTrustAmbient = smoothstep (ALE, AHE, ambientExp); frameTrust = frameTrustStrobe * frameTrustAmbient;

[0749] Here, strobe exposure (strobeExp) and ambient exposure (ambientExp) are each characterized as a weighted sum of corresponding low threshold intensity, median threshold intensity, and high threshold intensity values. Constants WSL, WSM, and WSH correspond to strobe histogram contribution weights for low threshold intensity, median threshold intensity, and high threshold intensity values, respectively. Variables SL, SM, and SH correspond to strobe histogram low threshold intensity, median threshold intensity, and high threshold intensity values, respectively. Similarly, constants WAL, WAM, and WAH correspond to ambient histogram contribution weights for low threshold intensity, median threshold intensity, and high threshold intensity values, respectively; and variables AL, AM, and A H correspond to ambient histogram low threshold intensity, median threshold intensity, and high threshold intensity values, respectively. A strobe frame-level trust value (frameT rustStrobe) is computed for a strobe frame associated with strobe pixel **22-520** to reflect how trustworthy the strobe frame is for the purpose of frame-level color correction. In one embodiment, WSL=WAL=1.0, WSM=WAM=2.0, and WSH=WAH=0.0. In other embodiments, different weights may be applied, for example, to customize the techniques taught herein to a particular camera apparatus. In certain embodiments, other percentile thresholds may be measured, and different combinations of weighted sums may be used to compute frame-level trust values.

[0750] In one embodiment, a smoothstep function with a strobe low edge (SLE) and strobe high edge (SHE) is evaluated based on strobeExp. Similarly, a smoothstep function with ambient low edge (ALE) and ambient high edge (AHE) is evaluated to compute an ambient frame-level trust value (frameTrustAmbient) for an ambient frame associated with ambient pixel **22-522** to reflect how trustworthy the ambient frame is for the purpose of frame-level color correction. In one embodiment, SLE=ALE=0.15, and SHE=AHE=0.30. In other embodiments, different low and high edge values may be used.

[0751] In one embodiment, a frame-level trust value (frameT rust) for frame-level color correction is computed as the product of frameT rustStrobe and frameT rustAmbient. When both the strobe frame and the ambient frame are sufficiently exposed and therefore trustworthy frame-level color references, as indicated by frameT rustStrobe and frameT rustAmbient, the product of frameT rustStrobe and frameT rustAmbient will reflect a high trust for frame-level color correction. If either the strobe frame or the ambient frame is inadequately exposed to be a trustworthy color reference, then a color correction based on a combination of strobe frame and ambient frame should not be trustworthy, as reflected by a low or zero value for frameT rust.

[0752] In an alternative embodiment, the frame-level trust value (frameT rust) is generated according to direct user input, such as via a UI color adjustment tool having a range of control positions that map to a frameTrust value. The UI color adjustment tool may generate a full range of frame-level trust values (0.0 to 1.0) or may generate a value constrained to a computed range. In certain settings, the mapping may be non-linear to provide a more natural user experience. In one embodiment, the control position also influences pixel-level trust factor **22-503** (pixelTrust), such as via a direct bias or a blended bias.

[0753] A pixel-level correction estimator **22-508** is configured to generate pixel-level correction factors **22-509** (pixCorrection) from sampled patch-level correction factors **22-505** (correct), adjusted frame-level correction factors **22-507**, and pixel-level trust factor **22-503**. In one

embodiment, pixel-level correction estimator **22-508** comprises a mix function, whereby sampled patch-level correction factors **22-505** is given substantially full mix weight when pixel-level trust factor **22-503** is equal to 1.0 and adjusted frame-level correction factors **22-507** is given substantially full mix weight when pixel-level trust factor **22-503** is equal to 0.0. Pixel-level correction estimator **22-508** may be implemented according to the pseudo-code of Table 22-7.
TABLE-US-00007 TABLE 22-7 pixCorrection.r = mix(adjCorrectFrame.r, correct.r, pixelTrust); pixCorrection.g= mix(adjCorrectFrame.g, correct.g, pixelTrust); pixCorrection.b = mix(adjCorrectFrame.b, correct.b, pixelTrust);
[0754] In another embodiment, line equation parameters comprising slope and offset define sampled patch-level correction factors **22-505** and adjusted frame-level correction factors **22-507**. These line equation parameters are mixed within pixel-level correction estimator **22-508** according to pixelTrust to yield pixel-level correction factors **22-509** comprising line equation parameters for red, green, and blue channels. In yet another embodiment, quadratic parameters define sampled patch-level correction factors **22-505** and adjusted frame-level correction factors **22-507**. In one embodiment, the quadratic parameters are mixed within pixel-level correction estimator **22-508** according to pixelTrust to yield pixel-level correction factors **22-509** comprising quadratic parameters for red, green, and blue channels. In another embodiment, quadratic equations are evaluated separately for frame-level correction factors and patch level correction factors for each color channel, and the results of evaluating the quadratic equations are mixed according to pixelTrust.
[0755] In certain embodiments, pixelTrust is at least partially computed by image capture information, such as exposure time or exposure ISO index. For example, if an image was captured with a very long exposure at a very high ISO index, then the image may include significant chromatic noise and may not represent a good frame-level color reference for color correction.
[0756] Pixel-level correction function **22-510** generates color corrected strobe pixel **22-512** from strobe pixel **22-520** and pixel-level correction factors **22-509**. In one embodiment, pixel-level correction factors **22-509** comprise correction factors pixCorrection.r, pixCorrection.g, and pixCorrection.b and color corrected strobe pixel **22-512** is computed according to the pseudo-code of Table 22-8.
TABLE-US-00008 TABLE 22-8 // scale red, green, blue vec3 pixCorrection = (pixCorrection.r, pixCorrection.g, pixCorrection.b); vec3 deNormCorrectedPixel = strobePixel * pixCorrection; normalizeFactor = length(strobePixel) / length(deNormCorrectedPixel); vec3 normCorrectedPixel = deNormCorrectedPixel * normalizeFactor; vec3 correctedPixel = cAttractor(normCorrectedPixel);
[0757] Here, pixCorrection comprises a vector of three components (vec3) corresponding pixel-level correction factors pixCorrection.r, pixCorrection.g, and pixCorrection.b. A de-normalized, color corrected pixel is computed as deNormCorrectedPixel. A pixel comprising a red, green, and blue component defines a color vector in a three-dimensional space, the color vector having a particular length. The length of a color vector defined by deNormCorrectedPixel may be different with respect to a color vector defined by strobePixel. Altering the length of a color vector changes the intensity of a corresponding pixel. To maintain proper intensity for color corrected strobe pixel **22-512**, deNormCorrectedPixel is re-normalized via normalizeFactor, which is computed as a ratio of length for a color vector defined by strobePixel to a length for a color vector defined by deNormCorrectedPixel. Color vector normCorrectedPixel includes pixel-level color correction and re-normalization to maintain proper pixel intensity. A length function may be performed using any technically feasible technique, such as calculating a square root of a sum of squares for individual vector component lengths.
[0758] A chromatic attractor function (cAttractor) gradually converges an input color vector to a target color vector as the input color vector increases in length. Below a threshold length, the chromatic attractor function returns the input color vector. Above the threshold length, the

chromatic attractor function returns an output color vector that is increasingly convergent on the target color vector. The chromatic attractor function is described in greater detail below in FIG. **22-4**B.

[0759] In alternative embodiments, pixel-level correction factors comprise a set of line equation parameters per color channel, with color components of strobePixel comprising function inputs for each line equation. In such embodiments, pixel-level correction function **22-510** evaluates the line equation parameters to generate color corrected strobe pixel **22-512**. This evaluation process is illustrated in the pseudo-code of Table 22-9.

TABLE-US-00009 TABLE 22-9 // evaluate line equation based on strobePixel for red, green, blue vec3 pixSlope = (pixSlope.r, pixSlope.g, pixSlope.b); vec3 pixOffset = (pixOffset.r, pixOffset.g, pixOffset.b); vec3 deNormCorrectedPixel = (strobePixel * pixSlope) + pixOffset; normalizeFactor = length(strobePixel) / length(deNormCorrectedPixel); vec3 normCorrectedPixel = deNormCorrectedPixel * normalizeFactor; vec3 correctedPixel = cAttractor(normCorrectedPixel);

[0760] In other embodiments, pixel level correction factors comprise a set of quadratic parameters per color channel, with color components of strobePixel comprising function inputs for each quadratic equation. In such embodiments, pixel-level correction function **22-510** evaluates the quadratic equation parameters to generate color corrected strobe pixel **22-512**.

[0761] In certain embodiments chromatic attractor function (cAttractor) implements a target color vector of white (1, 1, 1), and causes very bright pixels to converge to white, providing a natural appearance to bright portions of an image. In other embodiments, a target color vector is computed based on spatial color information, such as an average color for a region of pixels surrounding the strobe pixel. In still other embodiments, a target color vector is computed based on an average frame-level color. A threshold length associated with the chromatic attractor function may be defined as a constant, or, without limitation, by a user input, a characteristic of a strobe image or an ambient image or a combination thereof. In an alternative embodiment, pixel-level correction function **22-510** does not implement the chromatic attractor function.

[0762] In one embodiment, a trust level is computed for each patch-level correction and applied to generate an adjusted patch-level correction factor comprising sampled patch-level correction factors **22-505**. Generating the adjusted patch-level correction may be performed according to the techniques taught herein for generating adjusted frame-level correction factors **22-507**.

[0763] Other embodiments include two or more levels of spatial color correction for a strobe image based on an ambient image, where each level of spatial color correction may contribute a non-zero weight to a color corrected strobe image comprising one or more color corrected strobe pixels. Such embodiments may include patches of varying size comprising varying shapes of pixel regions without departing the scope of the present invention.

[0764] FIG. **22-4**B illustrates a chromatic attractor function **22-560**, according to one embodiment of the present invention. A color vector space is shown having a red axis **22-562**, a green axis **22-564**, and a blue axis **22-566**. A unit cube **22-570** is bounded by an origin at coordinate (0, 0, 0) and an opposite corner at coordinate (1, 1, 1). A surface **22-572** having a threshold distance from the origin is defined within the unit cube. Color vectors having a length that is shorter than the threshold distance are conserved by the chromatic attractor function **22-560**. Color vectors having a length that is longer than the threshold distance are converged towards a target color. For example, an input color vector **22-580** is defined along a particular path that describes the color of the input color vector **22-580**, and a length that describes the intensity of the color vector. The distance from the origin to point **22-582** along input color vector **22-580** is equal to the threshold distance. In this example, the target color is pure white (1, 1, 1), therefore any additional length associated with input color vector **22-580** beyond point **22-582** follows path **22-584** towards the target color of pure white.

[0765] One implementation of chromatic attractor function **22-560**, comprising the cAttractor function of Tables 22-8 and 22-9 is illustrated in the pseudo-code of Table 22-10.

TABLE-US-00010 TABLE 22-10 extraLength = max(length (inputColor), distMin); mixValue= (extraLength − distMin) / (distMax− distMin); outputColor = mix (inputColor, targetColor, mixValue);

[0766] Here, a length value associated with inputColor is compared to distMin, which represents the threshold distance. If the length value is less than distMin, then the "max" operator returns distMin. The mix Value term calculates a parameterization from 0.0 to 1.0 that corresponds to a length value ranging from the threshold distance to a maximum possible length for the color vector, given by the square root of 3.0. If extraLength is equal to distMin, then mixValue is set equal to 0.0 and outputColor is set equal to the inputColor by the mix operator. Otherwise, if the length value is greater than distMin, then mixValue represents the parameterization, enabling the mix operator to appropriately converge inputColor to targetColor as the length of inputColor approaches the square root of 3.0. In one embodiment, distMax is equal to the square root of 3.0 and distMin=1.45. In other embodiments different values may be used for distMax and distMin. For example, if distMin=1.0, then chromatic attractor **22-560** begins to converge to targetColor much sooner, and at lower intensities. If distMax is set to a larger number, then an inputPixel may only partially converge on targetColor, even when inputPixel has a very high intensity. Either of these two effects may be beneficial in certain applications.

[0767] While the pseudo-code of Table 22-10 specifies a length function, in other embodiments, computations may be performed in length-squared space using constant squared values with comparable results.

[0768] In one embodiment, targetColor is equal to (1,1,1), which represents pure white and is an appropriate color to "burn" to in overexposed regions of an image rather than a color dictated solely by color correction. In another embodiment, targetColor is set to a scene average color, which may be arbitrary. In yet another embodiment, targetColor is set to a color determined to be the color of an illumination source within a given scene.

[0769] FIG. **22-5** is a flow diagram of method **22-500** for generating an adjusted digital photograph, according to one embodiment of the present invention. Although the method steps are described in conjunction with the systems disclosed herein, persons skilled in the art will understand that any system configured to perform the method steps, in any order, is within the scope of the present invention.

[0770] Method **22-500** begins in step **22-510**, where a digital photographic system, such as digital photographic system **300** of FIG. **3**A, receives a trigger command to take a digital photograph. The trigger command may comprise a user input event, such as a button press, remote control command related to a button press, completion of a timer count down, an audio indication, or any other technically feasible user input event. In one embodiment, the digital photographic system implements digital camera **302** of FIG. **3**C, and the trigger command is generated when shutter release button **315** is pressed. In another embodiment, the digital photographic system implements mobile device **376** of FIG. **3**D, and the trigger command is generated when a UI button is pressed.

[0771] In step **22-512**, the digital photographic system samples a strobe image and an ambient image. In one embodiment, the strobe image is taken before the ambient image. Alternatively, the ambient image is taken before the strobe image. In certain embodiments, a white balance operation is performed on the ambient image. Independently, a white balance operation may be performed on the strobe image. In other embodiments, such as in scenarios involving raw digital photographs, no white balance operation is applied to either the ambient image or the strobe image.

[0772] In step **22-514**, the digital photographic system generates a blended image from the strobe image and the ambient image. In one embodiment, the digital photographic system generates the blended image according to data flow process **22-200** of FIG. **22-1**A. In a second embodiment, the digital photographic system generates the blended image according to data flow process **22-202** of FIG. **22-1**B. In a third embodiment, the digital photographic system generates the blended image according to data flow process **22-204** of FIG. **22-1**C. In a fourth embodiment, the digital photographic system generates the blended image according to data flow process **22-206** of FIG. **22-1**D. In each of these embodiments, the strobe image comprises strobe image **22-210**, the ambient image comprises ambient image **22-220**, and the blended image comprises blended image **22-280**.

[0773] In step **22-516**, the digital photographic system presents an adjustment tool configured to present at least the blended image, the strobe image, and the ambient image, according to a transparency blend among two or more of the images. The transparency blend may be controlled by a user interface slider. The adjustment tool may be configured to save a particular blend state of the images as an adjusted image. The adjustment tool is described in greater detail hereinabove.

[0774] The method terminates in step **22-590**, where the digital photographic system saves at least the adjusted image.

[0775] FIG. **22-6**A is a flow diagram of method **22-700** for blending a strobe image with an ambient image to generate a blended image, according to a first embodiment of the present invention. Although the method steps are described in conjunction with the systems of FIGS. **3**A-**3**D, persons skilled in the art will understand that any system configured to perform the method steps, in any order, is within the scope of the present invention. In one embodiment, method **22-700** implements data flow **22-200** of FIG. **22-1**A. The strobe image and the ambient image each comprise at least one pixel and may each comprise an equal number of pixels.

[0776] The method begins in step **22-710**, where a processor complex within a digital photographic system, such as processor complex **310** within digital photographic system **300** of FIG. **3**A, receives a strobe image and an ambient image, such as strobe image **22-210** and ambient image **22-220**, respectively. In step **22-712**, the processor complex generates a blended image, such as blended image **22-280**, by executing a blend operation **22-270** on the strobe image and the ambient image. The method terminates in step **22-790**, where the processor complex saves the blended image, for example to NV memory **316**, volatile memory **318**, or memory system **362**.

[0777] FIG. **22-6**B is a flow diagram of method **22-702** for blending a strobe image with an ambient image to generate a blended image, according to a second embodiment of the present invention. Although the method steps are described in conjunction with the systems of FIGS. **3**A-**3**D, persons skilled in the art will understand that any system configured to perform the method steps, in any order, is within the scope of the present invention. In one embodiment, method **22-702** implements data flow **22-202** of FIG. **22-1**B. The strobe image and the ambient image each comprise at least one pixel and may each comprise an equal number of pixels.

[0778] The method begins in step **22-720**, where a processor complex within a digital photographic system, such as processor complex **310** within digital photographic system **300** of FIG. **3**A, receives a strobe image and an ambient image, such as strobe image **22-210** and ambient image **22-220**, respectively. In step **22-722**, the processor complex generates a color corrected strobe image, such as corrected strobe image data **22-252**, by executing a frame analysis operation **22-240** on the strobe image and the ambient image and executing and a color correction operation **22-250** on the strobe image. In step **22-724**, the processor complex generates a blended image, such as blended image **22-280**, by executing a blend operation **22-270** on the color corrected strobe image and the ambient image. The method terminates in step **22-792**, where the processor complex saves the blended image, for example to NV memory **316**, volatile memory **318**, or memory system **362**.

[0779] FIG. **22-7**A is a flow diagram of method **22-800** for blending a strobe image with an ambient image to generate a blended image, according to a third embodiment of the present invention. Although the method steps are described in conjunction with the systems of FIGS. **3**A-**3**D, persons skilled in the art will understand that any system configured to perform the method steps, in any order, is within the scope of the present invention. In one embodiment, method **22-800** implements data flow **22-204** of FIG. **22-1**C. The strobe image and the ambient image each comprise at least one pixel and may each comprise an equal number of pixels.

[0780] The method begins in step **22-810**, where a processor complex within a digital photographic system, such as processor complex **310** within digital photographic system **300** of FIG. **3**A, receives a strobe image and an ambient image, such as strobe image **22-210** and ambient image **22-220**, respectively. In step **22-812**, the processor complex estimates a motion transform between the strobe image and the ambient image. In step **22-814**, the processor complex renders at least an aligned strobe image or an aligned ambient image based the estimated motion transform. In certain embodiments, the processor complex renders both the aligned strobe image and the aligned ambient image based on the motion transform. The aligned strobe image and the aligned ambient image may be rendered to the same resolution so that each is aligned to the other. In one embodiment, steps **22-812** and **814** together comprise alignment operation **22-230**. In step **22-816**, the processor complex generates a blended image, such as blended image **22-280**, by executing a blend operation **22-270** on the aligned strobe image and the aligned ambient image. The method terminates in step **22-890**, where the processor complex saves the blended image, for example to NV memory **316**, volatile memory **318**, or memory system **362**.

[0781] FIG. **22-7**B is a flow diagram of method steps for blending a strobe image with an ambient image to generate a blended image, according to a fourth embodiment of the present invention. Although the method steps are described in conjunction with the systems of FIGS. **3**A-**3**D, persons skilled in the art will understand that any system configured to perform the method steps, in any order, is within the scope of the present invention. In one embodiment, method **22-802** implements data flow **22-206** of FIG. **22-1**D. The strobe image and the ambient image each comprise at least one pixel and may each comprise an equal number of pixels.

[0782] The method begins in step **22-830**, where a processor complex within a digital photographic system, such as processor complex **310** within digital photographic system **300** of FIG. **3**A, receives a strobe image and an ambient image, such as strobe image **22-10** and ambient image **22-220**, respectively. In step **22-832**, the processor complex estimates a motion transform between the strobe image and the ambient image. In step **22-834**, the processor complex may render at least an aligned strobe image or an aligned ambient image based the estimated motion transform. In certain embodiments, the processor complex renders both the aligned strobe image and the aligned ambient image based on the motion transform. The aligned strobe image and the aligned ambient image may be rendered to the same resolution so that each is aligned to the other. In one embodiment, steps **22-832** and **834** together comprise alignment operation **22-230**.

[0783] In step **22-836**, the processor complex generates a color corrected strobe image, such as corrected strobe image data **22-252**, by executing a frame analysis operation **22-240** on the aligned strobe image and the aligned ambient image and executing a color correction operation **22-250** on the aligned strobe image. In step **22-838**, the processor complex generates a blended image, such as blended image **22-280**, by executing a blend operation **22-270** on the color corrected strobe image and the aligned ambient image. The method terminates in step **22-892**, where the processor complex saves the blended image, for example to NV memory **316**, volatile memory **318**, or memory system **362**.

[0784] While the techniques taught herein are discussed above in the context of generating a digital photograph having a natural appearance from an underlying strobe image and ambient image with potentially discordant color, these techniques may be applied in other usage models as well.

[0785] For example, when compositing individual images to form a panoramic image, color inconsistency between two adjacent images can create a visible seam, which detracts from overall image quality. Persons skilled in the art will recognize that frame analysis operation **22-240** may be used in conjunction with color correction operation **22-250** to generated panoramic images with color-consistent seams, which serve to improve overall image quality. In another example, frame analysis operation **22-240** may be used in conjunction with color correction operation **22-250** to improve color consistency within high dynamic range (HDR) images.

[0786] In yet another example, multispectral imaging may be improved by enabling the addition of a strobe illuminator, while maintaining spectral consistency. Multispectral imaging refers to imaging of multiple, arbitrary wavelength ranges, rather than just conventional red, green, and blue ranges. By applying the above techniques, a multispectral image may be generated by blending two or more multispectral images having different illumination sources.

[0787] In still other examples, the techniques taught herein may be applied in an apparatus that is separate from digital photographic system **22-100** of FIG. **22-1**A. Here, digital photographic system **22-100** may be used to generate and store a strobe image and an ambient image. The strobe image and ambient image are then combined later within a computer system, disposed locally with a user, or remotely within a cloud-based computer system. In one embodiment, method **22-802** comprises a software module operable with an image processing tool to enable a user to read the strobe image and the ambient image previously stored, and to generate a blended image within a computer system that is distinct from digital photographic system **22-100**.

[0788] Persons skilled in the art will recognize that while certain intermediate image data may be discussed in terms of a particular image or image data, these images serve as illustrative abstractions. Such buffers may be allocated in certain implementations, while in other implementations intermediate data is only stored as needed. For example, aligned strobe image **22-232** may be rendered to completion in an allocated image buffer during a certain processing step or steps, or alternatively, pixels associated with an abstraction of an aligned image may be rendered as needed without a need to allocate an image buffer to store aligned strobe image **22-232**.

[0789] While the techniques described above discuss color correction operation **22-250** in conjunction with a strobe image that is being corrected to an ambient reference image, a strobe image may serve as a reference image for correcting an ambient image. In one embodiment ambient image **22-220** is subjected to color correction operation **22-250**, and blend operation **22-270** operates as previously discussed for blending an ambient image and a strobe image.

[0790] In summary, a technique is disclosed for generating a digital photograph that beneficially blends an ambient image sampled under ambient lighting conditions and a strobe image sampled under strobe lighting conditions. The strobe image is blended with the ambient image based on a function that implements a blend surface. Discordant spatial coloration between the strobe image and the ambient image is corrected via a spatial color correction operation. An adjustment tool implements a user interface technique that enables a user to select and save a digital photograph from a gradation of parameters for combining related images.

[0791] On advantage of the present invention is that a digital photograph may be generated having consistent white balance in a scene comprising regions illuminated primarily by a strobe of one color balance and other regions illuminated primarily by ambient illumination of a different color balance.

[0792] FIG. **23-1** illustrates an exemplary method **23-100** for generating a high dynamic range (HDR) pixel stream, in accordance with one possible embodiment. As an option, the method **23-100** may be carried out in the context of any of the Figures. Of course, however, the method **23-100** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0793] As shown, at operation **23-102**, a pixel stream is received, and the pixel stream includes at least two exposures per pixel of a plurality of pixels of the image sensor. In one embodiment, the pixel stream may be received directly from the image sensor. In another embodiment, the pixel stream may be received from a controller, where the controller first receives the pixel stream from an image sensor. In yet another embodiment, the pixel stream may be received from a camera module, or any other hardware component, which may first receive the pixel stream generated by an image sensor.

[0794] The pixel stream includes at least two exposures per pixel of a plurality of pixels of an image sensor. In one embodiment, the pixel stream includes a sequence of digital pixel data associated with the pixels of the image sensor. The sequence of digital pixel data may include, for each of the pixels, values representative of pixel attributes, such as brightness, intensity, color, etc.

Each exposure of a given pixel may be associated with a different value for a given attribute, such as brightness, such that each of the exposures may include a unique attribute value. For example, in one embodiment, pixel data for a first exposure of a given pixel may include a first attribute value, pixel data for a third exposure of the pixel may include a third attribute value different than the first value, and pixel data for a second exposure of the pixel may include a second value between the first value and the third value. In one embodiment, each value may include a brightness value.

[0795] Further, the pixel stream may include at least two units of digital pixel data for each pixel, where each unit of digital pixel data is associated with a different exposure. Still further, a first unit of the digital pixel data for a pixel may be associated with a first set of digital pixel data, and a second unit of the digital pixel data for the pixel may be associated with a second set of digital pixel data. In such an embodiment, each set of digital pixel data may be associated with at least a portion of a digital image. For example, a first set of digital pixel data may be associated with a first digital image, and a second set of digital pixel data may be associated with a second digital image.

[0796] In on embodiment, each set of digital pixel data may be representative of an optical image of a photographic scene focused on an image sensor. For example, a first set of digital pixel data in the pixel stream may be representative of a first exposure of an optical image focused on an image sensor, and a second set of digital pixel data in the pixel stream may be representative of a second exposure of the optical image focused on the image sensor.

[0797] To this end, a pixel stream may include two sets of digital pixel data, where each set includes a corresponding unit of digital pixel data for a given pixel of an image sensor at a different exposure, such that the pixel stream includes digital pixel data for two different exposures of a same photographic scene image.

[0798] In one embodiment, the pixel stream may include a first set of digital pixel data interleaved with a second set of digital pixel data. For example, the pixel stream may include first digital pixel data for a first line of pixels, then second digital pixel data for the first line of pixels, then first digital pixel data for a second line of pixels, and then second digital pixel data for the second line of pixels, and so on. Of course, the pixel stream may include two or more sets of digital pixel data interleaved in any fashion. Still yet, the pixel stream may comprise two or more sets of digital pixel data organized in a non-interleaved fashion.

[0799] In one embodiment, the at least two exposures may be of the same photographic scene. For example, the at least two exposures may include a brighter exposure and a darker exposure of the same photographic scene. As another example, the at least two exposures may include each of the brighter exposure, the darker exposure, and a median exposure of the same photographic scene. The median exposure may be brighter than the darker exposure, but darker than the brighter exposure. In one embodiment, a brightness of an exposure may be controlled utilizing one or more exposure times. In another embodiment, a brightness of an exposure may be controlled utilizing one or more gains or one or more ISO values. Of course, a brightness of each exposure may be controlled utilizing any technically feasible technique.

[0800] In one embodiment, the image sensor may include a plurality of pixels arranged in a two-dimensional grid or array. Further, each of the pixels may include one or more cells, where each cell includes one or more photodiodes. Under the control of one or more control signals, each cell of the image sensor may measure or sample an amount of incident light focused on the photodiode of the cell, and store an analog value representative of the incident light sampled. In one embodiment, the analog values stored in the one or more cells of a pixel may be output in an analog signal, and the analog signal may then be amplified and/or converted to two or more digital signals, where each digital signal may be associated with a different effective exposure. An analog signal may be a set of spatially discrete intensity samples, each represented by continuous analog values. Analog pixel data may be analog signal values associated with one or more given pixels.

[0801] In another embodiment, each cell of a pixel may store two or more analog values, where

each of the analog values is obtained by sampling an exposure of incident light for a different sample time. The analog values stored in the one or more cells of a pixel may be output in two or more analog signals, and the analog signals may then be amplified and/or converted to two or more digital signals, where each digital signal may be associated with a different effective exposure.
[0802] To this end, the one or more digital signals may comprise a pixel stream including at least two exposures per pixel from a plurality of pixels of an image sensor.
[0803] Further, at operation **23-104**, a high dynamic range (HDR) pixel stream is generated by performing HDR blending on the received pixel stream. In one embodiment, the HDR blending of the received pixel stream may generate a HDR pixel for each pixel of the plurality of pixels of the image sensor, and the HDR pixel may be based on the at least two exposures from the pixel. For example, a HDR blending operation may receive as input the at least two exposures of a pixel of the image sensor, and then blend the at least two exposures of the pixel to generate a HDR pixel. In a specific embodiment, the blending of the at least two exposures of the pixel may include a mix operation. In one embodiment, a generated HDR pixel for a given pixel may be output in a HDR pixel stream, and the HDR pixel stream also includes HDR pixels generated based on exposures received from neighboring pixels of the given pixel. Each HDR pixel may be based on at least two exposures received from an image sensor.
[0804] Finally, at operation **23-106**, the HDR pixel stream is outputted. In one embodiment, the HDR pixel stream may be outputted as a sequence of individual HDR pixels. In another embodiment, the HDR pixel stream may be output to an application processor, which may then control storage and/or display of the HDR pixel stream. In yet another embodiment, the HDR pixel stream may be stored in associated with the pixel stream utilized to generate the HDR pixel stream. Storing the pixel stream in association with the HDR pixel stream may facilitate later retrieval of the pixel stream.
[0805] FIG. **23-2** illustrates a system **23-200** for generating a HDR pixel stream, in accordance with one embodiment. As an option, the system **23-200** may be implemented in the context of any of the Figures. Of course, however, the system **23-200** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0806] As shown in FIG. **23-2**, the system **23-200** includes a high dynamic range (HDR) blending circuitry **23-206** receiving a pixel stream **23-204** from an image sensor **23-202**. Still further, the HDR blending circuitry **23-206** is shown to output a HDR pixel stream **23-208**.
[0807] In one embodiment, the image sensor **23-202** may comprise a complementary metal oxide semiconductor (CMOS) image sensor, or charge-coupled device (CCD) image sensor, or any other technically feasible form of image sensor. In another embodiment, the image sensor **23-202** may include a plurality of pixels arranged in a two-dimensional array or plane on a surface of the image sensor **23-202**.
[0808] In another embodiment, an optical image focused on the image sensor **23-202** may result in a plurality of analog values being stored and output as an analog signal that includes at least one analog value for each pixel of the image sensor. The analog signal may be amplified to generate two or more amplified analog signals utilizing two or more gains. In such an embodiment, a digital signal may then be generated based on each amplified analog signal, such that two or more digital signals are generated. In various embodiments, the two or more digital signals may comprise the pixel stream **23-204**.
[0809] In yet another embodiment, a first set of analog values may be output as a first analog signal that includes at least one analog value for each pixel of the image sensor, and a second set of analog values may be output as a second analog signal that includes at least one analog value for each pixel of the image sensor. In such an embodiment, each analog signal may subsequently be processed and converted to one or more digital signals, such that two or more digital signals are generated. In various embodiments, the two or more digital signals may comprise the pixel stream **23-204**.

[0810] Accordingly, in one embodiment, the pixel stream **23-204** generated by the image sensor **23-202** may include at least two electronic representations of an optical image that has been focused on the image sensor **23-202**. Further, each electronic representation of the optical image may include digital pixel data generated utilizing one or more analog signals.
[0811] In one embodiment, the HDR blending circuitry **23-206** may include any hardware component or circuitry operable to receive a pixel stream and generate a HDR pixel stream based on the content of the received pixel stream. As noted above, the pixel stream may include multiple instances of digital pixel data. For example, the pixel stream may include first digital pixel data from a first exposure of a photographic scene and second digital pixel data from a second exposure of the photographic scene. The first exposure and the second exposure may vary based on exposure or sample timing, gain application or amplification, or any other exposure parameter that may result in a first exposure of a photographic scene and a second exposure of the photographic scene that is different than the first exposure.
[0812] Additionally, the HDR blending circuitry **23-206** may perform any blending operation on the pixel stream **23-204** that is operative to generate HDR pixel stream **23-208**. In one embodiment, a blending operation of the HDR blending circuitry **23-206** may include blending two exposures received from a pixel of the image sensor **23-202**. In another embodiment, a blending operation of the HDR blending circuitry **23-206** may include blending three or more exposures received from a pixel of the image sensor **23-202**. For example, the HDR blending circuitry **23-206** may perform a blending of the exposures received in the pixel stream.
[0813] Finally, HDR pixel stream **23-208** is output from the HDR blending circuitry **23-206**. In one embodiment, the HDR pixel stream **23-208** output from the HDR blending circuitry **23-206** may include any stream comprising one or more HDR pixels of one or more HDR images. For example, the HDR pixel stream **23-208** may include HDR pixels of a portion of a HDR image, an entirety of a HDR image, or more than one HDR image, such as multiple frames of a HDR video.
[0814] M ore illustrative information will now be set forth regarding various optional architectures and uses in which the foregoing method may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.
[0815] FIG. **23-3** illustrates a system **23-500** for receiving a pixel stream and outputting an HDR pixel stream, in accordance with an embodiment. As an option, the system **23-500** may be implemented in the context of any of the Figures. Of course, however, the system **23-500** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0816] As shown, the system **23-500** includes a blending circuitry **23-501** receiving a pixel stream **23-520**, and outputting at least one instance of a HDR pixel data **23-545** to an application processor **335**. The blending circuitry **23-501** is shown to include a buffer **23-531** and a HDR pixel generator **23-541**. In one embodiment, the pixel stream **23-520** may be received from an image sensor, such as the image sensor **332** of FIG. **3**G. For example, the pixel stream **23-520** may be received from an interface of the image sensor **332**. In another embodiment, the pixel stream **23-520** may be received from a controller, such as the controller **333** of FIG. **3**G. For example, the pixel stream **23-520** may be received from an interface of the controller **333**. The application processor **335** of FIG. **23-3** may be substantially identical to the application processor **335** of FIG. **3**G. Accordingly, the blending circuitry **23-501** may be operative to intercept a signal comprising the pixel data **23-520** as the pixel data **23-520** is being transmitted from an image sensor to the application processor **335**.
[0817] As illustrated in FIG. **23-3**, the pixel stream **23-520** is shown to include digital pixel data units **23-521-526**. Each of the digital pixel data units **23-521-23-526** may comprise digital pixel data for one or more pixels of an image sensor. In one embodiment, each of the digital pixel data units **23-521-23-526** may include digital pixel data representative of light measured or sampled at a

single pixel of an image sensor. In another embodiment, each of the digital pixel data units **23-521-23-526** may comprise digital pixel data for more than one pixel of an image sensor, such as for a line of pixels of an image sensor. In yet another embodiment, each of the digital pixel data units **23-521-23-526** may comprise digital pixel data for a frame of pixels of an image sensor.

[0818] In the various embodiments, the digital pixel data units **23-521-23-526** may be interleaved by pixel, line, or frame from of the image sensor. For example, in one embodiment, the pixel stream **23-520** may be output such that it includes digital pixel data for multiple pixels in a sequence at a first exposure, and then includes digital pixel data for the multiple pixels in the sequence at a second exposure. The multiple pixels in the sequence may comprise at least a portion of a line of pixels of an image sensor. In another embodiment, the pixel stream **23-520** may be output such that it includes digital pixel data comprising a sequence of different exposures of a single pixel, and then a sequence of different exposures of another single pixel.

[0819] As an example, in an embodiment where the pixel stream **23-520** includes two exposures per pixel of a plurality of pixels of an image sensor, a digital pixel data unit **23-521** may include first digital pixel data for a first pixel of the image sensor, a digital pixel data unit **23-522** may include second digital pixel data for the first pixel of the image sensor, a digital pixel data unit **23-523** may include first digital pixel data for a second pixel of the image sensor, a digital pixel data unit **23-524** may include second digital pixel data for the second pixel of the image sensor, a digital pixel data unit **23-525** may include first digital pixel data for a third pixel of the image sensor, and a digital pixel data unit **23-526** may include second digital pixel data for the third pixel of the image sensor. In such an example, each set of digital pixel data may be associated with a different exposure, such that each first digital pixel data is associated with a first exposure, and each second digital pixel data is associated with a second exposure different than the first exposure.

[0820] As another example, in an embodiment where the pixel stream **23-520** includes three exposures per pixel of a plurality of pixels of an image sensor, a digital pixel data unit **23-521** may include first digital pixel data for a first pixel of the image sensor, a digital pixel data unit **23-522** may include second digital pixel data for the first pixel of the image sensor, a digital pixel data unit **23-523** may include third digital pixel data for the first pixel of the image sensor, a digital pixel data unit **23-524** may include first digital pixel data for a second pixel of the image sensor, a digital pixel data unit **23-525** may include second digital pixel data for second pixel of the image sensor, and a digital pixel data unit **23-526** may include third digital pixel data for the second pixel of the image sensor. In such an example, each set of digital pixel data may be associated with a different exposure, such that each first digital pixel data is associated with a first exposure, each second digital pixel data is associated with a second exposure different than the first exposure, and each third digital pixel data is associated with a third exposure different than the first exposure and the second exposure.

[0821] As yet another example, in an embodiment where the pixel stream **23-520** includes two exposures per pixel of a plurality of pixels of an image sensor, and the pixel stream **23-520** is interleaved by groups of pixels, a digital pixel data unit **23-521** may include first digital pixel data for a first plurality of pixels of the image sensor, a digital pixel data unit **23-522** may include second digital pixel data for the first plurality of pixels of the image sensor, a digital pixel data unit **23-523** may include first digital pixel data for a second plurality of pixels of the image sensor, a digital pixel data unit **23-524** may include second digital pixel data for the second plurality of pixels of the image sensor, a digital pixel data unit **23-525** may include first digital pixel data for a third plurality of pixels of the image sensor, and a digital pixel data unit **23-526** may include second digital pixel data for the third plurality of pixels of the image sensor. In such an example, each plurality of pixels may include a line of pixels, such that the first plurality of pixels comprise a first line of pixels, the second plurality of pixels comprises a second line of pixels, and the third plurality of pixels comprises a third line of pixels. Further, each set of digital pixel data may be associated with a different exposure, such that each first digital pixel data is associated with a first exposure, and each second digital pixel data is associated with a second exposure different than the first exposure.

[0822] As still another example, in an embodiment where the pixel stream **23-520** includes three exposures per pixel of a plurality of pixels of an image sensor, and the pixel stream **23-520** is interleaved by groups of pixels, a digital pixel data unit **23-521** may include first digital pixel data for a first plurality of pixels of the image sensor, a digital pixel data unit **23-522** may include second digital pixel data for the first plurality of pixels of the image sensor, a digital pixel data unit **23-523** may include third digital pixel data for the first plurality of pixels of the image sensor, a digital pixel data unit **23-524** may include first digital pixel data for a second plurality of pixels of the image sensor, a digital pixel data unit **23-525** may include second digital pixel data for the second plurality of pixels of the image sensor, and digital pixel data unit **23-526** may include third digital pixel data for the second plurality of pixels of the image sensor. In such an example, each plurality of pixels may include a line of pixels, such that the first plurality of pixels comprises a first line of pixels, and the second plurality of pixels comprises a second line of pixels. Further, each set of digital pixel data may be associated with a different exposure, such that each first digital pixel data is associated with a first exposure, each second digital pixel data is associated with a second exposure different than the first exposure, and each third digital pixel data is associated with a third exposure different than the first exposure and the second exposure.

[0823] As shown in FIG. **23-3**, the buffer **23-531** of the blending circuitry **23-501** is operative to receive the pixel stream **23-520**. In one embodiment, the buffer **23-531** is operative to de-interleave the pixel stream. In another embodiment, the buffer **23-531** may be operative to identify each exposure of a particular pixel of the image sensor. For example, for a given pixel of a plurality of pixels of an image sensor, the buffer **23-531** may identify at least two different exposures of the pixel. More specifically, the buffer **23-531** may identify a first exposure of the pixel from a first unit of digital pixel data, and identify a second exposure of the pixel from a second unit of digital pixel data. Similarly, in embodiments including three exposures per pixel, the buffer **23-531** may identify a first exposure of the pixel from a first unit of digital pixel data, identify a second exposure of the pixel from a second unit of digital pixel data, and identify a third exposure of the pixel from a third unit of digital pixel data. To this end, the buffer may identify at least two exposures of a single pixel of a pixel array of an image sensor.

[0824] In an embodiment in which lines are interleaved in the pixel stream **23-520**, the buffer **23-531** may receive two or more digital pixel data units of a same line, where each digital pixel data unit is associated with a different exposure of the line. Further, the buffer **23-531** may then identify and select pixel data at each exposure for a given pixel in the line. In such an embodiment, pixel data that is not associated with the given pixel may be temporarily stored. Further, pixel data that is temporarily stored may be utilized for identifying and selecting pixel data at each of the exposures for another given pixel in the line. This process of pixel data storage and pixel data retrieval may repeat for each pixel in the line.

[0825] As used herein, pixel data for a pixel may describe a set of components of a color space, such as red, green, and blue in RGB color space; or cyan, magenta, yellow, and black, in CMYK color space. Further, an intensity of each of the color components may be variable, and may be described using one or more values for each component. Thus, in one embodiment, pixel data for a given exposure of a pixel may include the one or more values for the color components of the pixel at the given exposure. Further, the one or more values for the color components of a pixel may be utilized to calculate various attributes of the pixel in addition to color, such as, for example, saturation, brightness, hue, luminance, etc.

[0826] After identifying at least two exposures of a given pixel, the buffer **23-531** may then output first exposure pixel data **23-533** for the given pixel, second exposure pixel data **23-535** for the given pixel, and third exposure pixel data **23-537** for the given pixel. As shown in FIG. **23-3**, each of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537** are output from the buffer **23-531** to the HDR pixel generator **23-541**. Of course, in other embodiments, a buffer **23-531** may output, to a HDR pixel generator **23-541**, pixel data for only two exposures of the pixel, or for more than three exposures of the pixel.

[0827] The buffer **23-531** may be operative to identify pixel data of the two or more exposures of a given pixel in a line while saving received digital pixel data for remaining pixels of the line, as well as other lines, for subsequent processing. For example, if the buffer **23-531** receives first pixel data for a given line, second pixel data for the given line, and third pixel data for the given line, where each of the units of pixel data corresponds to a different exposure of the given line, the buffer **23-531** may be operative to identify a portion of pixel data associated with a first pixel in each of the received pixel data units. For example, the buffer **23-531** may identify a first exposure of the pixel, a second exposure of the pixel, and a third exposure of the pixel. Further, the buffer **23-531** may be operative to store unselected pixel data received in each unit of pixel data, and subsequently identify pixel data associated with a second pixel in each of the received pixel data units. For example, the buffer **23-531** may identify a first exposure of a second pixel adjacent to the first pixel, a second exposure of the second pixel, and a third exposure of the second pixel. To this end, the buffer **23-531** may be operative to identify each exposure of a plurality of exposures of each of the pixels of a line.

[0828] Referring again to FIG. **23-3**, the buffer **23-531** is shown to output each of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537** to the HDR pixel generator **23-541**. As noted above, each of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537** may comprise pixel data for different exposures of the same pixel.

[0829] In one embodiment, each exposure of a pixel may be characterized as having an exposure value (EV). In such an embodiment, an exposure of the pixel may be characterized as being obtained at exposure value 0 (EV 0), wherein the EV 0 exposure is characterized as being captured utilizing a first collection of capture parameters. Such capture parameters may include ISO or light sensitivity, aperture, shutter speed or sampling time, or any other parameter associated with image capture that may be controlled or modulated. The pixel characterized as captured at EV 0 may be captured using a particular combination of capture parameters, such as a particular ISO and a particular shutter speed.

[0830] Further, an exposure of another capture or sample of the pixel may be selected based on the capture parameters of the EV 0 pixel. More specifically, the other capture or sample of the pixel may be selected to have an increased or decreased exposure in comparison to the exposure of the EV 0 pixel. For example, an ISO capture parameter of the other sample of the pixel may be selected such that the exposure is increased or decreased with respect to the exposure of the EV 0 pixel. Still yet, an exposure time capture parameter of the other sample of the pixel may be selected such that the exposure time is increased or decreased with respect to the exposure time of the EV 0 pixel. As a specific example, the other sample of the pixel may be captured at an increased exposure when it is captured using a faster ISO and the same exposure time, or using a greater exposure time at the same ISO, with respect to the EV 0 pixel. In such an embodiment, the other capture or exposure of the pixel may be referred to as an EV +exposure, or an EV + pixel. Similarly, the other sample of the pixel may be captured at a decreased exposure when it is captured using a slower ISO and the same exposure time, or using a reduced exposure time at the same ISO, with respect to the EV 0 pixel. In such an embodiment, the other capture or exposure of the pixel may be referred to as an EV − exposure, or an EV-pixel.

[0831] In some embodiments, different exposures of a given pixel may be controlled based on an ISO value associated with the pixel during or following a capture operation, where the ISO value may be mapped to one or more gains that may be applied to an analog signal output from an image sensor during the capture operation.

[0832] In yet other embodiments, different exposures of a given pixel may be obtained by controlling exposure times for two or more sampling operations that occur simultaneously or concurrently at the pixel.

[0833] In some embodiments, a first exposure pixel data **23-533** may include pixel data for an EV − exposure of a given pixel, a second exposure pixel data **23-535** may include pixel data for an EV 0 exposure of the pixel, and a third exposure pixel data **23-537** may include pixel data for an EV +exposure of the pixel. Of course, any of the pixel data **23-533-537** may include pixel data for any exposure of the pixel. To this end, pixel data for three different exposures of a same pixel are shown provided by the buffer **23-531** to the HDR pixel generator **23-541** in FIG. **23-3**.

[0834] In other embodiments, an HDR pixel generator **23-541** may receive a different number of exposures of a given pixel. For example, in one embodiment, the HDR pixel generator **23-541** may receive pixel data for two exposures of a given pixel. As options, in such an embodiment, the HDR pixel generator **23-541** may receive data for an EV-exposure and an EV 0 exposure of a given pixel, or an EV 0 exposure and an EV +exposure of a given pixel.

[0835] After receiving each of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537**, the HDR pixel generator **23-541** may then perform a blend operation on the three instances of pixel data and output HDR pixel data **23-545**. As noted previously, in one embodiment the blend operation performed to generate the HDR pixel data **23-545** may be any of the blend operations.

[0836] To this end, the HDR pixel generator **23-541** may be operative to generate HDR pixel data **23-545** for an HDR pixel utilizing only pixel data from multiple exposures of a given pixel of an image sensor. Thus, the HDR pixel generator **23-541** does not require pixel data of additional pixels of the image sensor that neighbor the given pixel, and may perform an operation utilizing only two or more exposures of a single pixel. Further, because each of the two or more exposures of a given pixel may be generated in a manner with zero, or near zero, interframe time, the two or more exposures of the pixel may be used to generate the HDR pixel without performing an alignment step. In other words, pixel stream **23-520** may inherently include pre-aligned pixel data, which may be used by the blending circuitry **23-501** to generate HDR pixels.

[0837] To this end, using relatively low-power resources, a stream of HDR pixels may be rapidly generated and output based on an input stream of pixel data. For example, the stream of HDR pixels may be generated as the stream of pixel data is in transit from an image sensor. Further, the stream of HDR pixels may be generated without use of a graphics processing unit (GPU), which may allow for disabling at least a portion of the GPU, or for use of the GPU to perform other processing tasks. Such processing tasks may include performing dehazing operations or contrast enhancement on the HDR pixel stream.

[0838] Still further, in addition to outputting the HDR pixel data **23-545**, the blending circuitry **23-501** may also output a first received pixel data **23-543** and a second received pixel data **23-547**. In one embodiment, the first received pixel data **23-543** may comprise one of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537**. In such an embodiment, the second received pixel data **23-547** may comprise another one of the first exposure pixel data **23-533**, the second exposure pixel data **23-535**, and the third exposure pixel data **23-537**.

[0839] For example, the first received pixel data **23-543** may comprise the first exposure pixel data **23-533**, and the second received pixel data **23-547** may comprise the third exposure pixel data **23-537**. As noted previously, the first exposure pixel data **23-533** may include pixel data for an EV − exposure of a given pixel, and the third exposure pixel data **23-537** may include pixel data for an EV +exposure of the given pixel. Thus, in such an example, the first received pixel data **23-543** may include pixel data for the EV − exposure of the given pixel, and the second received pixel data **23-547** may include pixel data for the EV +exposure of the given pixel. To this end, in addition to outputting the HDR pixel data **23-545**, the blending circuitry **23-501** may also output various instances of the pixel data utilized to generate the HDR pixel data **23-545**. For example, the blending circuitry **23-501** may output for a pixel each of an EV +exposure of the pixel, an EV − exposure of the pixel, and an HDR pixel.

[0840] Of course, in other embodiments, the blending circuitry **23-501** may output an EV0 exposure of a pixel as either the first received pixel data **23-543** or the second received pixel data **23-547**, such that the EV 0 exposure of a pixel is output with the HDR pixel for subsequent processing and/or storage. In one embodiment, any output exposures of the pixel may be stored with the HDR pixel in flash storage. In some embodiments, it may be useful to retain one or more exposures of the pixel that were used to generate the HDR pixel. For example, the one or more exposures of the pixel used to generate the HDR pixel may be used in subsequent HDR processing, for generating a non-HDR image, or in any other technically feasible manner.

[0841] Still further, after outputting the HDR pixel data **23-545**, which was generated utilizing pixel data for multiple exposures of a first pixel, the blending circuit **23-501** may output second HDR pixel data for a second HDR pixel. The second HDR pixel data may be generated by the HDR pixel generator **23-541** utilizing pixel data for multiple exposures of a second pixel. The second pixel may be a neighboring pixel of the first pixel. For example, the second pixel may be adjacent to the first pixel in a row or line of pixels of an image sensor. Still further, after outputting the second HDR pixel data, the blending circuit **23-501** may output a third HDR pixel. The third HDR pixel may be generated by the HDR pixel generator **23-541** utilizing pixel data for multiple exposures of a third pixel. The third pixel may be a neighboring pixel of the second pixel. For example, the third pixel may be adjacent to the second pixel in the row or line of pixels of the image sensor. Still further, along with each of the second HDR pixel and the third HDR pixel, the blending circuit **23-501** may also output received pixel data utilized to generate, respectively, the second HDR pixel and the third HDR pixel.

[0842] The blending circuitry **23-501** may be operative to output a stream of pixel data for HDR pixels of an HDR image, where each of the HDR pixels is generated based on a respective pixel of an image sensor. Further still, with each output HDR pixel, the pixel data from corresponding the two or more exposures of the pixel may also be output. Thus, an HDR pixel may be output with the pixel data utilized to generate the HDR pixel.

[0843] Additionally, because the blending circuitry **23-501** may be operative to continuously process the pixel data of the pixel stream **23-520** as the pixel stream **23-520** is received, the pixel stream **23-520** may be received from an image sensor that is capturing and transmitting pixel data at a rate of multiple frames per second. In such an embodiment, digital pixel data units **23-521-23-526** may include pixel data for pixels or lines of a frame of video output by an image sensor. To this end, the blending circuitry **23-501** may be operative to receive pixels for a frame of video at two or more exposures, and generate HDR pixels for the frame of video utilizing the received pixels. Further, the blending circuitry **23-501** may be operative to receive pixels for the frame of video at the two or more exposures and generate HDR pixels for the frame as additional digital pixel data is received in the pixel stream **23-520** for one or more other frames of the video. In one embodiment, one or more pixels of a second frame of video may be buffered by a buffer **23-531** as a HDR pixel generator **23-541** outputs HDR pixels for a first frame of the video.

[0844] As shown in FIG. **23-3**, the blending circuitry **23-501** may be a discrete component that exists along one or more electrical interconnects between an image sensor and an application processor **335**. In one embodiment, the pixel stream **23-520** may be received by the blending circuit **23-501** on a single electrical interconnect. In other embodiments, the pixel stream **23-520** may be received by the blending circuitry **23-501** along two or more electrical interconnects. Such an implementation may allow for concurrent receipt of multiple instances of pixel data at the blending circuitry **23-501**. In one embodiment, a first received pixel data **23-543**, a second received pixel data **23-547**, and a HDR pixel data **23-545** may be output to an application processor **335** along a single electrical interconnect. In other embodiments, a first received pixel data **23-543**, a second received pixel data **23-547**, and a HDR pixel data **23-545** may be output to an application processor

335 along two or more electrical interconnects. Such an implementation may allow for concurrent receipt of multiple instances of pixel data at the application processor **335**.

[0845] To this end, the blending circuitry **23-501** may be operative to receive pixels for a frame of video at two or more exposures, and generate HDR pixels for the frame of video utilizing the received pixels. Further, the blending circuitry **23-501** may be operative to receive pixels for the frame of video at the two or more exposures and generate HDR pixels for the frame as additional digital pixel data is received in the pixel stream **23-520** for one or more other frames of the video.

[0846] As noted above, blending circuitry **23-501** may be operative to continuously process pixel data of a pixel stream **23-520** as the pixel stream **23-520** is received, such that a stream of HDR pixels is output from the blending circuitry **23-501**. In such an embodiment, first received pixel data **23-543** may be included in a stream of pixel data associated with a first exposure, and second received pixel data **23-547** may be included in a stream of pixel data associated with a second exposure. Thus, in one embodiment, in addition to outputting a stream of HDR pixels, the blending circuitry **23-501** may also output at least one stream of pixel data utilized to generate the HDR pixels. For example, the blending circuitry may output a stream of EV 0 pixel data utilized to generate the HDR pixels, a stream of EV-pixel data utilized to generate the HDR pixels, and/or a stream of EV + pixel data utilized to generate the HDR pixels.

[0847] In one embodiment, sets of pixel data may be saved separately. For example, a stream of EV 0 pixel data may be used to generate a stream of HDR pixels at the blending circuitry **23-501**, and then the stream of EV 0 pixels may stored separately from the stream of HDR pixels. Similarly, a stream of EV − or EV + pixels may be stored separately from the HDR pixels. To this end, a stored stream of HDR pixels may comprise a HDR video, a stored stream of EV 0 pixels may comprise the same video captured at EV 0, and a stored stream of EV + or EV-pixels may comprise the same video captured at EV + or EV −, respectively.

[0848] In another embodiment, an application processor **335** may generate a residue image utilizing two or more received pixel streams. For example, the application processor **335** may receive a stream of HDR pixels from the blending circuitry **23-501**, as well as one or more streams of received pixel data from the blending circuitry **23-501**. Each of the one or more streams of received pixel data may include an EV 0, EV +, or EV − pixel stream. The application processor **335** may be operative to perform a compare operation that compares the received stream of HDR pixels with one or more of the EV 0, EV +, or EV − pixel stream to generate the residue image. For example, the application processor **335** may compare a given pixel within the HDR pixel stream with the given pixel within the EV 0 pixel stream to generate a difference or scaling value, and then store the difference or scaling value. The application processor **335** may generate a plurality of difference values or scaling values for a plurality of corresponding pixels between the HDR pixel stream and the EV 0 pixel stream. The plurality of difference values or scaling values may then be stored as a residue image. Of course, comparing any of the EV +, EV0, and EV − pixel streams with the HDR pixel stream may work equally well to generate difference values or scaling values.

[0849] Further, one or more generated residue images may then be stored in association with the HDR pixel stream. In such an embodiment, one or more of the EV0, EV −, or EV + pixel streams may be discarded. Storing residue images in lieu of the one or more discarded EV 0, EV −, or EV + pixel streams may utilize less storage space. For example, a discarded EV − pixel stream may be subsequently reconstructed utilizing an associated HDR pixel stream, an associated EV 0 pixel stream, and/or an associated EV + pixel stream in conjunction with residue images previously generated utilizing the discarded EV − pixel stream. In such an embodiment, storage of the residue images may require substantially less storage capacity than storage of the EV − pixel stream.

[0850] In another embodiment, blending circuitry may be included in an application processor **335**. In certain embodiments, blending circuitry includes histogram accumulation circuitry for implementing level mapping, such as contrast-limited adaptive histogram equalization (CLAHE). In such embodiments, the accumulation circuitry generates a cumulative distribution function

(CDF) operative to perform localized level mapping. To this end, localized contrast enhancement may be implemented, for example by the either the blending circuitry or the application processor **335** based on the CDF.

[0851] In one embodiment, the non-linear mix function **23-530** may be performed by the blending circuitry **23-501** of FIG. **23-5**. For example, the non-linear mix function **23-530** may be performed by an HDR pixel generator **23-501** of FIG. **23-5**. In one embodiment, the HDR pixel generator **23-501** may be configured to receive two pixels, identify an attribute of each of the two pixels, select a scalar or mix value based on the attributes of the two pixels, and then perform a mix function on the two pixels using the selected scalar or mix value, where performing the mix function on the two pixels using the selected scalar or mix value generates a HDR pixel. The HDR pixel may then be output in an HDR pixel stream.

[0852] As described in the context of FIG. **5**, pixel data for one or more exposures from a given pixel may be referred to as a "pixel." For example, pixel data from a first exposure of a pixel may be referred to as a first pixel, pixel data from a second exposure of the pixel may be referred to as a second pixel, and pixel data from a third exposure of the pixel may be referred to as a third pixel. Further, each of the pixel data from the first exposure, the second exposure, and the third exposure may be referred to as a brighter pixel or bright exposure pixel, medium pixel or medium exposure pixel, or darker pixel or dark exposure pixel in comparison to other pixel data sampled from the same pixel of an image sensor. For example, pixel data captured at an EV 0 exposure may be referred to as a medium exposure pixel, pixel data captured at an EV − exposure may be referred to as a darker exposure pixel, and pixel data captured at an EV + exposure may be referred to as a brighter exposure pixel. As an option, an EV 0 exposure may be referred to as a brighter pixel or a darker pixel, depending on other exposures of the same pixel. Accordingly, it should be understood that in the context of FIG. **5**, any blending or mixing operation of two or more pixels refers to a blending or mixing operation of pixel data obtained from a single pixel of an image sensor sampled at two or more exposures.

[0853] As described in the context of FIGS. **6-7**, pixel data for one or more exposures from a given pixel may be referred to as a "pixel." For example, pixel data from a first exposure of a pixel may be referred to as a first pixel, pixel data from a second exposure of the pixel may be referred to as a second pixel, and pixel data from a third exposure of the pixel may be referred to as a third pixel. Further, each of the pixel data from the first exposure, the second exposure, and the third exposure may be referred to as a brighter pixel or bright exposure pixel, medium pixel or medium exposure pixel, or darker pixel or dark exposure pixel in comparison to other pixel data sampled from the same pixel of an image sensor. For example, pixel data captured at an EV 0 exposure may be referred to as a medium exposure pixel, pixel data captured at an EV − exposure may be referred to as a darker exposure pixel, and pixel data captured at an EV + exposure may be referred to as a brighter exposure pixel. As an option, an EV 0 exposure may be referred to as a brighter pixel or a darker pixel, depending on other exposures of the same pixel. Accordingly, it should be understood that in the context of FIGS. **6-7**, any blending or mixing operation of two or more pixels refers to a blending or mixing operation of pixel data obtained from a single pixel of an image sensor sampled at two or more exposures.

[0854] With respect to FIG. **7**, in one embodiment, the pixel blend operation **731** may be performed by the blending circuitry **23-501** of FIG. **23-5**. For example, the pixel blend operation **731** may be performed by an HDR pixel generator **23-501** of FIG. **235**. In one embodiment, the HDR pixel generator **501** may be configured to receive three pixels, identify an attribute of each of the three pixels, select mix values based on the attributes of the three pixels, perform mix functions using the selected mix values to obtain two resulting pixels, and then combine the resulting pixels to generate an HDR pixel. The HDR pixel may then be output in an HDR pixel stream.

[0855] As described in the context of FIGS. **10**A-**10**B, pixel data for one or more exposures from a given pixel may be referred to as a "pixel." For example, pixel data from a first exposure of a pixel may be referred to as a first pixel, pixel data from a second exposure of the pixel may be referred to as a second pixel, and pixel data from a third exposure of the pixel may be referred to as a third pixel. Further, each of the pixel data from the first exposure, the second exposure, and the third exposure may be referred to as a brighter pixel or bright exposure pixel, medium pixel or medium exposure pixel, or darker pixel or dark exposure pixel in comparison to other pixel data sampled from the same pixel of an image sensor. For example, pixel data captured at an EV 0 exposure may be referred to as a medium exposure pixel, pixel data captured at an EV − exposure may be referred to as a darker exposure pixel, and pixel data captured at an EV + exposure may be referred to as a brighter exposure pixel. As an option, an EV 0 exposure may be referred to as a brighter pixel or a darker pixel, depending on other exposures of the same pixel. Accordingly, it should be understood that in the context of FIG. **10**A-**10**B, any blending or mixing operation of two or more pixels refers to a blending or mixing operation of pixel data obtained from a single pixel of an image sensor sampled at two or more exposures.

[0856] In one embodiment, the pixel blend operation **1442** may be implemented within blending circuitry, such as blending circuitry **23-501** of FIG. **23-5**. For example, the synthetic image **1450** may comprise a plurality of HDR pixels of an HDR pixel stream, which is generated based on a received pixel stream including two or more exposures of an image. In other embodiments, at least two images of images **1410**, **1412**, **1414** are generated from two or more analog images that are captured or sampled simultaneously.

[0857] Still yet, in various embodiments, one or more of the techniques disclosed herein may be applied to a variety of markets and/or products. For example, although the techniques have been disclosed in reference to a still photo capture, they may be applied to televisions, video capture, web conferencing (or live streaming capabilities, etc.), security cameras (e.g. increase contrast to determine characteristic, etc.), automobiles (e.g. driver assist systems, in-car infotainment systems, etc.), and/or any other product which includes a camera input.

[0858] Embodiments of the present disclosure enable a digital photographic system to capture an image stack for a photographic scene. Exemplary digital photographic systems include, without limitation, digital cameras and mobile devices such as smart phones that are configured to include a digital camera module. A given photographic scene is a portion of an overall scene sampled by the digital photographic system. Two or more images are sampled by the digital photographic system to generate an image stack.

[0859] A given image stack comprises images of the photographic scene sampled with potentially different exposure, different strobe illumination, or a combination thereof. For example, each image within the image stack may be sampled according to a different exposure time, exposure sensitivity, or a combination thereof. A given image within the image stack may be sampled in conjunction with or without strobe illumination added to the photographic scene. Images comprising an image stack should be sampled over an appropriately short span of time to reduce visible differences or changes in scene content among the images. In one embodiment, images comprising a complete image stack are sampled within one second. In another embodiment, images comprising a complete image stack are sampled within a tenth of a second.

[0860] In one embodiment, two or more images are captured according to different exposure levels during overlapping time intervals, thereby reducing potential changes in scene content among the two or more images. In other embodiments, the two or more images are sampled sequentially under control of an image sensor circuit to reduce inter-image time. In certain embodiments, at least one image of the two or more images is sampled in conjunction with a strobe unit being enabled to illuminate a photographic scene. Image sampling may be controlled by the image sensor circuit to reduce inter-image time between an image sampled using only ambient illumination and an image sampled in conjunction with strobe illumination. The strobe unit may comprise a light-emitting diode (LED) configured to illuminate the photographic scene.

[0861] In one embodiment, each pixel of an image sensor comprises a set of photo-sensitive cells, each having specific color sensitivity. For example, a pixel may include a photo-sensitive cell configured to be sensitive to red light, a photo-sensitive cell configured to be sensitive to blue light, and two photo-sensitive cells configured to be sensitive to green light. Each photo-sensitive cell is configured to include two or more analog sampling circuits. A set of analog sampling circuits comprising one analog sampling circuit per photo-sensitive cell within the image sensor may be configured to sample and store a first image. Collectively, one set of analog sampling circuits forms a complete image plane and is referred to herein as an analog storage plane. A second set of substantially identically defined analog sampling circuits within the image sensor may be configured to sample and store a second image. A third set of substantially identically defined storage elements within the image sensor may be configured to sample and store a third image, and so forth. Hence an image sensor may be configured to sample and simultaneously store multiple images within analog storage planes.

[0862] Each analog sampling circuit may be independently coupled to a photodiode within the photo-sensitive cell, and independently read. In one embodiment, the first set of analog sampling circuits are coupled to corresponding photodiodes for a first time interval to sample a first image having a first corresponding exposure time. A second set of analog sampling circuits are coupled to the corresponding photodiodes for a second time interval to sample a second image having a second corresponding exposure time. In certain embodiments, the first time duration overlaps the second time duration, so that the first set of analog sampling circuits and the second set of analog sampling circuits are coupled to the photodiode concurrently during an overlap time. In one embodiment, the overlap time is within the first time duration. Current generated by the photodiode is split over the number of analog sampling circuits coupled to the photodiode at any given time. Consequently, exposure sensitivity varies as a function how many analog sampling circuits are coupled to the photodiode at any given time and how much capacitance is associated with each analog sampling circuit. Such variation needs to be accounted for in determining exposure time for each image.

[0863] FIG. **24-1**A illustrates a flow chart of a method **24-100** for generating an image stack comprising two or more images of a photographic scene, in accordance with one embodiment. Although method **24-100** is described in conjunction with the systems disclosed hereinabove, persons of ordinary skill in the art will understand that any system that performs method **24-100** is within the scope and spirit of embodiments of the present disclosure. In one embodiment, a digital photographic system, such as digital photographic system, is configured to perform method **24-100**. The digital photographic system may be implemented within a digital camera, such as digital camera or a mobile device. In certain embodiments, a camera module, such as camera module, is configured to perform method **24-100**. Method **24-100** may be performed with or without a strobe unit, such as strobe unit, enabled to contribute illumination to the photographic scene.

[0864] Method **24-100** begins in step **24-110**, where the camera module configures exposure parameters for an image stack to be sampled by the camera module. Configuring the exposure parameters may include, without limitation, writing registers within an image sensor comprising the camera module that specify exposure time for each participating analog storage plane, exposure sensitivity for one or more analog storage planes, or a combination thereof. Exposure parameters may be determined prior to this step according to any technically feasible technique, such as well-known techniques for estimating exposure based on measuring exposure associated with a sequence of test images sampled using different exposure parameters.

[0865] In step **24-112**, the camera module receives a capture command. The capture command directs the camera module to sample two or more images comprising the image stack. The capture command may result from a user pressing a shutter release button, such as a physical button or a user interface button. In step **24-114**, the camera module initializes a pixel array within the image sensor. In one embodiment, initializing the pixel array comprises driving voltages on internal nodes of photo-sensitive cells within one or more analog storage planes to a reference voltage, such as a supply voltage or a bias voltage. In step **24-116**, the camera module enables analog sampling circuits within two or more analog storage planes to simultaneously integrate (accumulate) an image corresponding to a photographic scene. In one embodiment, integrating an image comprises each analog sampling circuit within an analog storage plane integrating a current generated by a corresponding photodiode. In step **24-118**, analog sampling circuits within enabled analog storage planes integrate a respective image during a sampling interval. Each sampling interval may comprise a different time duration.

[0866] If, in step **24-120**, the camera module should sample another image, then the method proceeds to step **24-122**, where the camera module disables sampling for one analog storage plane within the image sensor. Upon disabling sampling for a given analog storage plane, an image associated with the analog storage plane has been sampled completely for an appropriate exposure time.

[0867] Returning to step **24-120**, if the camera module should not sample another image then the method terminates. The camera module should not sample another image after the last sampling interval has lapsed and sampling of the last image has been completed.

[0868] Reading an image from a corresponding analog storage plane may proceed using any technically feasible technique.

[0869] FIG. **24-1**B illustrates a flow chart of a method **24-102** for generating an image stack comprising an ambient image and a strobe image of a photographic scene, in accordance with one embodiment. Although method **24-102** is described in conjunction with the systems of FIGS. **2**A-**3**B, persons of ordinary skill in the art will understand that any system that performs method **24-102** is within the scope and spirit of embodiments of the present disclosure. In one embodiment, a digital photographic system, such as digital photographic system as disclosed herein, is configured to perform method **24-102**. The digital photographic system may be implemented within a digital camera, such as digital camera or a mobile device.

[0870] Method **24-102** begins in step **24-140**, where the camera module configures exposure parameters for an image stack to be sampled by the camera module. Configuring the exposure parameters may include, without limitation, writing registers within an image sensor comprising the camera module that specify exposure time for each participating analog storage plane, exposure sensitivity for one or more analog storage planes, or a combination thereof. Exposure parameters may be determined prior to this step according to any technically feasible technique, such as well-known techniques for estimating exposure based on measuring exposure associated with a sequence of test images sampled using different exposure parameters.

[0871] In step **24-142**, the camera module receives a capture command. The capture command directs the camera module to sample two or more images comprising the image stack. The capture command may result from a user pressing a shutter release button, such as a physical button or a user interface button. In step **24-144**, the camera module initializes a pixel array within the image sensor. In one embodiment, initializing the pixel array comprises driving voltages on internal nodes of photo-sensitive cells within one or more analog storage planes to a reference voltage, such as a supply voltage or a bias voltage.

[0872] In step **24-146**, the camera module samples one or more ambient images within corresponding analog storage planes. In one embodiment, step **24-146** implements steps **24-116** through **24-122** of method **24-100** of FIG. **24-1**A.

[0873] In step **24-150**, the camera module determines that a strobe unit, such as strobe unit as disclosed herein, is enabled. In one embodiment, determining that the strobe unit is enabled includes the camera module directly enabling the strobe unit, such by transmitting a strobe control command through strobe control signal as disclosed herein. In another embodiment, determining that the strobe unit is enabled includes the camera module detecting that the strobe unit has been enabled, such as by processor complex as disclosed herein.

[0874] In step **24-152**, the camera module samples one or more strobe images within corresponding analog storage planes. In one embodiment, step **24-152** implements steps **24-116** through **24-122** of method **24-100** of FIG. **24-1**A. In one embodiment, the camera module directly disables the strobe unit after completing step **24-152**, such as by transmitting a strobe control command through strobe control signal as disclosed herein. In another embodiment, processor complex as disclosed herein disables the strobe unit after the camera module completes step **24-152**.

[0875] In certain embodiments, the camera module is configured to store both ambient images and strobe images concurrently within analog storage planes. In other embodiments, the camera module offloads one or more ambient images prior to sampling a strobe image.

[0876] FIG. **24-2** illustrates a block diagram of image sensor as disclosed herein, according to one embodiment of the present disclosure. As shown, image sensor as disclosed herein comprises row logic **24-412**, a control (CTRL) unit **24-414**, a pixel array **24-410**, a column read out circuit **24-420**, an analog-to-digital unit **24-422**, and an input/output interface unit **24-426**. The image sensor as disclosed herein may also include a statistics unit **24-416**.

[0877] Pixel array **24-410** comprises a two-dimensional array of pixels **24-440** configured to sample focused optical image information and generate a corresponding electrical representation. Each pixel **24-440** samples intensity information for locally incident light and stores the intensity information within associated analog sampling circuits. In one embodiment, the intensity information comprises a color intensity value for each of a red, a green, and a blue color channel. Row logic **24-412** includes logic circuits configured to drive row signals associated with each row of pixels. The row signals may include, without limitation, a reset signal, a row select signal, and at least two independent sample control signals. One function of a row select signal is to enable switches associated with analog sampling circuits within a row of pixels to couple analog signal values (e.g., analog current values or analog voltage values) to a corresponding column output signal, which transmits the analog signal value to column read out circuit **24-420**. Column read out circuit **24-420** may be configured to multiplex the column output signals to a smaller number of column sample signals, which are transmitted to analog-to-digital unit **24-422**. Column read out circuit **24-420** may multiplex an arbitrary ratio of column output signals to column sample signals. Analog-to-digital unit **24-422** quantizes the column sample signals for transmission to interconnect as disclosed herein via input/output interface **24-426**.

[0878] In one embodiment, the analog signal values comprise analog currents, and the analog-to-digital unit **24-422** is configured to convert an analog current to a corresponding digital value. In other embodiments, column read out circuit **24-420** is configured to convert analog current values to corresponding analog voltage values (e.g. through a transimpedance amplifier or TIA), and the analog-to-digital unit **24-422** is configured to convert the analog voltage values to corresponding digital values. In certain embodiments, column read out circuit **24-420** implements an analog gain function, which may be configured according to a digital gain value.

[0879] In one embodiment, control unit **24-414** is configured to generate detailed timing control signals for coordinating operation of row logic **24-412**, column read out circuit **24-420**, analog-to-digital unit **24-422**, input output interface unit **24-426**, and statistics unit **24-416**.

[0880] In one embodiment, statistics unit **24-416** is configured to monitor pixel data generated by analog-to-digital unit **24-422** and, from the monitored pixel data, generate specified image statistics. The image statistics may include, without limitation, histogram arrays for individual pixel color channels for an image, a histogram array for intensity values derived from each pixel intensity value for an image, intensity sum values for each color channel taken over an image, a median intensity value for an image, an exposure value (EV) for an image, and the like. Image statistics may further include, without limitation, a pixel count for pixels meeting certain defined criteria, such as a pixel count for pixels brighter than a high threshold intensity, a pixel count for pixels darker than a low threshold intensity, a weighted pixel sum for pixels brighter than a high threshold intensity, a weighted pixel sum for pixels darker than a low threshold intensity, or any combination thereof. Image statistics may further include, without limitation, curve fitting parameters, such as least squares parameters, for linear fits, quadratic fits, non-quadratic polynomial fits, exponential fits, logarithmic fits, and the like.

[0881] Image statistics may further include, without limitation, one or more parameters computed from one or more specified subsets of pixel information sampled from pixel array **24-410**. One exemplary parameter defines a subset of pixels to be a two-dimensional contiguous region of pixels associated with a desired exposure point. Here, an exposure parameter may be computed, for example, as a median intensity value for the region, or as a count of pixels exceeding a threshold brightness for the region. For example, a rectangular region corresponding to an exposure point may be defined within an image associated with the pixel array, and a median intensity may be generated for the rectangular region, given certain exposure parameters such as exposure time and ISO sensitivity.

[0882] Image statistics may be accumulated and computed as digital samples become available from pixel array **24-410**. For example, image statistics may be accumulated as digital samples are generated by the analog-to-digital unit **24-422**. In certain embodiments, the samples may be accumulated during transmission through interconnect as disclosed herein. In one embodiment, the image statistics are mapped in a memory-mapped register space, which may be accessed through interconnect as disclosed herein. In other embodiments, the image statistics are transmitted in conjunction with transmitting pixel data for a captured image. For example, the image statistics for a given image may be transmitted as in-line data, following transmission of pixel intensity data for the image.

[0883] In one embodiment, image statistics are computed using a fixed-function logic circuit comprising statistics unit **24-416**. In other embodiments, image statistics are computed via a programmable processor comprising statistics unit **24-416**. In certain embodiments, programming instructions may be transmitted to the programmable processor via interconnect as disclosed herein.

[0884] In one embodiment, control unit **24-414** is configured to adjust exposure parameters for pixel array **24-410** based on images statistics for a previous image. In this way, image sensor as disclosed herein may advantageously determine proper exposure parameters per one or more specified exposure points without burdening processor resources within processor complex as disclosed herein, and without incurring concomitant latencies. The proper exposure parameters may be determined by sampling sequential images and adjusting the exposure parameters for each subsequent image based on exposure parameters for a corresponding previous image. The exposure parameters for a given captured image may be read by camera interface unit as disclosed herein and stored as metadata for the image.

[0885] In one embodiment, input/output interface unit **24-426** is configured to modify pixel intensity data associated with a captured frame based on certain image statistics. In one implementation, input/output interface unit **24-426** adjusts white balance of an image during transmission of image data through interconnect as disclosed herein. Red, green, and blue components of each pixel may be scaled based on previously computed image statistics. Such image statistics may include a sum of red, green, and blue components. With these sums, input/output interface unit **24-426** may be configured to perform a conventional gray world white balance correction. Alternatively, the image statistics may include quadratic curve fit parameters. With quadratic fit components, input/output interface unit **24-426** may be configured to perform a quadratic white balance mapping. Additional embodiments provide for illuminator identification via selecting for pixels above a lower threshold and below an upper threshold for consideration in determining white balance. Still further embodiments provide for color temperature identification by mapping selected samples to a color temperature snap-point. Mapping color temperature to a snap-point thereby applies an assumption that scene illumination is provided by an illuminator having a standard color temperature. In each example, image statistics may be optionally applied to adjust pixel information prior to transmission via interconnect as disclosed herein.

[0886] In an alternative embodiment, statistics unit **24-416**, as well as pixel modification functions discussed herein with respect to input/output interface unit **24-426** are instead implemented within sensor interface as disclosed herein, residing within processor complex as disclosed herein. In such an embodiment, power and heat dissipation associated with statistics unit **24-416** and related pixel modification functions is shifted away from pixel array **24-410**, which may incorporate circuitry that is sensitive to heat. In another alternative embodiment, statistics unit **24-416**, as well as pixel modification functions discussed herein with respect to input/output interface unit **24-426** are instead implemented within a separate die disposed within camera module as disclosed herein. In such an embodiment, related power and heat dissipation is also shifted away from pixel array **24-410**. In this embodiment, camera module as disclosed herein is configured to offer statistics and pixel modification functions in conjunction with a conventional processor complex as disclosed herein, which may be configured to include a conventional sensor interface.
[0887] FIG. **24-3** is a circuit diagram for a conventional photo-sensitive cell **24-300** within a pixel, implemented using complementary-symmetry metal-oxide semiconductor (CMOS) devices. Photo-sensitive cell **24-300** may be used to implement cells comprising a conventional pixel. A photodiode (PD) **510** is configured to convert incident light **24-312** into a photodiode current (I_PD). Field-effect transistors (FETs) **24-320**, **24-322**, **24-324**, **24-326**, and capacitor C **24-328** are configured to integrate the photodiode current over an exposure time, to yield a resulting charge associated with capacitor C **24-328**. Capacitor C **24-328** may comprise a distinct capacitor structure, as well as gate capacitance associated with FET **24-324**, and diffusion to well capacitance, such as drain capacitance, associated with FETS **24-24-320**, **24-322**.
[0888] FET **24-24-320** is configured to provide a path to charge node **24-329** to a voltage associated with voltage supply V2 when reset0 **24-330** is active (e.g., low). FET **24-322** provides a path for the photodiode current to discharge node **24-329** in proportion to an intensity of incident light **24-312**, thereby integrating incident light **24-312**, when sample **24-334** is active (e.g., high). The resulting charge associated with capacitor C **24-328** is an integrated electrical signal that is proportional to the intensity of incident light **24-312** during the exposure time. The resulting charge provides a voltage potential associated with node **24-329** that is also proportional to the intensity of incident light **24-312** during the exposure time.
[0889] When row select **24-336** is active (e.g., high), FET **24-326** provides a path for an output signal current from voltage source V1 through FET **24-324**, to out **24-338**. FET **24-324** converts a voltage on node **24-329**, into a corresponding output current signal through node out **538**. During normal operation, incident light sampled for an exposure time corresponding to an active time for sample **24-334** is represented as a charge on capacitor C **24-328**. This charge may be coupled to output signal out **24-338** and read as a corresponding current value. This circuit topology facilitates non-destructive reading of charge on node **24-329**.
[0890] FIG. **24-4**A is a circuit diagram for a photo-sensitive cell **24-600**, according to one embodiment. An instance of photo-sensitive cell **24-600** may implement one cell of cells **24-442-24-445** comprising a pixel **24-440**. As shown, photo-sensitive cell **24-600** comprises two analog sampling circuits **24-601**, and photodiode **24-620**. Analog sampling circuit **24-601**(A) comprises FETs **24-622**, **24-624**, **24-626**, **24-628**, and node C **24-610**. Analog sampling circuit **24-601**(B) comprises FETs **24-652**, **24-654**, **24-656**, **24-658**, and node C **24-640**.
[0891] Node C **24-610** represents one node of a capacitor that includes gate capacitance for FET **24-24-624** and diffusion capacitance for FETs **24-622** and **24-628**. Node C **24-610** may also be coupled to additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any other technically feasible capacitor structures. Node C **24-640** represents one node of a capacitor that includes gate capacitance for FET **24-654** and diffusion capacitance for FETs **24-652** and **24-658**. Node C **24-640** may also be coupled to additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any

other technically feasible capacitor structures.

[0892] When reset1 **24-630** is active (low), FET **24-628** provides a path from voltage source V2 to node C **24-610**, causing node C **24-610** to charge to the potential of V2. When sample1 **24-632** is active, FET **24-622** provides a path for node C **24-610** to discharge in proportion to a photodiode current (I_PD) generated by photodiode **24-620** in response to incident light **24-621**. In this way, photodiode current I_PD is integrated for a first exposure time when sample1 **24-632** is active, resulting in a corresponding voltage on node C **24-610**. When row select **24-634** is active, FET **24-24-626** provides a path for a first output current from V1 to output outA **24-612**. The first output current is generated by FET **24-24-624** in response to the voltage on C **24-610**. When row select **24-634** is active, the output current at outA **24-612** is therefore proportional to the integrated intensity of incident light **24-621** during the first exposure time.

[0893] When reset2 **24-660** is active (low), FET **24-658** provides a path from voltage source V2 to node C **24-640**, causing node C **24-640** to charge to the potential of V2. When sample2 **24-662** is active, FET **24-652** provides a path for node C **24-640** to discharge according to a photodiode current (I_PD) generated by photodiode **24-620** in response to incident light **24-621**. In this way, photodiode current I_PD is integrated for a second exposure time when sample2 **24-662** is active, resulting in a corresponding voltage on node C **24-640**. When row select **24-664** is active, FET **24-656** provides a path for a second output current from V1 to output outB **24-642**. The second output current is generated by FET **24-654** in response to the voltage on C **24-640**. When row select **24-664** is active, the output current at outB **24-642** is therefore proportional to the integrated intensity of incident light **24-621** during the second exposure time.

[0894] Photo-sensitive cell **24-600** includes independent reset signals reset1 **24-630** and reset2 **24-660**, independent sample signals sample1 **24-632** and sample2 **24-662**, independent row select signals row select1 **24-634** and row select2 **24-664**, and independent output signals outA **24-612** and outB **24-642**. In one embodiment, column signals as disclosed herein comprise independent signals outA **24-612** and outB **24-642** for each cell within each pixel **24-440** within a row of pixels. In one embodiment, row control signals **24-430** comprise signals for row select1 **24-634** and row select2 **24-664**, which are shared for a given row of pixels.

[0895] A given row of instances of photo-sensitive cell **24-600** may be selected to drive respective outA **24-612** signals through one set of column signals **24-432**. The row of instances of photo-sensitive cell **24-600** may also be selected to independently drive respective outB **24-642** signals through a second, parallel set of column signals **24-432**. In one embodiment, reset1 **24-630** is coupled to reset2 **24-660**, and both are asserted together.

[0896] Summarizing the operation of photo-sensitive cell **24-600**, two different samples of incident light **24-621** may be captured and stored independently on node C **24-610** and node C **24-640**. An output current signal corresponding to the first sample of the two different samples may be coupled to output outA **24-612** when row select1 **24-634** is active. Similarly, an output current signal corresponding to the second of the two different samples may be coupled to output outB **24-642** when row select2 **24-664** is active.

[0897] FIG. **24-4**B is a circuit diagram for a photo-sensitive cell **24-602**, according to one embodiment. An instance of photo-sensitive cell **24-602** may implement one cell of cells **24-442-24-445** comprising a pixel **24-440**. Photo-sensitive cell **24-602** operates substantially identically to photo-sensitive cell **24-600** of FIG. **24-4**A, with the exception of having a combined output signal out **24-613** rather than independent output signals outA **24-612**, outB **24-642**. During normal operation of photo-sensitive cell **24-602**, only one of row select1 **24-634** and row select2 **24-664** should be driven active at any one time. In certain scenarios, photo-sensitive cell **24-602** may be designed to advantageously implement cells requiring less layout area devoted to column signals **24-432** than photo-sensitive cell **24-600**.

[0898] FIG. **24-4**C is a circuit diagram for a photo-sensitive cell **24-604**, according to one embodiment. Photo-sensitive cell **24-604** operates substantially identically to sensitive cell **24-600** of FIG. **24-4**A, with the exception of implementing a combined row select **24-635** rather than independent row select signals row select1 **24-634** and row select2 **24-664**. Photo-sensitive cell **24-604** may be used to advantageously implement cells requiring less layout area devoted to row control signals **24-430**.

[0899] Although photo-sensitive cell **24-600**, photo-sensitive cell **24-602**, and photo-sensitive cell **24-604** are each shown to include two analog sampling circuits **24-601**, persons skilled in the art will recognize that these circuits can be configured to instead include an arbitrary number of analog sampling circuits **24-601**, each able to generate an independent sample. Furthermore, layout area for a typical cell is dominated by photodiode **24-620**, and therefore adding additional analog sampling circuits **24-601** to a photo-sensitive cell has a relatively modest marginal impact on layout area.

[0900] In general, sample1 **24-632** and sample2 **24-662** may be asserted to an active state independently. In certain embodiments, sample1 **24-632** and sample2 **24-662** are asserted to an active state sequentially, with only one analog sampling circuit **24-601** sourcing current to the photodiode **24-620** at a time. In other embodiments, sample1 **24-632** and sample2 **24-662** are asserted to an active state simultaneously to generate images that are sampled substantially concurrently, but with each having a different effective exposure time.

[0901] When both sample1 **24-632** and sample2 **24-662** are asserted simultaneously, photodiode current I_PD will be divided between discharging node C **24-610** and node C **24-640**. For example, if sample1 **24-632** and sample2 **24-662** are both initially asserted, then I_PD is split initially between discharging node C **24-610** and discharging node C **24-640**, each at an initial discharge rate. A short time later, if sample2 **24-662** is unasserted (set to inactive), then C **24-610** is discharged at a faster rate than the initial discharge rate. In such a scenario, C **24-640** may be used to capture a color component of a pixel within a first image having a less sensitive exposure (shorter effective exposure time), while C **24-610** may be used to capture a corresponding color component of a pixel within a second image having a more sensitive exposure (longer effective exposure time). While both of the above color components were exposed according to different effective and actual exposure times, both color components were also captured substantially coincidentally in time, reducing the likelihood of any content change between the first image and the second image.

[0902] In one exemplary system, three substantially identical analog sampling circuits **24-601** are instantiated within a photo-sensitive cell. In a first sampling interval lasting one half of a unit of time, all three analog sampling currents are configured to source current (sample signal active) into the photodiode **24-620**, thereby splitting photodiode current I_PD substantially equally three ways. In a second sampling interval, lasting one unit of time, a first of the three analog sampling circuits **24-601** is configured to not continue sampling and therefore not source current into the photodiode **24-620**. In a third sampling interval, lasting two units of time, a second of the three analog sampling circuits **24-601** is configured to not continue sampling and therefore not source current into the photodiode **24-620**.

[0903] In this example, the first analog sampling circuit **24-601** is able to integrate one quarter of the photodiode current multiplied by time as the second analog sampling circuit **24-601**, which was able to integrate one quarter of the photodiode current multiplied by time as the third analog sampling circuit **24-601**. The second analog sampling circuit **24-601** may be associated with a proper exposure (0 EV), while the first analog sampling circuit **24-601** is therefore associated with a two-stop under exposure (−2 EV), and the third analog sampling circuit **24-601** is therefore associated with a two-stop over exposure (+2 EV). In one embodiment, digital photographic system as disclosed herein determines exposure parameters for proper exposure for a given scene, and subsequently causes the camera module as disclosed herein to sample three images based on the exposure parameters. A first image of the three images is sampled according to half an exposure time specified by the exposure parameters (−2 EV), a second image of three images is sampled according to the exposure time specified by the exposure parameters (0 EV), while a third image of three images is sampled according to twice the exposure time specified by the exposure parameters (2 EV). The first image is sampled concurrently with the second image and third image, while the second image is sample concurrently with the third image. As a consequence of concurrent sampling, content differences among the three images are significantly reduced and advantageously bounded by differences in exposure time between images, such as images comprising an image stack. By contrast, prior art systems sample images sequentially rather than concurrently, thereby introducing greater opportunities for content differences between each image.

[0904] These three exposure levels (−2, 0, +2 EV) for images comprising an image stack are suitable candidates for HDR blending techniques, including a variety of conventional and well-known techniques. In certain embodiments, conventional techniques may be implemented to determine exposure parameters, including a mid-range exposure time, for a given scene associated with a proper exposure (0 EV). Continuing the above example, the first sampling interval would implement an exposure time of half the mid-range exposure time. The second sampling interval would implement the mid-range exposure time, and the third sampling interval would implement an exposure time of twice the mid-range exposure time.

[0905] In other embodiments, the analog sampling circuits **24-601** are not substantially identical. For example, one of the analog sampling circuits **24-601** may include twice or one half the storage capacitance (such as the capacitance associated with node C **24-610** of FIG. **24-4**A) of a different analog sampling circuit **24-601** within the same pixel. Persons skilled in the art will understand that relative sample times for each different analog sampling circuit **24-601** may be computed based on relative capacitance and target exposure ratios among corresponding images.

[0906] In one embodiment, image sensor as disclosed herein comprising pixels **24-440** fabricated to include two or more instances of analog sampling circuits **24-601** is configured to sample one or more ambient image and sequentially sample one or more images with strobe illumination.

[0907] FIG. **24-4**D depicts exemplary physical layout for a pixel **24-440** comprising four photo-sensitive cells **24-442**, **24-443**, **24-444**, **24-445**, according to one embodiment. As shown, each photo-sensitive cell **24-442**, **24-443**, **24-444**, **24-445** includes a photodiode **24-620** and analog sampling circuits **24-601**. Two analog sampling circuits **24-601** are shown herein, however in other embodiments, three, four, or more analog sampling circuits **24-601** are included in each photo-sensitive cell.

[0908] In one embodiment, column signals **24-432** are routed vertically between photo-sensitive cells **24-442** and **24-443**, and between photo-sensitive cells **24-444** and **24-445**. Row control signals **24-430** are shown herein as running between photo-sensitive cells **24-442** and **24-444**, and between photo-sensitive cells **24-443** and **24-445**. In one embodiment, layout for cells **24-442**, **24-443**, **24-444**, and **24-445** is reflected substantially symmetrically about an area centroid of pixel **24-440**. In other embodiments, layout for the cells **24-442**, **24-443**, **24-444**, and **24-445** is instantiated without reflection, or with different reflection than shown here.

[0909] FIG. **24-5**A illustrates exemplary timing for controlling cells within a pixel array to sequentially capture an ambient image and a strobe image illuminated by a strobe unit, according to one embodiment of the present disclosure. As shown, an active-low reset signal (RST) is asserted to an active low state to initialize cells within the pixel array. Each cell may implement two or more analog sampling circuits, such as analog sampling circuit **24-601** of FIGS. **6**A-**6**C, coupled to a photodiode, such as photodiode **24-620**. In one embodiment, each cell comprises an instance of photo-sensitive cell **24-600**. In another embodiment, each cell comprises an instance of photo-sensitive cell **24-602**. In yet another embodiment, each cell comprises an instance of photo-sensitive cell **24-604**. In still yet another embodiment, each cell comprises an instance of a photo-sensitive cell that includes two or more technically feasible analog sampling circuits, each configured to integrate a signal from a photodiode, store an integrated value, and drive a representation of the integrated value to a sense wire, such as a column signal, such as a column signal **24-432**.

[0910] A first sample enable signal (S1) enables a first analog sampling circuit comprising a first analog storage plane to integrate a signal from an associated photodiode. A second sample enable signal (S2) enables a second analog sampling circuit comprising a second analog storage place to integrate the signal from the photodiode. In one embodiment, both reset1 **24-630** and reset2 **24-660** correspond to reset signal RST, sample1 **24-632** corresponds to S1, and sample2 **24-662** corresponds to S2. Furthermore, row select1 **24-634** corresponds to RS1 and row select **24-664** corresponds to RS2. In certain embodiments, RST is asserted briefly during each assertion of S1 and S2 to bias the photodiode prior to sampling the photodiode current. In certain other embodiments, each photodiode is coupled to a FET that is configured to provide a reset bias signal to the photodiode independent of the RST signal. Such biasing may be implemented in FIGS. **24-5**B through **24-5**F.

[0911] An Out signal depicts an analog signal being driven from an analog sampling circuit **24-601**. The Out signal may represent outA **24-612**, outB **24-642**, or Out **24-613**, depending on a particular selection of analog sampling circuit **24-601**. For example, in an embodiment that implements photo-sensitive cell **24-602**, RS1 and RS2 are asserted mutually exclusively and the Out signal corresponds to Out **24-613**.

[0912] A strobe enable signal (STEN) corresponds in time to when a strobe unit is enabled. In one embodiment, camera module generates STEN to correspond in time with S1 being de-asserted at the conclusion of sampling an ambient image (Amb1).

[0913] FIG. **24-5**B illustrates exemplary timing for controlling cells within a pixel array to concurrently capture an ambient image and an image illuminated by a strobe unit, according to one embodiment of the present disclosure. As shown, the active duration of STEN is shifted in time between two different sampling intervals for the same ambient image. This technique may result in charge sharing between each analog sampling circuit and the photodiode. In this context, charge sharing would manifest as inter-signal interference between a resulting ambient image and a resulting strobe image. Removing the inter-signal interference may attenuated in the ambient image and the strobe image using any technically feasible technique.

[0914] FIG. **24-5**C illustrates exemplary timing for controlling cells within a pixel array to concurrently capture two ambient images having different exposures, according to one embodiment of the present disclosure. As shown, S1 and S2 are asserted active at substantially the same time. As a consequence, sampling of the two ambient images is initiated concurrently in time. In other embodiments, the strobe unit is enabled during Amb1 and at least one of the images comprises a strobe image rather than an ambient image.

[0915] FIG. **24-5**D illustrates exemplary timing for controlling cells within a pixel array to concurrently capture two ambient images having different exposures, according to one embodiment of the present disclosure. As shown, S2 is asserted after S1, shifting the sample time of the second image to be centered with that of the first image. In certain scenarios, centering the sample time may reduce content differences between the two images.

[0916] FIG. **24-5**E illustrates exemplary timing for controlling cells within a pixel array to concurrently capture four ambient images, each having different exposure times, according to one embodiment of the present disclosure. Each of the four ambient images corresponds to an independent analog storage plane. In certain embodiments, a strobe unit is enabled and strobe images are captured rather than ambient images.

[0917] FIG. **24-5**F illustrates exemplary timing for controlling cells within a pixel array to concurrently capture three ambient images having different exposures and subsequently capture a strobe image, according to one embodiment of the present disclosure.

[0918] While row select signals (RS1, RS2) are shown in FIGS. **7**A through **7**F, different implementations may require different row selection configurations. Such configurations are within the scope and spirit of different embodiments of the present disclosure.

[0919] While various embodiments have been described above with respect to a digital camera and a mobile device, any device configured to perform the method **24-100** of FIG. **24-1**A or method **24-102** of FIG. **24-1**B is within the scope and spirit of the present disclosure. In certain embodiments, two or more digital photographic systems implemented in respective devices are configured to sample corresponding image stacks in mutual time synchronization.

[0920] FIG. **25-1** shows an exemplary flow diagram **25-100** for performing operations on pixel data utilizing a hardwired element, in accordance with one embodiment. As an option, the flow diagram **25-100** may be implemented in the context of the details of any of the Figures. Of course, however, the flow diagram **25-100** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0921] As shown, the operation begins in step **25-102** by receiving pixel data. In one or more embodiments, the pixel data may include exposure data, exposure statistics, color data, color statistics, color space data, intensity data, saturation data, luminance data, chrominance data, and/or any other data which may be associated with a pixel in some manner. In various embodiments, the pixel data may be received by an image sensor. In other embodiments, the pixel data may be associated with a compressed photo which is used for editing.

[0922] In one embodiment, the color data and/or color statistics may include a data relating to a white balance. For example, in various embodiments, color channels (e.g. red, green, blue color channels, etc.) may be used to determine the intensity of the color balance, which may then be used to perform a correction of the white balance on the associated image. In some embodiments, the color statistics may be associated with a curve and/or some other mathematical modeling of white balance.

[0923] In other embodiments, the color data and/or color statistics may be used for color matching. For example, in one embodiment, the color matching may be used to correlate one or more images prior to a merge or blending of the one or more images (e.g. HDR mix, etc.). In various embodiments, color statistics may be computed to aid in determining the color associated with the pixel data.

[0924] As shown, in response to receiving pixel data, an operation is performed in step **25-104** on the pixel data, utilizing a hardwired element. In various embodiments, an operation may include adjusting the exposure, adjusting the white balance, adjusting metering the pixel data, adjusting focus, and/or adjusting any feature associated with the pixel data.

[0925] In some embodiments, the operation may be performed while the pixel data is within a camera module. For example, in one embodiment, the operation may be performed on the data while it is in transit between an image sensor and an image controller, both of which may be located in a camera module. In other embodiments, the operation may be performed while the pixel data is in transit between a camera module and an application processor. Of course, the operation may be performed on pixel data at any point in a camera module and/or any other module or processor associated with an image sensor.

[0926] In one embodiment, the operation being performed may occur utilizing a hardwired element. Similar to the operation which may be performed on the pixel data, the hardwired element may be located within a camera module, an application processor, and/or any other module or processor associated with an image sensor.

[0927] As shown, in decision **25-106**, it is determined whether requirements are satisfied. Of course, in one embodiment, the requirements may include one or more requirements. In various embodiments, the one or more requirements may include determining whether the pixel data is within a set range. For example, in one embodiment, pixel data may include exposure, and a requirement may include having a median exposure point within a set numeric range. For example, a numeric range associated with pixel intensity may be from 0.0 to 1.0, and a median exposure point of 0.5 may indicate that an image is within a target exposure range. In other embodiments, a requirement may include ensuring that a set percentage of pixel data is not within a top 5% and bottom 5% of exposure data. For example, in one embodiment, a requirement may be to ensure that no more than 5% of the pixel data is in the top 5% of exposure data. As such, the pixel data may be continually fed back into the image sensor until no more than 5% of pixel data is in the top 5% of exposure data.

[0928] In other embodiments, a requirement may be associated with a histogram. For example, in one embodiment, the numeric range may be based on a histogram output of the pixel data. In another embodiment, the histogram may be used to determine the spread of intensities of pixels associated with, for example, exposure and/or any other parameter associated with the pixel data. For example, in one embodiment, the number of pixels at each exposure may be counted, and a requirement may be that a set number of pixels must fall within a set portion of the histogram. For example, the number of pixels in the top and bottom 5% of the histogram may be determined, and a requirement may be that the 90% of the pixels (e.g. as determined by counting, etc.) must fall in the region between 5% and 95% of the histogram. Of course, in other embodiments, the region and/or requirement may be any value.

[0929] In one embodiment, the requirement may be set by a user. For example, in one embodiment, the user may select and/or input a range, value, median, distribution, and/or any other constraint which may be used as a requirement. In another embodiment, the requirement may be set automatically. For example, in one embodiment, optimized settings may be associated with pixel data, and the optimized settings may include one or more requirements. For example, in one embodiment, it may be determined that the user is using a camera module associated with mobile device X, and that the image blows out a high percentage of the pixel data (e.g. large count of pixel data may be in the overexposed range of greater than 90% on a histogram distribution, etc.). In view of this, optimized settings may include correcting a lens distortion known to be present with mobile device X (e.g. apply a distortion correction with a set point, etc.), applying a target percentage of at least 80% of the pixel data not contained in the bottom or top 5% of the histogram distribution, and/or taking any other action to apply an optimized setting(s). In some embodiments, the one or more requirements may come from a parameter associated with a device (e.g. Apple iPhone, Samsung Galaxy, Canon Mach 3, Nikon D, Panasonic Lumix, etc.).

[0930] In other embodiment, the one or more requirements may be associated with an individual user, with two or more individuals (e.g. group settings, group sharing, etc.), with a remote entity (e.g. dropbox, Google Drive, Box.com, etc.), and/or any other source. In some embodiments, the one or more requirements may be stored on the device (e.g. local memory of the device, etc.), may be transferred from another device (e.g. via Bluetooth, via WiFi, via Wifi direct, etc.), may be stored in the cloud (e.g. Facebook, Dropbox, Google Drive, Microsoft One, etc.), and/or any other storage location.

[0931] As shown, if the requirements are satisfied, then the flow is complete. However, if the requirements are not satisfied, then the flow loops back to performing an operation on the pixel data, utilizing a hardwired element. See operation **25-106**. In some embodiments, the operation may change based off of feedback. For example, in one embodiment, it may be determined that the white balance was not correct (e.g. based off of pixel count, etc.). As such, the white balance may be modified until the white balance is within a threshold of, or reaches, a predetermined value.

[0932] In various embodiments, utilizing a hardwired element may help to quickly meter a scene and/or image, and/or adjust a parameter associated with pixel data. In some embodiments, the hardwired element may be used to correct deficiencies associated with the image sensor, camera lens, and/or another element associated with the camera module. As such, utilizing the hardwired element may aid in decreasing time for control loops. For example, in one embodiment, the pixel data may be metered, and a parameter (e.g. exposure, etc.) may be evaluated in a hardwired element to determine if it complies with a set requirement. If it does comply, the image is captured. If it doesn't comply, a setting associated with the parameter is altered to comply with the requirement. In some embodiments, the control loop may need to be repeated several times before the requirement is satisfied.

[0933] FIG. **25-2** shows an exemplary method **25-200** for performing operations on pixel data utilizing a hardwired element, in accordance with one embodiment. As an option, the method **25-200** may be implemented in the context of the details of any of the Figures. Of course, however, the method **25-200** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0934] As shown, pixel data is received. See operation **25-202**. Additionally, a first aspect of the pixel data is identified, utilizing a hardwired logic element of circuitry. See operation **25-204**. Further, an operation is performed in connection with the first aspect of the pixel data, utilizing the hardwired logic element of the circuitry. See operation **25-206**.

[0935] In one embodiment, pixel data may be received from an image sensor. In some embodiments, the pixel data may include a single scalar element of data received from an image sensor, and/or may include a one or more sets of intensities for data received from an image sensor.

[0936] In various embodiments, the operation **25-206** may occur, at least in part, in an application processor, and/or in a camera module. In a separate embodiment, the operation may occur entirely in a camera module. Of course, in other embodiments, the operation may occur in any processor and/or module associated with the image sensor.

[0937] In one embodiment, a first aspect may include at least one of a white balance, a focus, an exposure, an intensity, and/or any other parameter associated with the pixel data. In one embodiment, the first aspect of the pixel data may include two or more points of interest in the pixel data. Additionally, the two or more points of interest may include at least one of two or more points of white balance, two or more points of focus, two or more points of exposure, two or more points of intensity, and/or two or more points of another parameter associated with the pixel data. Additionally, a point of interest may include a region of pixels within the pixel data.

[0938] In various embodiments, having two or more points of interest may be related. For example, in one embodiment, a first point of interest may relate to a first white point and a second point of interest may relate to a second white point, and the first aspect may include both the first and second white point. In some embodiments, parameters related to the first and second points of interest may be blended, mixed, normalized, averaged, and/or otherwise combined in some manner, such that the combined information is used as a first aspect of the pixel data.

[0939] In other embodiments, the two or more points of interest may not be related. For example, in one embodiment, a first point of interest may relate to an exposure setting for a part of an image that shows the outdoors, and a second point of interest may relate to an exposure setting for a part of the image that shows the indoors. Of course, in other embodiments, a point of interest may be associated with any location of a photo, and the point of interest may be associated with any parameter of the pixel data.

[0940] Still yet, in one embodiment, identifying the first aspect may include summing one or more values for a region associated with the pixel data, and determining a range of highest points associated with the pixel data for the region. In one specific embodiment, performing the operation may be based on a range of highest points associated with pixel data for a region. Of course, in other embodiments, any mathematical operation may be used to perform the operation.

[0941] As shown, a result of the operation is fed back. See operation **25-208**. In one embodiment, feeding back the result of the operation may include providing the result to the image sensor. In some embodiments, in response to feeding back the result to an image sensor, the image sensor may adjust a parameter to increase the probability that it will comply with a requirement.

[0942] In one embodiment, a result of the operation may to include at least one of an outcome of normalizing or summing elements associated with an exposure of the pixel data, an outcome of normalizing or summing elements associated with a white balance of the pixel data, an outcome of normalizing or summing elements associated with a focus of the pixel data, an outcome of normalizing or summing elements associated with an intensity of the pixel data, and/or an outcome

of a mathematical operation.
[0943] In one embodiment, a first aspect may be associated with a white balance value, and feeding back the result of the operation may include adjusting the pixel data based on the white balance value. Additionally, in one embodiment, the adjusting may occur utilizing the hardwired logic element of the circuitry. In a separate embodiment, the adjusting may occur entirely within a camera module.
[0944] Additionally, as shown, at least one of the performing an operation in connection with the first aspect of the pixel data, utilizing the hardwired logic element of the circuitry or the feeding back a result of the operation is repeated, until the result of the operation satisfies a predetermined requirement. See operation **25-210**.
[0945] In one embodiment, the requirement may involve at least one of a maximum value, a threshold value, and/or a range. In one embodiment, the requirement may involve a range, and the range may include at least a median value. Further, in another embodiment, the requirement may involve a range, and the range may include a 40%-60% distribution associated with a first aspect (e.g. exposure, saturation, intensity, color, white balance, etc.) of the pixel data. Still yet, in one embodiment, the requirement may involve a range, and the range may include a specific set point associated with the first aspect of the pixel data.
[0946] In various embodiments, a camera module may be provided in association with a lens assembly which focuses an aperture (e.g. with or without and adjustable aperture, etc.) to capture optical information onto the image sensor. In one embodiment, a controller may be provided also within a camera module. Including a controller may aid in reducing heat on the image sensor, thereby decreasing potential noise of the resulting captured image. Of course, in some embodiments, an analog to digital converter may be contained within the image sensor, may be provided on the controller, and/or may be located anywhere within a camera module and/or another module associated with the image sensor.
[0947] In one embodiment, the camera module may include optics (e.g. lens, etc.), an image sensor, a controller, as well as the ability to couple any of the foregoing components to an application processor. Additionally, in one embodiment, the image sensor may provide image data which may be processed in hardware (e.g. within the camera module, etc.), or in processing kernel (e.g. application processor, etc.). Of course, in other embodiments, the data may be processed at any point after being initially captured by the image sensor.
[0948] In another embodiment, performing an operation in connection with the first aspect of the pixel data may include focus metering. For example, in one embodiment, an image sensor may include a focus actuator where, when pixel data is inputted into a camera module hardwired logic element, the result is fed back into the image sensor to adjust the focus actuator. In this manner, the focus can occur very quickly and very accurately. For example, in one embodiment, the image sensor may do an initial sweep, then overshoot the pixel data, and then apply optimized settings (e.g. based on the feedback result, etc.) to comply with a requirement. In one embodiment, the image sensor may capture pixel data at a lower resolution, feed the pixel data to a hardwired logic element of the circuitry, and refine the settings prior to capturing the pixel data at a higher resolution.
[0949] In one embodiment, performing an operation in connection with the first aspect of the pixel data may include counting the number of pixels to the side of a median value. For example, in one embodiment, if more pixels are evaluated to the right of a median value, then the image sensor may lower the ISO, shorten the exposure time, and/or take any other action to prevent the pixel data from being overblown. Of course, in other embodiments, adjusting the exposure time and/or ISO (or potentially other parameters associated with the image sensor) may directly shift the histogram, thereby allowing adjustments to be made to comply with a requirement.
[0950] In another embodiment, a count of pixels may include one or more groups of data. For example, in one embodiment, pixel data may be processed using statistics, wherein the statistics

includes a counter to determine whether each pixel's intensity falls between 0-0.5 and 0.5-1.0 on an intensity histogram. In this manner, each pixel is classified into two groupings, and each group is counted. Of course, in other embodiments, the median value may be any value, and the operation (e.g. greater than, equal, less than, etc.) may be used to compare the groupings of data. Additionally, the counting of pixels may occur utilizing a hardwired logic element on the circuitry.
[0951] As a separate example, in one embodiment, if pixel data is found to be completely left of the median (e.g. 0-0.5, etc.) for an intensity histogram, then the pixel data may be significantly underexposed. Additionally, if pixel data is found to be completely right of the median (e.g. 0.5-1.0, etc.) for an intensity histogram, then the pixel data may be significantly overexposed. Of course, in various embodiments, using a hardwired logic element to modify ISO, exposure times, and other parameters associated with the image sensors may assist in getting a more even distribution of pixels across an intensity histogram.
[0952] Still yet, in another embodiment, any type of statistics (or mathematical operation) may be used to compute a count or any other result which may then be used by the image sensor to determine if the result complies with a predetermined requirement. In one embodiment, utilizing a hardwired logic element rather than involving software and/or a memory module, may aid in decreasing the amount of time necessary to process the pixel data.
[0953] In another embodiment, one or more groups of pixel data may be used to determine brightness, focus, exposure, and/or any other parameter associated with the pixel data. In one embodiment, a portion of the entire pixel data, rather than all of the pixel data, may be used for processing. For example, in one embodiment, 1000 incoming pixels may be queued to be processed, and after processing 25-100 pixels, it is determined that the count of pixels for just the first 25-100 pixels exceeds a certain threshold (e.g. count of pixels above a certain intensity histogram range, etc.). In such an embodiment, the 900 remaining pixels may not be processed, thereby decreasing the amount of time needed for processing. As such, in some embodiments, if a certain amount of pixels surpass a threshold, that may trigger giving immediate feedback to the image sensor without processing the rest of the pixels.
[0954] In some embodiments, the image sensor may take into consideration the feedback result (e.g. from the hardwired logic element, etc.), the manufacture of the camera module, the manufacture of the lens assembly (e.g. to correct for chromatic deficiencies, etc.), and/or any other information which may affect the pixel data and which can be corrected in some manner by the image sensor. Of course, in various embodiments, settings applied by the image sensor may account for best operating parameters (e.g. for the lens, for the camera module, etc.).
[0955] In one embodiment, rather than computing a mathematical operation (e.g. count the pixels falling into groups, etc.), a processor (e.g. application processor, etc.) may be used to process pixel data (e.g. compare exposure to tables associated with the image sensor, etc.). However, in such an embodiment, rather than involving all of the system memory (e.g. of the application processor, etc.), the processor may use one or more references tables (e.g. associated with the image sensor, etc.) to assist in processing the pixel data. The tables may be used by the application processor to look up and then process a decision based on the pixel data value and the corresponding look up value.
[0956] In various embodiments, look ups may occur at a variety of locations, including the camera module, the application processor, within software (e.g. located on an application processor, located on a camera module, etc.), a device driver (e.g. within an application processor module, etc.), and/or any location capable of performing a look up and performing a decision based on the look up.
[0957] Of course, in another embodiment, once a pixel has been grouped, additional sub-groups may be created with a grouping. For example, in one embodiment, it may be determined that a pixel falls in the 0-0.5 intensity histogram group. However, falling into a 0-0.1 bucket (e.g. severely underexposed, etc.) may be considerably different than falling into a 0.1-0.5 bucket (e.g. some

underexposure, etc.). As such, sub-groups within a grouping may be used as needed to extract relevant information (e.g. count of pixels within 0-0.1 range with triggers based on thresholds, etc.).

[0958] In other embodiments, at least some processing may involve both a hardwired logic element and one or more software elements. For example, in one embodiment, a hardwired logic element may be used to adjust the exposure settings for pixel data. After quickly refining the exposure settings in the hardwired logic element, the pixel data may be forwarded on to be further processed by a software module (e.g. in the camera module, in the application processor, etc.). For example, in one embodiment, the hardwired logic element may refine the exposure based on a median value as determined by an intensity histogram. However, in some instances, it may be desired to allow the pixel data to remain overexposed, in which case the median value as set by the hardwired logic element may not be correct. In one embodiment, software (e.g. driver, proprietary software, etc.) may be used to adjust the image so that the resulting image is not based solely off of median (or any mathematical statistic) value, but takes into consideration optimized settings which can be implemented.

[0959] In one embodiment, the software may be controlled, at least in part, by a user. For example, in various embodiments, the user may adjust the median value of the histogram, and/or may give some other feedback which can be used to adjust the photo. In other embodiments, the software may implement optimized settings as determined by a manufacture, by a cloud based source (e.g. best settings to be implemented for a camera, etc.), and/or by any other source. As such, in some embodiments, the user may bypass settings as applied by a hardwired logic element and/or a software element associated with the image sensor. Additionally, in this manner, the user may purposefully meter extra light, and/or meter extra dark as applied to the pixel data.

[0960] In one embodiment, a device driver may be used to determine a range associated with the pixel data. For example, in one embodiment, it may be desired to not focus on completely dark or completely light pixels. In such an embodiment, histogram data may be multiplied by a predefined curve, the result of which may be fed back to the image sensor to adjust the capture of the pixel data. Additionally, in one embodiment, multiplying the histogram data by an curve may allow the pixels in the middle of the histogram distribution to be the focus of the result.

[0961] In various embodiments, the pixel data may be categorized using a histogram. In other embodiments, if 8 bits of resolution were used (e.g. 8-bit color, etc.), the categorization could include 256 groups (e.g. maximum number of color groupings for 8-bit color, etc.) which may allow for finer granularity. Of course, any method may be used to categorize the pixel data.

[0962] In some embodiments, the feeding back may include a result based on the mathematical computation (e.g. counting of pixels in groups, etc.). In other embodiments, the feeding back may include updated exposure parameters as determined by the hardwired logic element. For example, in one embodiment, if the pixel data was overexposed, the updated exposure parameters may include lowering an ISO, increasing the shutter speed, narrowing the aperture (e.g. changing the f-stop to a higher number, etc.), and/or applying any other setting which may limit the amount of light entering the image sensor. Of course, in other embodiments, any instruction and/or parameter may be fed back to the image sensor which may then be used to alter the capture of the image.

[0963] In some embodiments, a point of interest may include a secondary region. For example, in one embodiment, the secondary region may include a border region around a point of interest. In various embodiments, the border region may be used to determine a difference in exposure (e.g. inside exposure v outside exposure, etc.), and/or be used to determine an edge. In one embodiment, an edge may be used to apply more than one filter and/or setting. For example, in one embodiment, a detected edge may cause a first exposure to be applied to a first region and a second exposure to be applied to a second region. Of course, in other embodiments, any parameter in association with the detected edge may be used. Additionally, in other embodiments, a secondary region may include any region of the photo and/or a point of interest.

[0964] In one embodiment, the edge may be detected based on a user input. For example, in one embodiment, the user may trace a pattern which is used for edge detection. In some embodiments, the traced pattern may define the edge to be applied. In other embodiments, the traced pattern may determine a region of the image to be used for automatic edge detection. For example, in one embodiment, the user may trace a region to correspond with an edge to be applied. Based on the traced region, the device may then automatically detect the edge.

[0965] In other embodiments, the edge may be detected automatically. For example, in one embodiment, a device may increase the contrast, filter the image by one or more channels (e.g. red, green, blue, etc.), and/or apply any other parameter to aid in determining an edge. Of course, in one embodiment, parameters applied to the image in order to aid in determining an edge may be temporary and applied for purposes only of determining an edge. In another embodiment, an edge may be detected by analyzing a difference in color, brightness (e.g. exposure, etc.), and/or any other parameter associated with the pixel data. Of course, in other embodiments, any technically feasible method for detecting an edge may be used.

[0966] Still yet, in one embodiment, a point of interest may be mapped using a variety of methods, including, but not limited to, a one-to-one mapping (e.g. identify region on CCD and then identify region on image sensor, etc.), a row select and a column select (e.g. based on point of interest and/or region selected, etc.), a full frame metering (e.g. discard data which is not needed and/or relevant, etc.), and/or any other method which may be used to select a region or point of interest in some manner. In one embodiment, a whole frame associated with the pixel data may be obtained, and then all rows and/or columns which were not selected via the selected region may be discarded. In this manner, pixel data associated with the selected region may be used a basis for further processing and/or analysis.

[0967] In one embodiment, a hardware logic element may be used to correct a first parameter (e.g. overall exposure, etc.), and software may be used to correct a second parameter (e.g. region specific exposure, etc.). In other embodiments, the hardware logic element and software may be used individually or in combination in any manner to correct one or more parameters.

[0968] In another embodiment, an image may be output based on a blending of two or more parameters. For example, in one embodiment, pixel data associated with a first ISO may be captured, and pixel data associated with a second ISO may be captured, and the pixel data from both ISOs may be blended. Additionally, pixel data associated with a first ISO may relate to a first region and pixel data associated with a second ISO may relate to a second region, and blending the pixel data from both ISOs may include giving a preference (in blending) to the pixel data associated with the first or second regions, respectively. Of course, any portion of an image may be associated with a specific ISO and/or parameter, and blending may take into consideration the part of the image which relates to the specific ISO and/or parameter.

[0969] As an example, in one embodiment, one exposure may be associated with a first point of interest, and the hardwired logic element may be used to meter a first exposure for the first point of interest. Additionally, in such an embodiment, software may be used so that a second point of interest may be identified with a second exposure parameter. The software may then instruct the camera module (e.g. image sensor, etc.) to expose and capture one or more sets of pixel data based on the first and second identified exposure parameters. Additionally, the resulting image may be blended based on the captured one or more sets of pixel data.

[0970] In a separate embodiment, a hardwired logic element may be used to meter the entire frame of the photo at a first exposure. Additionally, a region within the frame may be selected, the region being separately metered. Based on the metered information, the image sensor may capture a first frame at a first exposure and then capture a second frame at a second exposure. In other embodiments, the image sensor may capture one set of pixel data, and two or more ISO values (or any other applicable parameter, etc.) may be applied to the pixel data.

[0971] In one embodiment, white balance may be calculated through a normalization calculation.

For example, in one specific embodiment, pixel intensity associated each color channel (e.g. red, green, blue, etc.) may be individually counted. The summation of each color channel may then be used to normalize the channels wherein each of the color channels may be used to compute a white balance (e.g. in a grey world setting, etc.). In one additional embodiment, the summation and normalization of each color channel may occur on a hardwired logic element. In various embodiments, the summation and/or normalization may be used, at least in part, by a hardwired logic element in combination with software. For example, in one embodiment, the hardwired logic element may return the white balanced RGB data, and the software may take such normalized data and perform a compression (e.g. JPEG, lossless, etc.). In this manner, a resulting image (e.g.JPEG, etc.) may be based on correct white balance compensation as outputted by a hardwired logic element.

[0972] In one embodiment, the hardwired logic element may be used to focus an image. For example, in one embodiment, the pixel data may be inputted into the hardwired logic element and a frequency analysis may be performed. In one embodiment, the frequency analysis may include a fast Fourier transform ("FFT") of one or more lines of pixel data. In another embodiment, the frequency analysis may include a discrete cosine transform ("DCT") of a block of pixel data. In one embodiment, if an image is very much out of focus, and a DCT was performed on the image, there may be more low frequency energy ("low frequency components") associated with a majority of DCT blocks associated with the image. This, for example, may be contrasted with an image which is in focus, and which may include a higher number of blocks having dominantly high frequency energy ("high frequency components"), in a focused image scenario, DC and low frequency components are relatively attenuated in a majority of DCT blocks. In such an embodiment, a hardwired logic element may be used to analyze at least one or more lines of pixel data, the analysis including performing a frequency analysis.

[0973] In a particular embodiment, a line of pixel data may be inputted into a hardwired logic element and an operation may be performed on the pixel data, including a 1D Fourier transform (e.g. FFT, etc.), producing a result including both high and low frequency data. A histogram showing the frequency data may be compiled over multiple lines within an image based on summing frequency values for a particular range, and repeating the summing for multiple ranges. In this embodiment, a new line of pixel data may be inputted into a hardwired element logic, with the end summation of frequency values being computed in a histogram for a range of lines. In this manner, a complete histogram may be built based on multiple line pixel data. In one embodiment, the net value over all the lines may yield a maximum value, and the maximum value may correspond with the point at which the image may be in focus. Of course, any technically feasible method may be used to compute the maximum value associated with the curve (e.g. derivative analysis, probability analysis based on tried values, etc.).

[0974] In this manner, in various embodiments, an entire image, or one or more points of interest associated with the image, may be used as the basis for computing the focus. In another embodiment, a set of 8×8 blocks of pixel data may be inputted into a hardwired element logic and an operation may be performed on the pixel data, including a DCT, producing a result including both high and low frequency data. The frequency values may be summed for a particular range (and/or ranges) and the result may be displayed on a histogram. In one embodiment, the histogram may be used to compute the maximum value based on multiple blocks of pixel data, rows of pixel data, columns of pixel data, etc. Of course, in some embodiments, the ability to focus may operate on any image data, including a scene and/or textual information, based on the foregoing descriptions. Additionally, in one embodiment, a focus metric for a particular frame may be the sum of the high frequency components for that frame. In another embodiment, a focus metric for a particular frame comprises a median of a frequency domain histogram taken over lines comprising the frame or DCT blocks comprising the frame. In yet another embodiment, a focus metric for a particular frame comprises a high threshold (e.g., top 10%) value for a frequency domain histogram

taken over lines comprising the frame or DCT blocks comprising the frame.
[0975] In other embodiments, a combination of software and hardware logic elements may be used to focus. For example, in one embodiment, a static scene may be entirely focused using hardware logic element. In another embodiment, however, a point of interest may be a child running around. In such an embodiment, software may be employed to enable tracking of the point of interest, and hardware logic element may be used to focus based on the determined location as set by the software. Of course, in other embodiments, any combination of the hardware and software may be used to focus the pixel data.
[0976] In various embodiments, computing a white balance using a hardwired logic element, as hereinabove described, may apply to display devices (e.g. monitor calibration, etc.), presentation devices (e.g. projector, etc.), between two or more devices (e.g. calibrate screens of multiple devices, etc.), and/or any other device which may be used to present pixel data in some manner. In another embodiment, computing white balance using a hardwired logic element may be used for 3D imaging, wherein more than one lens input may be correlated so that the pixel data result is consistent between the two lenses.
[0977] FIG. **25-3** illustrates a camera system **25-500** in communication with an application processor, in accordance with an embodiment. As an option, the camera system **25-500** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera system **25-500** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0978] As shown, a camera module **330** may include an image sensor **332** which may be in communication with an analog to digital converter **25-502** ("A/D Converter") which may be in communication with a controller **333**, which may be in communication with an application processor **335**. In one embodiment, the A/D Converter output **25-504** is provided to controller **333**. In another embodiment, the A/D Converter **25-504** is integrated within the controller **333**.
[0979] In one embodiment, the lens **390** may be configured to focus optical scene information onto image sensor **332** to be sampled. The optical scene information sampled by the image sensor **332** may then be communicated from the image sensor **332** to the A/D Converter **25-502** and then to the controller **333** for at least one of subsequent processing and communication to the application processor **335**. In another embodiment, the controller **333** may control storage of the optical scene information sampled by the image sensor **332**, or storage of processed optical scene information.
[0980] In one embodiment, the controller **333** may be in direct communication with the image sensor **332**. For example, in one embodiment, the controller may include a hardwired element logic which is configured to process at least some aspect of pixel data captured by the image sensor **332** and converted by the A/D Converter **25-502**. In such an embodiment, the controller may process the converted pixel data and provide resulting control signals back to the image sensor. For example, in one embodiment, the controller may process an exposure level for the capture image, and provide feedback in the form of control signals to the image sensor in response to the captured image (e.g. exposure is correct, exposure is overexposed, exposure is underexposed, etc.).
[0981] In another embodiment, the controller **333** may be in communication with the application processor **335**. Additionally, as shown, the application processor **335** includes a camera interface **25-506** which may be in communication with a device driver **25-508** and with a software module **25-510**.
[0982] In one embodiment, the camera interface **25-506** may receive a request from the controller **333** within the camera module **330**, and may provide a result directly back to the controller **333**. In another embodiment, the camera interface **25-506** may communicate with a device driver **25-508**. In various embodiments, look ups may occur within the controller **333**, within the camera interface **25-506**, within the device driver **25-508**, and/or within the software module **25-510**.
[0983] In one embodiment, the device driver **25-508** may be used to determine a range associated with the pixel data. For example, in one embodiment, it may be desired to not focus on completely

dark or completely light pixels. In such an embodiment, histogram data may be multiplied by a predefined interest curve, the result of which may be fed back to the image sensor to adjust the capture of the pixel data. Additionally, in one embodiment, multiplying the histogram data by an interest curve may allow the pixels in the middle of the histogram distribution to be the focus of the result. Of course, in other embodiments, the camera interface **25-506** and/or the software module **25-510** may be used to determine a range associated with the pixel data.

[0984] Further, in another embodiment, any of the components of the application processor **335** may be used in conjunction with the camera module **330** to assist in processing the pixel data (e.g. determine exposure of the pixel data, determine white balance of the pixel data, etc.), metering the pixel data (e.g. to determine proper exposure, etc.), outputting the pixel data (e.g. convert to JPEG, etc.), determining a point of interest (e.g. automatically or via manual feedback, etc.), tracking a point of interest, applying one of more optimized settings (e.g. based on manufacturer, based on cloud settings, etc.), and/or providing any other functionality in association with the image sensor **332**. In one embodiment processor complex **310** of FIG. **3**A includes application processor **335**.

[0985] FIG. **25-4** illustrates a camera system **25-600** for processing one or more points of interest, in accordance with an embodiment. As an option, the camera system **25-600** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera system **25-600** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[0986] As shown, the camera module **330**, as hitherto described, may include receiving an image **25-602** at an image sensor **332**. Additionally, the image sensor **332** may output the image via an A/D Converter **25-502**. In one embodiment, the image **25-602** may include one or more points of interest **25-604 25-606**.

[0987] In some embodiments, the one or more points of interest **25-604 25-606** may be selected automatically be the device. For example, in one embodiment, a first exposure may be associated with the image and metered off of an indoor exposure setting. Additionally, a first point of interest (e.g. item **25-604**, etc.) may correspond with an exposure associated with the outdoors, and a second point of interest (e.g. item **25-606**, etc.) may correspond with an exposure associated with a face. In such an embodiment, the first exposure may have been initially metered (e.g. by a hardwired logic element, etc.) to optimize the results. The points of interest may have been selected by the device (e.g. based off of high overexposure area, based on a detected face and/or object, etc.).

[0988] In another embodiment, the points of interest may be selected manually by the user. For example, in one embodiment, an image may be outputted by the image sensor **332** via the A/D Converter **25-502** and displayed on a presentation device (e.g. screen, etc.). A user of the device may select (e.g. by touching the screen, etc.) a first point of interest (e.g. the outdoor, etc.) and indicate to darken the selected area. Additionally, the user may select a second point of interest (e.g. face, etc.) and indicate that the object selected is a face and optimized facial settings should apply. Based on these selections, exposure information generated from the points of interest (with the accompanying exposure and/or settings, etc.) are fed back to the image sensor **332**. The image sensor may then proceed to capture the image based on the information associated with the points of interest.

[0989] In one embodiment, the image sensor **332** may capture multiple images (e.g. a first general exposure image, a second exposure based on the outdoor setting, a third exposure to optimize facial features, etc.), the multiple images being later blended together to form one cohesive resulting image. In a separate embodiment, the image sensor **332** may capture one set of pixel data, and more than one gain may be applied to the pixel data (e.g. a first ISO is applied to the pixel data, a second ISO is then applied to the pixel data, etc.), whereby each resulting image (e.g. gain+pixel data, etc.) is then used in combination with all other resulting images to form one resulting and blended image.

[0990] In some embodiments, blending the two or more resulting images may include assigning a priority to the point of interest. For example, in one embodiment, a first resulting image may be associated with a general exposure, and a second resulting image may be associated with a first point of interest, and when blending the first and second resulting images, the second image will be giving priority with respect to the first point of interest (i.e. the pixel data relating to the first point of interest will be blended primarily from the second image, etc.).
[0991] In a separate embodiment, capturing pixel data may relate to the point of interest. For example, in one embodiment, a first point of interest may be selected and the user may indicate that the exposure needs to be darkened (e.g. outdoor part, etc.). As such, the exposure may be decreased for that point of interest, and when capturing the pixel data, the image sensor may only capture pixel data as it relates to the point of interest (i.e. it does not capture pixel data for non point of interest locations, etc.). In this manner, a decrease amount of pixel data is captured as it may relate to the point of interest. This decreased amount of pixel data may then be processed more quickly to determine exposure information for capturing a whole image. In a separate embodiment, if the image sensor has captured the pixel data, and a first gain has been applied to the analog pixel data (e.g. first general exposure, etc.), a second gain may be applied to the analog pixel as it may relate to a first point of interest, and when applying the second gain to the analog pixel, the second gain may only be applied to the first point of interest (i.e. at the exclusion of other areas of the pixel data, etc.).
[0992] Of course, in other embodiments, after being outputted from the A/D Converter **25-502**, the output may continue on to other components as here before described (e.g. FIG. **25-3**, FIG. **3**G, etc.).
[0993] FIG. **25-5** illustrates a camera system **25-700** for adjusting white balance, in accordance with an embodiment. As an option, the camera system **25-700** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the camera system **25-700** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[0994] As shown, camera system **25-700** may include a camera module **330**, an image sensor **332**, an A/D Converter **25-502**, an A/D Converter output **25-504**, an RGB Controller **25-702**, a red channel output **25-704**, a green channel output **25-706**, a blue channel output **25-708**, a summation module **25-710**, and a modification signal **25-712**.
[0995] In various embodiments, the image sensor **332**, A/D Converter **25-502**, and A/D Converter output **25-504** may operate in a manner already described.
[0996] In one embodiment, the RGB Controller **25-702** may receive an output from A/D Converter **25-502** for processing. In one embodiment, the RGB Controller **25-702** may be used to determine the pixel intensity associated with each color channel of the pixel data. Additionally, the RGB **25-702** may be used to normalize each channel (e.g. red, green, blue, etc.).
[0997] After the RGB Controller **25-702** finishes processing the pixel data (e.g. normalizing each channel, etc.), RGB Controller **25-702** may output a color channel output. For example, in one embodiment, the RGB Controller **25-702** may output a coefficient for red, green, and blue color channels. In various embodiments, the coefficient may correspond with a red channel output **25-704**, a green channel output **25-706**, and a blue channel output **25-708**.
[0998] In one embodiment, a coefficient may include an intensity value for one color channel for one pixel. For example, in one embodiment, correcting white balance may occur on a frame by frame basis in summation module **25-710**, the feedback specifying an analog gain that causes the white balance constraint(s) (e.g. based on the color correction coefficients, etc.) to be accomplished. In such an embodiment, the white balance correction may be based, at least in part, on a gray world constraint (e.g. gray world algorithm, average of all colors is gray, etc.). Further, the feedback specifying an analog gain per color channel may be fed back to the image sensor **332**.
[0999] In a separate embodiment, correcting white balance may occur on a frame by frame basis in

summation module **25-710**, the feedback specifying white balance correction which may be applied in the analog domain (e.g. at the image sensor **332**, etc.), prior to digital quantization (e.g. by A/D Converter **25-502**, etc.), or in the digital domain (e.g. at the RGB Controller **25-702**, etc.). Of course, in one embodiment, feeding back the result of the operation may include providing the result to at least one of the image sensor, an analog-to-digital converter, or to a digital output from the analog-to-digital converter.

[1000] In one embodiment, the modification signal **25-712** may be applied to digital pixel data exiting the RGB Controller **25-702**. In one embodiment, the RGB Controller **25-702** separates the digital pixel data into color components (e.g. red, green, blue, etc.), and sends the digital pixels via **704**, **706**, **708** (and/or any other path, etc.) to summation module **25-710**. In one embodiment, the summation module sums and averages each of the individual color channels, assuming a gray world constraint.

[1001] In another embodiment, after exiting the summation module **25-710**, the pixel data may be fed back into a RGB controller to determine whether any other parameters need to be modified (e.g. exposure, saturation, etc.). Of course, in other embodiments, the RGB Controller **25-702** and Summation module **25-710** may be implemented on the same component (e.g. within the same image sensor die, a controller die, or a die in a processor complex/application processor, etc.).

[1002] In a separate embodiment, the Summation module **25-710** may be used for other statistics associated with the pixel data. For example, in one embodiment, the summation module may sum values for color channel intensities, which may be used to calculate white balance correction factors. In such an embodiment, modification signal **25-712** may comprise a white balance compensation signal. In another embodiment, summation module **25-710** is configured to generate a histogram of a given frame; the histogram may then be processed to generate exposure information, which may be fed back to the image sensor **332** in a subsequent frame.

[1003] In one embodiment, applying the modification signal **25-712** to RGB Controller **25-702** output pixels **25-714** may include applying the correction factors (e.g. calculated by Summation module **25-710**, etc.) to the current (or any subsequent) image by the RGB Controller **25-702** (or another processing complex on the processor die, etc.). Additionally, the correction factors may be applied to a following (or next) image by the RGB Controller **25-702**. In such an embodiment, applying the correction factors to a following image may have particular application to video frames where color correction (e.g. white balance, etc.) may be computed and corrected in real time on frames as they are played (i.e. frames are corrected on subsequent frames rather than computing and correcting on each frame which may otherwise slow down the display of the video stream, etc.).

[1004] In one embodiment, modification signal **25-712** may include statistics from the summation module **25-710**, and the statistics (e.g. white balance statistics, white balance factors, exposure, exposure factors, etc.) may be passed through a low-pass filter (e.g. moving average filter, etc.) to provide a damping. For example, damping may allow a substantially new white balance to take effect within a few seconds, but not on the very next frame. As such, in one embodiment, as a scene changes (e.g. a camera is moved and focuses on a new object, etc.), the white balance may readjust based on the initial scene (where the camera was originally pointed) and the final scene (where the camera is currently pointed to), rather than readjusting the white balance on every frame as the camera is moved from one scene to a second scene.

[1005] FIG. **25-6** illustrates a frequency method **25-800** for focusing, in accordance with an embodiment. As an option, the frequency method **25-800** may be implemented in the context of the details of any of the Figures disclosed herein. Of course, however, the frequency method **25-800** may be carried out in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[1006] As shown, frequency method **25-800** may include a row **25-802** of pixel data. In one embodiment, the row **25-802** may include one or more blocks **25-804** of pixel data. In one embodiment, the one or more blocks **25-804** may include a set of 8×8 blocks of pixel data. Additionally, in one embodiment, a discrete cosine transform ("DCT") may be performed on the pixel data (e.g. blocks of pixel data, etc.). In other embodiments, the pixel data may have already been processed by a DCT.

[1007] In an alternative embodiment, lines of pixel data may be processed according to a one-dimensional Fast Fourier Transform (1DFFT) **806**. In both such embodiments spatial domain image data (e.g., intensity image data) is transformed to frequency domain image data. Other techniques may be similarly applied to transform spatial domain image data to frequency domain image date.

[1008] As shown, a frequency domain graph **25-810** may include low frequency values **25-808** and high frequency values **25-812**. In one embodiment, the frequency domain graph **25-810** may be used to categorize the pixel data based on one or more frequency values. In one embodiment, a sum of values representing the top 25% **816** of frequency domain values may be used as the basis to generate a focus signal.

[1009] In one embodiment, if an image is very much out of focus, and a DCT was performed on the image, there may be very low frequency components. This, for example, may be contrasted with an image which is in focus, and which may include a higher sum of high frequency components (e.g. DC component goes down, etc.). In such an embodiment, a hardwired logic element may be used to analyze at least one or more lines of pixel data, the analysis including performing a frequency analysis.

[1010] In a particular embodiment, a line of pixel data may be inputted into a hardwired logic element and an operation may be performed on the pixel data, including a 1DFFT (e.g. FFT, etc.), producing a result including both high and low frequency data. A histogram showing the frequency data may be compiled based on summing frequency values lines comprising an image frame. In this embodiment, a new line of pixel data may be inputted into a hardwired logic element, with the end summation of frequency values being generated within a frequency histogram for a given frame. In this manner, a complete histogram may be built based on lines of pixel data comprising a frame of pixel data. In one embodiment, a histogram parameter, such as the median frequency point may represent a focus metric, and maximizing the focus metric over a range of focus positions for a lens within a camera module may correspond with the point at which the image may be in optimal focus. This operation of computing a frequency domain histogram may be performed for a sub-region within a frame, so as to focus an image about a focus point of interest. As shown, curve **25-818** depicts the focus metric as a function of lens focus position. As shown, a seeking operation may be performed to find a lens focus position that optimizes the focus metric. Of course, any technically feasible method may be used to compute the maximum value associated with the curve (e.g. derivative analysis, probability analysis based on tried values, etc.).

[1011] In this manner, in various embodiments, an entire image, or one or more points of interest associated with the image, may be used as the basis for computing the focus. In another embodiment, a set of 8×8 blocks of pixel data may be inputted into a hardwired element logic and an operation may be performed on the pixel data, including a DCT, producing a result including both high and low frequency data. The frequency values may be summed in a histogram for a particular range (and/or ranges) and the result may be used to generate the frequency histogram. In one embodiment, the frequency histogram may be used to compute the maximum value (e.g., a focus metric) based on multiple blocks of pixel data, rows of pixel data, columns of pixel data, etc., Of course, in some embodiments, the ability to focus may operate on any image data, including a scene and/or textual information, based on the foregoing descriptions. Additionally, in one embodiment, a focus metric for a particular frame may be the sum of the frequency components for that frame.

[1012] In other embodiments, a combination of software and hardware logic elements may be used to focus. For example, in one embodiment, a static scene may be entirely focused using hardware logic element. In another embodiment, however, a point of interest may be a child running around.

In such an embodiment, software may be employed to enable tracking of the point of interest, and hardware logic element may be used to focus based on the determined location as set by the software. Of course, in other embodiments, any combination of the hardware and software may be used to focus the pixel data.

[1013] As shown, a plot **25-820** of the focus metric versus focus position is shown. In one embodiment, curve **25-818** corresponds to the focus metric value as a function of focus position. Additionally, a first point **25-822** represents a first blurry focus position ("Blurry **1**"), and a second point **25-824** represents a second blurry focus position ("Blurry **2**"). Based on the first point **25-822** and the second point **25-824**, a correct point **25-826** is determined corresponding with the maximum focus metric point. In various embodiments, one or more processors may include two or more points along the focus metric curve **25-818** to determine a focus position. Of course, any method known in the art (e.g. take derivative to determine maximum, etc.) may be used to determine the highest focus metric value. In other embodiments, the focus metric curve **25-818** represents a simple sum of high frequency components for a frame. For example, focus metric **25-818** may represent a sum of the top 25% of frequency components as a function of focus position.

[1014] Embodiments of the present invention enable a digital photographic system to generate a digital image (or simply "image") of a photographic scene subjected to strobe illumination. Exemplary digital photographic systems include, without limitation, digital cameras and mobile devices such as smart phones that are configured to include a digital camera module and a strobe unit. A given photographic scene is a portion of an overall scene sampled by the digital photographic system.

[1015] The digital photographic system may capture separate image data for chrominance components (i.e., color) and luminance (i.e., intensity) components for a digital image. For example, a first image sensor may be used to capture chrominance data and a second image sensor may be used to capture luminance data. The second image sensor may be different than the first image sensor. For example, a resolution of the second image sensor may be higher than the first image sensor, thereby producing more detail related to the luminance information of the captured scene when compared to the chrominance information captured by the first image sensor. The chrominance information and the luminance information may then be combined to generate a resulting image that produces better images than captured with a single image sensor using conventional techniques.

[1016] In another embodiment, two or more images are sequentially sampled by the digital photographic system to generate an image set. Each image within the image set may be generated in conjunction with different strobe intensity, different exposure parameters, or a combination thereof. Exposure parameters may include sensor sensitivity ("ISO" parameter), exposure time (shutter speed), aperture size (f-stop), and focus distance. In certain embodiments, one or more exposure parameters, such as aperture size, may be constant and not subject to determination. For example, aperture size may be constant based on a given lens design associated with the digital photographic system. At least one of the images comprising the image set may be sampled in conjunction with a strobe unit, such as a light-emitting diode (LED) strobe unit, configured to contribute illumination to the photographic scene.

[1017] Separate image sets may be captured for chrominance information and luminance information. For example, a first image set may capture chrominance information under ambient illumination and strobe illumination at different strobe intensities and/or exposure parameters. A second image set may capture luminance information under the same settings. The chrominance information and luminance information may then be blended to produce a resulting image with greater dynamic range that could be captured using a single image sensor.

[1018] FIG. **26-1** illustrates a flow chart of a method **26-100** for generating a digital image, in accordance with one embodiment. Although method **26-100** is described in conjunction with the systems herein, persons of ordinary skill in the art will understand that any system that performs method **26-100** is within the scope and spirit of embodiments of the present invention. In one embodiment, a digital photographic system, such as digital photographic system **300** of FIG. **3**A, is configured to perform method **26-100**. The digital photographic system **300** may be implemented within a digital camera, such as digital camera **302** of FIG. **3**C, or a mobile device, such as mobile device **376** of FIG. **3**D.

[1019] Method **26-100** begins at step **26-102**, where a processor, such as processor complex **310**, receives a first image of an optical scene that includes a plurality of chrominance values (referred to herein as a chrominance image). The chrominance image may be captured using a first image sensor, such as a CMOS image sensor or a CCD image sensor. In one embodiment, the chrominance image includes a plurality of pixels, where each pixel is associated with a different color channel component (e.g., red, green, blue, cyan, magenta, yellow, etc.). In another embodiment, each pixel is associated with a tuple of values, each value in the tuple associated with a different color channel component (i.e., each pixel includes a red value, a blue value, and a green value).

[1020] At step **26-104**, the processor receives a second image of the optical scene that includes a plurality of luminance values (referred to herein as a luminance image). The luminance image may be captured using a second image sensor, which is different than the first image sensor. Alternatively, the luminance image may be captured using the first image sensor. For example, the chrominance values may be captured by a first subset of photodiodes of the first image sensor and the luminance values may be captured by a second subset of photodiodes of the first image sensor. In one embodiment, the luminance image includes a plurality of pixels, where each pixel is associated with an intensity component. The intensity component specifies a brightness of the image at that pixel. A bit depth of the intensity component may be equal to or different from a bit depth of each of the color channel components in the chrominance image. For example, each of the color channel components in the chrominance image may have a bit depth of 8 bits, but the intensity component may have a bit depth of 12 bits. The bit depths may be different where the first image sensor and the second image sensor sample analog values generated by the photodiodes in the image sensors using analog-to-digital converters (ADCs) having a different level of precision.

[1021] In one embodiment, each pixel in the chrominance image is associated with one or more corresponding pixels in the luminance image. For example, the chrominance image and the luminance image may have the same resolution and pixels in the chrominance image have a 1-to-1 mapping to corresponding pixels in the luminance image. Alternatively, the luminance image may have a higher resolution than the chrominance image, where each pixel in the chrominance image is mapped to two or more pixels in the luminance image. It will be appreciated that any manner of mapping the pixels in the chrominance image to the pixels in the luminance image is contemplated as being within the scope of the present invention.

[1022] At step **26-106**, the processor generates a resulting image based on the first image and second image. In one embodiment, the resulting image has the same resolution as the second image (i.e., the luminance image). For each pixel in the resulting image, the processor blends the chrominance information and the luminance information to generate a resulting pixel value in the resulting image. In one embodiment, the processor determines one or more pixels in the chrominance image associated with the pixel in the resulting image. For example, the processor may select a corresponding pixel in the chrominance image that includes a red value, a green value, and a blue value that specifies a color in an RGB color space. The processor may convert the color specified in the RGB color space to a Hue-Saturation-Value (HSV) color value. In the HSV model, Hue represents a particular color, Saturation represents a “depth” of the color (i.e., whether the color is bright and bold or dim and grayish), and the Value represents a lightness of the color (i.e., whether the color intensity is closer to black or white). The processor may also determine one or more pixels in the luminance image associated with the pixel in the resulting image. A luminance value may be determined from the one or more pixels in the luminance image. The luminance value may be combined with the Hue value and Saturation value determined from the chrominance image to produce a new color specified in the HSV model. The new color may be different from the color specified by the chrominance information alone because the luminance value may be captured more accurately with respect to spatial resolution or precision (i.e., bit depth, etc.). In one embodiment, the new color specified in the HSV model may be converted back into the RGB color space and stored in the resulting image. Alternatively, the color may be converted into any technically feasible color space representation, such as Y CrCb, R′G′B′, or other types of color spaces well-known in the art.

[1023] In one embodiment, the processor may apply a filter to a portion of the chrominance image to select a number of color channel component values from the chrominance image. For example, a single RGB value may be determined based on a filter applied to a plurality of individual pixel values in the chrominance image, where each pixel specifies a value for a single color channel component.

[1024] More illustrative information will now be set forth regarding various optional architectures and features with which the foregoing framework may or may not be implemented, per the desires of the user. It should be strongly noted that the following information is set forth for illustrative purposes and should not be construed as limiting in any manner. Any of the following features may be optionally incorporated with or without the exclusion of other features described.

[1025] In one embodiment, the first image may comprise a chrominance image generated by combining two or more chrominance images, as described in greater detail below. Furthermore, the second image may comprise a luminance image generated by combining two or more luminance images, as described in greater detail below.

[1026] FIG. **26-2** illustrates an image processing subsystem **26-200** configured to implement the method **26-100** of FIG. **26-1**, in accordance with one embodiment. In one embodiment, the image processing subsystem **26-200** includes a software module, executed by a processor, which causes the processor to generate the resulting image **26-250** from the chrominance image **26-202** and the luminance image **26-204**. The processor may be a highly parallel processor such as a graphics processing unit (GPU). In one embodiment, the software module may be a shader program, such as a pixel shader or fragment shader, which is executed by the GPU once per pixel in the resulting image **26-250**. Each of the chrominance image **26-202** and the luminance image **26-204** may be stored as texture maps in a memory and accessed by the shader program using, e.g., a texture cache of the GPU.

[1027] In one embodiment, each instance of the shader program is executed for a corresponding pixel of the resulting image **26-250**. Each pixel in the resulting image **26-250** is associated with a set of coordinates that specifies a location of the pixel in the resulting image **26-250**. The coordinates may be used to access values in the chrominance image **26-202** as well as values in the luminance image **26-204**. The values may be evaluated by one or more functions to generate a value(s) for the pixel in the resulting image **26-250**. In one embodiment, at least two instances of the shader program associated with different pixels in the resulting image **26-250** may be executed in parallel.

[1028] In another embodiment, the image processing subsystem **26-200** may be a special function unit such as a logic circuit within an application-specific integrated circuit (ASIC). The A SIC may include the logic circuit for generating the resulting image **26-250** from a chrominance image **26-202** and a luminance image **26-204**. In one embodiment, the chrominance image **26-202** is captured by a first image sensor at a first resolution and values for pixels in the chrominance image **26-202** are stored in a first format. Similarly, the luminance image **26-204** is captured by a second image sensor at a second resolution, which may be the same as or different from the first resolution, and values for pixels in the luminance image **26-204** are stored in a second format. The logic may be designed specifically for the chrominance image **26-202** at the first resolution and first format and the luminance image **26-204** at the second resolution and second format.

[1029] In yet another embodiment, the image processing subsystem **26-200** is a general purpose processor designed to process the chrominance image **26-202** and the luminance image **26-204** according to a specific algorithm. The chrominance image **26-202** and the luminance image **26-204** may be received from an external source. For example, the image processing subsystem **26-200** may be a service supplied by a server computer over a network. A source (i.e., a client device connected to the network) may send a request to the service to process a pair of images, including a chrominance image **26-202** and a luminance image **26-204**. The source may transmit the chrominance image **26-202** and luminance image **26-204** to the service via the network. The image processing subsystem **26-200** may be configured to receive a plurality of pairs of images from one or more sources (e.g., devices connected to the network) and process each pair of images to generate a corresponding plurality of resulting images **26-250**. Each resulting image **26-250** may be transmitted to the requesting source via the network.
[1030] As described above, a chrominance image and a luminance image may be combined to generate a resulting image that has better qualities than could be achieved with conventional techniques. For example, a typical image sensor may generate only chrominance data, which results in a perceived luminance from the combination of all color channel components. However, each individual color channel component may be sampled from a different discrete location and then combined to generate a digital image where each spatial location (i.e., pixel) is a combination of all color channel components. In other words, the digital image is a blurred version of the raw optical information captured by the image sensor. By utilizing luminance information that has not been filtered and then adding color component information to each pixel, a more precise digital image may be reproduced. Furthermore, splitting the capture of the chrominance information from the luminance information allows each component of the image to be captured separately, potentially with different image sensors tailored to each application. Such advantages will be discussed in more detail below.
[1031] FIG. **26-3**A illustrates a circuit diagram for a photosensitive cell **18-600**, in accordance with one possible embodiment. As an option, the cell **18-600** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the cell **18-600** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.
[1032] As shown in FIG. **26-3**A, a photosensitive cell **18-600** includes a photodiode **18-602** coupled to an analog sampling circuit **18-603**. The photodiode **18-602** may be implemented as any of the photodiodes **18-562**. In one embodiment, a unique instance of photosensitive cell **18-600** may implemented as each of cells **542-545** comprising a pixel **18-540** within the context of FIGS. **18-5**A-**18-5**E. The analog sampling circuit **18-603** comprises transistors **18-610**, **18-612**, **18-614**, and a capacitor **18-604**. In one embodiment, each of the transistors **18-610**, **18-612**, and **18-614** may be a field-effect transistor.
[1033] The photodiode **18-602** may be operable to measure or detect incident light **18-601** of a photographic scene. In one embodiment, the incident light **18-601** may include ambient light of the photographic scene. In another embodiment, the incident light **18-601** may include light from a strobe unit utilized to illuminate the photographic scene. In yet another embodiment, the incident light **18-601** may include ambient light and/or light from a strobe unit, where the composition of the incident light **18-601** changes as a function of exposure time. For example, the incident light **18-601** may include ambient light during a first exposure time, and light from a strobe unit during a second exposure time. Of course, the incident light **18-601** may include any light received at and measured by the photodiode **18-602**. Further still, and as discussed above, the incident light **18-601** may be concentrated on the photodiode **18-602** by a microlens, and the photodiode **18-602** may be one photodiode of a photodiode array that is configured to include a plurality of photodiodes arranged on a two-dimensional plane.
[1034] In one embodiment, each capacitor **18-604** may comprise gate capacitance for a transistor

18-610 and diffusion capacitance for transistor **18-614**. The capacitor **18-604** may also include additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any other technically feasible capacitor structures.

[1035] With respect to the analog sampling circuit **18-603**, when reset **18-616**(**0**) is active (e.g., high), transistor **18-614** provides a path from voltage source V2 to capacitor **18-604**, causing capacitor **18-604** to charge to the potential of V2. When reset **18-616**(**0**) is inactive (e.g., low), the capacitor **18-604** I allowed to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **18-602** in response to the incident light **18-601**. In this way, photodiode current I_PD is integrated for an exposure time when the reset **18-616**(**0**) is inactive, resulting in a corresponding voltage on the capacitor **18-604**. This voltage on the capacitor **18-604** may also be referred to as an analog sample. In embodiments, where the incident light **18-601** during the exposure time comprises ambient light, the sample may be referred to as an ambient sample; and where the incident light **18-601** during the exposure time comprises flash or strobe illumination, the sample may be referred to as a flash sample. When row select **18-634**(**0**) is active, transistor **18-612** provides a path for an output current from V1 to output **18-608**(**0**). The output current is generated by transistor **18-610** in response to the voltage on the capacitor **18-604**. When the row select **18-634**(**0**) is active, the output current at the output **18-608**(**0**) may therefore be proportional to the integrated intensity of the incident light **18-601** during the exposure time.

[1036] The sample may be stored in response to a photodiode current I_PD being generated by the photodiode **18-602**, where the photodiode current I_PD varies as a function of the incident light **18-601** measured at the photodiode **18-602**. In particular, a greater amount of incident light **18-601** may be measured by the photodiode **18-602** during a first exposure time including strobe or flash illumination than during a second exposure time including ambient illumination. Of course, characteristics of the photographic scene, as well as adjustment of various exposure settings, such as exposure time and aperture for example, may result in a greater amount of incident light **18-601** being measured by the photodiode **18-602** during the second exposure time including the ambient illumination than during the first exposure time including the strobe or flash illumination.

[1037] In one embodiment, the photosensitive cell **18-600** of FIG. **26-3**A may be implemented in a pixel array associated with a rolling shutter operation. As shown in FIG. **26-3**A, the components of the analog sampling circuit **18-603** do not include any mechanism for storing the analog sample for a temporary amount of time. Thus, the exposure time for a particular sample measured by the analog sampling circuit **18-603** may refer to the time between when reset **18-616**(**0**) is driven inactive and the time when the row select **634**(**0**) is driven active in order to generate the output current at output **18-608**(**0**).

[1038] It will be appreciated that because each column of pixels in the pixel array **18-510** may share a single column signal **18-532** transmitted to the column read-out circuitry **18-520**, and that a column signal **18-532** corresponds to the output **18-608**(**0**), that analog values from only a single row of pixels may be transmitted to the column read-out circuitry **18-520** at a time. Consequently, the rolling shutter operation refers to a manner of controlling the plurality of reset signals **18-616** and row select signals **18-634** transmitted to each row **18-534** of pixels **18-540** in the pixel array **18-510**. For example, a first reset signal **18-616**(**0**) may be asserted to a first row **18-534**(**0**) of pixels **18-540** in the pixel array **18-510** at a first time, t**0**. Subsequently, a second reset signal **18-616**(**1**) may be asserted to a second row **18-534**(**1**) of pixels **18-540** in the pixel array **18-510** at a second time, t**1**, a third reset signal **18-616**(**2**) may be asserted to a third row **18-534**(**2**) of pixels **18-540** in the pixel array **18-510** at a third time, t**2**, and so forth until the last reset signal **18-616**(*z*) is asserted to a last row **18-534**(*z*) of pixels **18-540** in the pixel array **18-510** at a last time, tz. Thus, each row **18-534** of pixels **18-540** is reset sequentially from a top of the pixel array **18-510** to the bottom of the pixel array **18-510**. In one embodiment, the length of time between asserting the reset signal **18-616** at each row may be related to the time required to read-out a row of sample data by the column read-out circuitry **18-520**. In one embodiment, the length of time between asserting the reset signal **18-616** at each row may be related to the number of rows **18-534** in the pixel array **18-510** divided by an exposure time between frames of image data.

[1039] In order to sample all of the pixels **18-540** in the pixel array **18-510** with a consistent exposure time, each of the corresponding row select signals **18-634** are asserted a delay time after the corresponding reset signal **18-616** is reset for that row **18-534** of pixels **18-540**, the delay time equal to the exposure time. The operation of sampling each row in succession, thereby capturing optical scene information for each row of pixels during different exposure time periods, may be referred to herein as a rolling shutter operation. While the circuitry included in an image sensor to perform a rolling shutter operation is simpler than other circuitry designed to perform a global shutter operation, discussed in more detail below, the rolling shutter operation can cause image artifacts to appear due to the motion of objects in the scene or motion of the camera. Objects may appear skewed in the image because the bottom of the object may have moved relative to the edge of a frame more than the top of the object when the analog signals for the respective rows **18-534** of pixels **18-540** were sampled.

[1040] FIG. **26-3**B illustrates a circuit diagram for a photosensitive cell **18-640**, in accordance with another possible embodiment. As an option, the cell **18-640** may be implemented in the context of any of the Figures disclosed herein. Of course, however, the cell **18-640** may be implemented in any desired environment. Further, the aforementioned definitions may equally apply to the description below.

[1041] As shown in FIG. **26-3**B, a photosensitive cell **18-640** includes a photodiode **18-602** coupled to an analog sampling circuit **18-643**. The photodiode **18-602** may be implemented as any of the photodiodes **18-562** of FIG. **18-5**E. In one embodiment, a unique instance of photosensitive cell **18-640** may implemented as each of cells **542-545** comprising a pixel **18-540** within the context of FIGS. **18-5**A-**18-5**E. The analog sampling circuit **18-643** comprises transistors **18-646**, **18-610**, **18-612**, **18-614**, and a capacitor **18-604**. In one embodiment, each of the transistors **18-646**, **18-610**, **18-612**, and **18-614** may be a field-effect transistor.

[1042] The transistors **18-610**, **18-612**, and **18-614** are similar in type and operation to the transistors **18-610**, **18-612**, and **18-614** of FIG. **26-3**A. The transistor **18-646** may be similar in type to the transistors **18-610**, **18-612**, and **18-614**, but the transistor **18-646** has the effect of turning capacitor **18-604** into an in-pixel-memory of an analog voltage value. In other words, the capacitor **18-604** is allowed to discharge in proportion to the photodiode current (I_PD) when the transistor **18-646** is active, and the capacitor **18-604** is prevented from discharging when the transistor **18-646** is inactive. The capacitor **18-604** may comprise gate capacitance for a transistor **18-610** and diffusion capacitance for transistors **18-614** and **646**. The capacitor **18-604** may also include additional circuit elements (not shown) such as, without limitation, a distinct capacitive structure, such as a metal-oxide stack, a poly capacitor, a trench capacitor, or any other technically feasible capacitor structures. Unlike analog sampling circuit **18-603**, analog sampling circuit **18-643** may be used to implement a global shutter operation where all pixels **18-540** in the pixel array are configured to generate a sample at the same time.

[1043] With respect to the analog sampling circuit **18-643**, when reset **18-616** is active (e.g., high), transistor **18-614** provides a path from voltage source V2 to capacitor **18-604**, causing capacitor **18-604** to charge to the potential of V2. When reset **18-616** is inactive (e.g., low), the capacitor **18-604** is allowed to discharge in proportion to a photodiode current (I_PD) generated by the photodiode **18-602** in response to the incident light **18-601** as long as the transistor **18-646** is active. Transistor **18-646** may be activated by asserting the sample signal **18-618**, which is utilized to control the exposure time of each of the pixels **18-540**. In this way, photodiode current I_PD is integrated for an exposure time when the reset **18-616** is inactive and the sample **18-618** is active, resulting in a corresponding voltage on the capacitor **18-604**. After the exposure time is complete, the sample signal **18-618** may be reset to deactivate transistor **18-646** and stop the capacitor from discharging. When row select **634**(**0**) is active, transistor **18-612** provides a path for an output current from V1 to output **18-608**(**0**). The output current is generated by transistor **18-610** in response to the voltage on the capacitor **18-604**. When the row select **634**(**0**) is active, the output current at the output **18-608**(**0**) may therefore be proportional to the integrated intensity of the incident light **18-601** during the exposure time.

[1044] In a global shutter operation, all pixels **18-540** of the pixel array **18-510** may share a global reset signal **18-616** and a global sample signal **18-618**, which control charging of the capacitors **18-604** and discharging of the capacitors **18-604** through the photodiode current I_PD. This effectively measures the amount of incident light hitting each photodiode **18-602** substantially simultaneously for each pixel **18-540** in the pixel array **18-510**. However, the external read-out circuitry for converting the analog values to digital values for each pixel may still require each row **18-534** of pixels **18-540** to be read out sequentially. Thus, after the global sample signal **18-618** is reset each corresponding row select signal **18-634** may be asserted and reset in order to read-out the analog values for each of the pixels. This is similar to the operation of the row select signal **18-634** in the rolling shutter operation except that the transistor **18-646** is inactive during this time such that any further accumulation of the charge in capacitor **18-604** is halted while all of the values are read.

[1045] It will be appreciated that other circuits for analog sampling circuits **18-603** and **643** may be implemented in lieu of the circuits set forth in FIGS. **18-3**A and **18-3**B, and that such circuits may be utilized to implement a rolling shutter operation or a global shutter operation, respectively. For example, the analog sampling circuits **18-603**, **18-643** may include per cell amplifiers (e.g., op-amps) that provide a gain for the voltage stored in capacitor **18-604** when the read-out is performed. In other embodiments, an analog sampling circuit **18-643** may include other types of analog memory implementations decoupled from capacitor **18-604** such that the voltage of capacitor **18-604** is stored in the analog memory when the sample signal **18-618** is reset and capacitor **18-604** is allowed to continue to discharge through the photodiode **18-602**. In yet another embodiment, each output **18-608** associated with a column of pixels may be coupled to a dedicated analog-to-digital converter (ADC) that enables the voltage at capacitor **18-604** to be sampled and converted substantially simultaneously for all pixels **18-540** in a row or portion of a row comprising the pixel array **18-510**. In certain embodiments, odd rows and even rows may be similarly coupled to dedicated ADC circuits to provide simultaneous conversion of all color information for a given pixel. In one embodiment, a white color cell comprising a pixel is coupled to an ADC circuit configured to provide a higher dynamic range (e.g., 12 bits or 14 bits) than a dynamic range for ADC circuits coupled to a cell having color (e.g., red, green, blue) filters (e.g., 8 bits or 10 bits).

[1046] FIG. **26-4**A illustrates a configuration of the camera module **330**, in accordance with one embodiment. As shown in FIG. **26-4**A, the camera module **330** may include two lenses **18-734** positioned above two image sensors **18-732**. A first lens **18-734**(**0**) is associated with a first image sensor **18-732**(**0**) and focuses optical scene information **752**(**0**) from a first viewpoint onto the first image sensor **18-732**(**0**). A second lens **18-734**(**1**) is associated with a second image sensor **18-732**(**1**) and focuses optical scene information **18-752**(**1**) from a second viewpoint onto the second image sensor **18-732**(**1**).

[1047] In one embodiment, the first image sensor **18-732**(**0**) may be configured to capture chrominance information associated with the scene and the second image sensor **18-732**(**1**) may be configured to capture luminance information associated with the scene. The first image sensor **18-732**(**0**) may be the same or different than the second image sensor **18-732**(**1**). For example, the first image sensor **18-732**(**0**) may be an 8 megapixel CMOS image sensor **18-732**(**0**) having a Bayer color filter array (CFA), as shown in the arrangement of pixel **18-540** of FIG. **18-5**B, that is configured to capture red, green, and blue color information; and the second image sensor **18-732**(**1**) may be a 12 megapixel CMOS image sensor **18-732**(**1**) having no color filter array (or a color filter array in which every cell is a white color filter) that is configured to capture intensity

information (over substantially all wavelengths of the visible spectrum).
[1048] In operation, the camera module **330** may receive a shutter release command from the camera interface **386**. The camera module **330** may reset both the first image sensor **18-732(0)** and the second image sensor **18-732(1)**. One or both of the first image sensor **18-732(0)** and the second image sensor **18-732(1)** may then be sampled under ambient light conditions (i.e., the strobe unit **336** is disabled). In one embodiment, both the first image sensor **18-732(0)** and the second image sensor **18-732(1)** are sampled substantially simultaneously to generate a chrominance image and a luminance image under ambient illumination. Once the pair of images (chrominance image and luminance image) has been captured, one or more additional pairs of images may be captured under ambient illumination (e.g., using different exposure parameters for each pair of images) or under strobe illumination. The additional pairs of images may be captured in quick succession (e.g., less than 200 milliseconds between sampling each simultaneously captured pair) such that relative motion between the objects in the scene and the camera, or relative motion between two distinct objects in the scene, is minimized.
[1049] In the camera module **330**, it may be advantageous to position the first lens **18-734(0)** and first image sensor **18-732(0)** proximate to the second lens **18-734(1)** and the second image sensor **18-732(0)** in order to capture the images of the scene from substantially the same viewpoint. Furthermore, direction of the field of view for both the first image sensor **18-732(0)** and the second image sensor **18-732(1)** should be approximately parallel. Unlike stereoscopic cameras configured to capture two images using parallax to represent depth of objects within the scene, the pair of images captured by the first image sensor **18-732(0)** and the second image sensor **18-732(1)** is not meant to capture displacement information for a given object from two disparate viewpoints.
[1050] One aspect of the invention is to generate a new digital image by combining the chrominance image with the luminance image to generate a more detailed image of a scene than could be captured with a single image sensor. In other words, the purpose of having two image sensors in the same camera module **330** is to capture different aspects of the same scene to create a blended image. Thus, care should be taken to minimize any differences between the images captured by the two image sensors. For example, positioning the first image sensor **18-732(0)** and the second image sensor **18-732(1)** close together may minimize image artifacts resulting from parallax of nearby objects. This may be the opposite approach taken for cameras designed to capture stereoscopic image data using two image sensors in which the distance between the two image sensors may be selected to mimic an intra-ocular distance of the human eyes.
[1051] In one embodiment, the images generated by the first image sensor **18-732(0)** and the second image sensor **18-732(1)** are close enough that blending the two images will not results in any image artifacts. In another embodiment, one of the images may be warped to match the other image to correct for the disparate viewpoints. There are many techniques available to warp one image to match another and any technically feasible technique may be employed to match the two images. For example, homography matrices may be calculated that describe the transformation from a portion (i.e., a plurality of pixels) of one image to a portion of another image. A homography matrix may describe a plurality of affine transformations (e.g., translation, rotation, scaling, etc.) that, when applied to a portion of an image, transform the portion of the image into another portion of a second image. By applying the homography matrices to various portions of the first image, the first image may be warped to match the second image. In this manner, any image artifacts resulting from blending the first image with the second image may be reduced.
[1052] In one embodiment, each of the image sensors **18-732** may be configured to capture an image using either a rolling shutter operation or a global shutter operation. The image sensors **18-732** may be configured to use the same type of shutter operation or different shutter operations. For example, the first image sensor **18-732(0)** configured to capture chrominance information may be a cheaper image sensor that only includes analog sampling circuitry capable of implementing in a rolling shutter operation. In contrast, the second image sensor **18-732(1)** configured to capture

luminance information may be a more expensive image sensor that includes more advanced analog sampling circuitry capable of implementing a global shutter operation. Thus, the first image may be captured according to a rolling shutter operation while the second image may be captured according to a global shutter operation. Of course, both image sensors **18-732** may be configured to use the same shutter operation, either a rolling shutter operation or a global shutter operation. The type of shutter operation implemented by the image sensor **18-732** may be controlled by a control unit, such as control unit **18-514**, included in the image sensor **18-732** and may be triggered by a single shutter release command.

[1053] FIG. **26-4**B illustrates a configuration of the camera module **330**, in accordance with another embodiment. As shown in FIG. **26-4**B, the camera module **330** may include a lens **18-734** positioned above a beam splitter **18-736**. The beam splitter **18-736** may act to split the optical information **18-752** received through the lens **18-734** into two separate transmission paths. The beam splitter **18-736** may be a cube made from two triangular glass prisms, a pellicle mirror like those typically utilized in single-lens reflex (SLR) cameras, or any other type of device capable of splitting a beam of light into two different directions. A first beam of light is directed onto the first image sensor **18-732(0)** and a second beam of light is directed onto the second image sensor **18-732(1)**. In one embodiment, the first beam of light and the second beam of light include approximately the same optical information for the scene.

[1054] The two transmission paths focus the optical information **18-752** from the same viewpoint onto both the first image sensor **18-732(0)** and the second image sensor **18-732(1)**. Because the same beam of light is split into two paths, it will be appreciated that intensity of light reaching each of the image sensors **18-732** is decreased. In order to compensate for the decrease in light reaching the image sensors, the exposure parameters can be adjusted (e.g., increasing the time between resetting the image sensor and sampling the image sensor to allow more light to activate the charge of each of the pixel sites). Alternatively, a gain applied to the analog signals may be increased, but this may also increase the noise in the analog signals as well.

[1055] FIG. **26-4**C illustrates a configuration of the camera module **330**, in accordance with yet another embodiment. As shown in FIG. **26-4**C, the camera module **330** may include a lens **18-734** positioned above a single image sensor **18-732**. The optical information **18-752** is focused onto the image sensor **18-732** by the lens **18-734**. In such embodiments, both the chrominance information and the luminance information may be captured by the same image sensor. A color filter array (CFA) may include a plurality of different color filters, each color filter positioned over a particular photodiode of the image sensor **18-732** to filter the wavelengths of light that are measured by that particular photodiode. Some color filters may be associated with photodiodes configured to measure chrominance information, such as red color filters, blue color filters, green color filters, cyan color filters, magenta color filters, or yellow color filters. Other color filters may be associated with photodiodes configured to measure luminance information, such as white color filters. As used herein, white color filters are filters that allow a substantially uniform amount of light across the visible spectrum to pass through the color filter. The color filters in the CFA may be arranged such that a first portion of the photodiodes included in the image sensor **18-732** capture samples for a chrominance image from the optical information **18-752** and a second portion of the photodiodes included in the image sensor **18-732** capture samples for a luminance image from the optical information **18-752**.

[1056] In one embodiment, the each pixel in the image sensor **18-732** may be configured with a plurality of filters as shown in FIG. **18-5**C. The photodiodes associated with the red, green, and blue color filters may capture samples included in the chrominance image as an RGB tuple. The photodiodes associated with the white color filter may capture samples included in the luminance image. It will be appreciated that each pixel **18-540** in the pixel array **18-510** of the image sensor **18-732** will produce one color in an RGB format stored in the chrominance image as well as an intensity value stored in a corresponding luminance image. In other words, the chrominance image

and the luminance image will have the same resolution with one value per pixel.
[1057] In another embodiment, the each pixel in the image sensor **18-732** may be configured with a plurality of filters as shown in FIG. **18-5**D. The photodiodes associated with the cyan, magenta, and yellow color filters may capture samples included in the chrominance image as a CMY tuple. The photodiodes associated with the white color filter may capture samples included in the luminance image. It will be appreciated that each pixel **18-540** in the pixel array **18-510** of the image sensor **18-732** will produce one color in a CMY format stored in the chrominance image as well as an intensity value stored in a corresponding luminance image.
[1058] In yet another embodiment, the CFA may contain a majority of color filters for producing luminance information and a minority of color filters for producing chrominance information (e.g., 60% white, 10% red, 20% green, and 10% blue, etc.). Having a majority of the color filters being related to collecting luminance information will produce a higher resolution luminance image compared to the chrominance image. In one embodiment, the chrominance image has a lower resolution than the luminance image, due to the fewer number of photodiodes associated with the filters of the various colors. Furthermore, various techniques may be utilized to interpolate or “fill-in” values of either the chrominance image or the luminance image to fill in values associated with photodiodes that captured samples for the luminance image or chrominance image, respectively. For example, an interpolation of two or more values in the chrominance image or the luminance image may be performed to generate virtual samples in the chrominance image or the luminance image. It will be appreciated that a number of techniques for converting the raw digital pixel data associated with the individual photodiodes into a chrominance image and/or a luminance image may be implemented and is within the scope of the present invention.
[1059] FIG. **26-5** illustrates a flow chart of a method **18-800** for generating a digital image, in accordance with one embodiment. Although method **18-800** is described in conjunction with the systems herein, persons of ordinary skill in the art will understand that any system that performs method **18-800** is within the scope and spirit of embodiments of the present invention. In one embodiment, a digital photographic system, such as digital photographic system **300** of FIG. **3**A, is configured to perform method **18-800**. The digital photographic system **300** may be implemented within a digital camera, such as digital camera **302** of FIG. **3**C, or a mobile device, such as mobile device **376** of FIG. **3**D.
[1060] The method **18-800** begins at step **26-802**, where the digital photographic system **300** samples an image under ambient illumination to determine white balance parameters for the scene. For example, the white balance parameters may include separate linear scale factors for red, green, and blue for a gray world model of white balance. The white balance parameters may include quadratic parameters for a quadratic model of white balance, and so forth. In one embodiment, the digital photographic system **300** causes the camera module **330** to capture an image with one or more image sensors **332**. The digital photographic system **300** may then analyze the captured image to determine appropriate white balance parameters. In one embodiment, the white balance parameters indicate a color shift to apply to all pixels in images captured with ambient illumination. In such an embodiment, the white balance parameters may be used to adjust images captured under ambient illumination. A strobe unit **336** may produce a strobe illumination of a pre-set color that is sufficient to reduce the color shift caused by ambient illumination. In another embodiment, the white balance parameters may identify a color for the strobe unit **336** to generate in order to substantially match the color of ambient light during strobe illumination. In such an embodiment, the strobe unit **336** may include red, green, and blue LEDs, or, separately, a set of discrete LED illuminators having different phosphor mixes that each produce different, corresponding chromatic peaks, to create color-controlled strobe illumination. The color-controlled strobe illumination may be used to match scene illumination for images captured under only ambient illumination and images captured under both ambient illumination and color-controlled strobe illumination.
[1061] At step **26-804**, the digital photographic system **300** captures (i.e., samples) two or more

images under ambient illumination. In one embodiment, the two or more images include a chrominance image **26-202** from a first image sensor **332**(**0**) and a luminance image **26-204** from a second image sensor **332**(**1**) that form an ambient image pair. The ambient image pair may be captured using a first set of exposure parameters.

[1062] In one embodiment, the two or more images may also include additional ambient image pairs captured successively using different exposure parameters. For example, a first image pair may be captured using a short exposure time that may produce an underexposed image. Additional image pairs may capture images with increasing exposure times, and a last image pair may be captured using a long exposure time that may produce an overexposed image. These images may form an image set captured under ambient illumination. Furthermore, these images may be combined in any technically feasible HDR blending or combining technique to generate an HDR image, including an HDR image rendered into a lower dynamic range for display. Additionally, these images may be captured using a successive capture rolling shutter technique, whereby complete images are captured at successively higher exposures by an image sensor before the image sensor is reset in preparation for capturing a new set of images.

[1063] At step **26-806**, the digital photographic system **300** may enable a strobe unit **336**. The strobe unit **336** may be enabled at a specific time prior to or concurrent with the capture of an image under strobe illumination. Enabling the strobe unit **336** should cause the strobe unit **336** to discharge or otherwise generate strobe illumination. In one embodiment, enabling the strobe unit **336** includes setting a color for the strobe illumination. The color may be set by specifying an intensity level of each of a red, green, and blue LED to be discharged substantially simultaneously; for example the color may be set in accordance with the white balance parameters.

[1064] At step **26-808**, the digital photographic system **300** captures (i.e., samples) two or more images under strobe illumination. In one embodiment, the two or more images include a chrominance image **26-202** from a first image sensor **332**(**0**) and a luminance image **26-204** from a second image sensor **332**(**1**) that form a strobe image pair. The strobe image pair may be captured using a first set of exposure parameters.

[1065] In one embodiment, the two or more images may also include additional pairs of chrominance and luminance images captured successively using different exposure parameters. For example, a first image pair may be captured using a short exposure time that may produce an underexposed image. Additional image pairs may capture images with increasing exposure times, and a last image pair may be captured using a long exposure time that may produce an overexposed image. The changing exposure parameters may also include changes to the configuration of the strobe illumination unit **336**, such as an intensity of the discharge or a color of the discharge. These images may form an image set captured under strobe illumination. Furthermore, these images may be combined in any technically feasible HDR blending or combining technique to generate an HDR image, including an HDR image rendered into a lower dynamic range for display. Additionally, these images may be captured using a successive capture rolling shutter technique, whereby complete images are captured at successively higher exposures by an image sensor before the image sensor is reset in preparation for capturing a new set of images.

[1066] At step **26-810**, the digital photographic system **300** generates a resulting image from the at least two images sampled under ambient illumination and the at least two images sampled under strobe illumination. In one embodiment, the digital photographic system **300** blends the chrominance image sampled under ambient illumination with the chrominance image sampled under strobe illumination. In another embodiment, the digital photographic system **300** blends the luminance image sampled under ambient illumination with the luminance image sampled under strobe illumination. In yet another embodiment, the digital photographic system **300** may blend a chrominance image sampled under ambient illumination with a chrominance image sampled under strobe illumination to generate a consensus chrominance image, such as through averaging, or weighted averaging. The consensus chrominance image may then be blended with a selected luminance image, the selected luminance image being sampled under ambient illumination or strobe illumination, or a combination of both luminance images.

[1067] In one embodiment, blending two images may include performing an alpha blend between corresponding pixel values in the two images. In such an embodiment, the alpha blend weight may be determined by one or more pixel attributes (e.g., intensity) of a pixel being blended, and may be further determined by pixel attributes of surrounding pixels. In another embodiment, blending the two images may include, for each pixel in the resulting image, determining whether a corresponding pixel in a first image captured under ambient illumination is underexposed. If the pixel is underexposed, then the pixel in the resulting image is selected from the second image captured under strobe illumination. Blending the two images may also include, for each pixel in the resulting image, determining whether a corresponding pixel in a second image captured under strobe illumination is overexposed. If the pixel is overexposed, then the pixel in the resulting image is selected from the first image captured under ambient illumination. If pixel in the first image is not underexposed and the pixel in the second image is not overexposed, then the pixel in the resulting image is generated based on an alpha blend between corresponding pixel values in the two images. Furthermore, any other blending technique or techniques may be implemented in this context without departing the scope and spirit of embodiments of the present invention.

[1068] In one embodiment, the at least two images sampled under ambient illumination may include two or more pairs of images sampled under ambient illumination utilizing different exposure parameters. Similarly, the at least two images sampled under strobe illumination may include two or more pairs of images sampled under strobe illumination utilizing different exposure parameters. In such an embodiment, blending the two images may include selecting two pairs of images captured under ambient illumination and selecting two pairs of images captured under strobe illumination. The two pairs of images sampled under ambient illumination may be blended using any technically feasible method to generate a blended pair of images sampled under ambient illumination. Similarly, the two pairs of images sampled under strobe illumination may be blended using any technically feasible method to generate a blended pair of images sampled under strobe illumination. Then, the blended pair of images sampled under ambient illumination may be blended with the blended pair of images sampled under strobe illumination.

[1069] FIG. **26-6**A illustrates a viewer application **26-910** configured to generate a resulting image **26-942** based two image sets **26-920**, in accordance with one embodiment. A first image set **26-920**(**0**) includes two or more source images **26-922**, which may be generated by sampling a first image sensor **18-732**(**0**) of the camera module **330**. The source images **26-922** may correspond to chrominance images. A second image set **26-920**(**1**) includes two or more source images **26-923**, which may be generated by sampling a second image sensor **18-732**(**1**) of the camera module **330**. The source images **26-923** may correspond to luminance images. Each source image **26-922** in the first image set **26-920**(**0**) has a corresponding source image **26-923** in the second image set **26-920**(**1**). In another embodiment, the source images **26-922** may be generated by sampling a first portion of photodiodes in an image sensor **18-732** and the source images **26-923** may be generated by sampling a second portion of photodiodes in the image sensor **18-732**.

[1070] In one embodiment, the resulting image **26-942** represents a pair of corresponding source images **26-922** (*i*), **923** (*i*) that are selected from the image set **26-920**(**0**) and **920**(**1**), respectively, and blended using a color space blend technique, such as the HSV technique described above in conjunction with FIGS. **26-1** & **26-2**. The pair of corresponding source images may be selected according to any technically feasible technique. For example, a given source image **26-922** from the first image set **26-920**(**0**) may be selected automatically based on exposure quality. Then, a corresponding source image **26-923** from the second image set **26-920**(**1**) may be selected based on the source image **26-922** selected in the first image set **26-920**(**0**).

[1071] Alternatively, a pair of corresponding source images may be selected manually through a UI control **26-930**, discussed in greater detail below in FIG. **26-6**B. The UI control **26-930** generates a selection parameter **26-918** that indicates the manual selection. An image processing subsystem **26-912** is configured to generate the resulting image **26-942** by blending the selected source image **26-922** with the corresponding source image **26-923**. In certain embodiments, the image processing subsystem **26-912** automatically selects a pair of corresponding source images and transmits a corresponding recommendation **26-919** to the UI control **26-930**. The recommendation **26-919** indicates, through the UI control **26-930**, which pair of corresponding source images was automatically selected. A user may keep the recommendation or select a different pair of corresponding source images using the UI control **26-930**.

[1072] In an alternative embodiment, viewer application **26-910** is configured to combine two or more pairs of corresponding source images to generate a resulting image **26-942**. The two or more pairs of corresponding source images may be mutually aligned by the image processing subsystem **26-912** prior to being combined. Selection parameter **26-918** may include a weight assigned to each of two or more pairs of corresponding source images. The weight may be used to perform a transparency/opacity blend (known as an alpha blend) between two or more pairs of corresponding source images.

[1073] In certain embodiments, source images **26-922**(**0**) and **923**(**0**) are sampled under exclusively ambient illumination, with the strobe unit off. Source image **26-922**(**0**) is generated to be white-balanced, according to any technically feasible white balancing technique. Source images **26-922**(**1**) through **922**(N−1) as well as corresponding source images **26-923**(**1**) though **923**(N−1) are sampled under strobe illumination, which may be of a color that is discordant with respect to ambient illumination. Source images **26-922**(**1**) through **922**(N−1) may be white-balanced according to the strobe illumination color. Discordance in strobe illumination color may cause certain regions to appear incorrectly colored with respect to other regions in common photographic settings. For example, in a photographic scene with foreground subjects predominantly illuminated by white strobe illumination and white-balanced accordingly, background subjects that are predominantly illuminated by incandescent lights may appear excessively orange or even red.

[1074] In one embodiment, spatial color correction is implemented within image processing subsystem **26-912** to match the color of regions within a selected source image **26-922** to that of source image **26-922**(**0**). Spatial color correction implements regional color-matching to ambient-illuminated source image **26-922**(**0**). The regions may range in overall scene coverage from individual pixels, to blocks of pixels, to whole frames. In one embodiment, each pixel in a color-corrected image includes a weighted color correction contribution from at least a corresponding pixel and an associated block of pixels.

[1075] In certain implementations, viewer application **26-910** includes an image cache **26-916**, configured to include a set of cached images corresponding to the source images **26-922**, but rendered to a lower resolution than source images **26-922**. The image cache **26-916** provides images that may be used to readily and efficiently generate or display resulting image **26-942** in response to real-time changes to selection parameter **26-918**. In one embodiment, the cached images are rendered to a screen resolution of display unit **312**. When a user manipulates the UI control **26-930** to select a pair of corresponding source images, a corresponding cached image may be displayed on the display unit **312**. The cached images may represent a down-sampled version of a resulting image **26-942** generated based on the selected pair of corresponding source images. Caching images may advantageously reduce power consumption associated with rendering a given corresponding pair of source images for display. Caching images may also improve performance by eliminating a rendering process needed to resize a given corresponding pair of source images for display each time UI control **1530** detects that a user has selected a different corresponding pair of source images.

[1076] FIG. **26-6**B illustrates an exemplary user interface associated with the viewer application **26-910** of FIG. **26-6**A, in accordance with one embodiment. The user interface comprises an application window **26-940** configured to display the resulting image **26-942** based on a position of the UI control **26-930**. The viewer application **26-910** may invoke the UI control **26-930**, configured to generate the selection parameter **26-918** based on a position of a control knob **26-934**. The recommendation **26-919** may determine an initial position of the control knob **26-934**, corresponding to a recommended corresponding pair of source images. In one embodiment, the UI control **26-930** comprises a linear slider control with a control knob **26-934** configured to slide along a slide path **26-932**. A user may position the control knob **26-934** by performing a slide gesture. For example, the slide gesture may include touching the control knob **26-934** in a current position, and sliding the control knob **26-934** to a new position. Alternatively, the user may touch along the slide path **26-932** to move the control knob **26-934** to a new position defined by a location of the touch.

[1077] In one embodiment, positioning the control knob **26-934** into a discrete position **26-936** along the slide path **26-932** causes the selection parameter **26-918** to indicate selection of a source image **26-922** (*i*) in the first image set **26-920**(**0**) and a corresponding source image **26-923** in the second image set **26-920**(**1**). For example, a user may move control knob **26-934** into discrete position **26-936**(**3**), to indicate that source image **26-922**(**3**) and corresponding source image **26-923**(**3**) are selected. The UI control **26-930** then generates selection parameter **26-918** to indicate that source image **26-922**(**3**) and corresponding source image **26-923**(**3**) are selected. The image processing subsystem **26-912** responds to the selection parameter **26-918** by generating the resulting image **26-942** based on source image **26-922**(**3**) and corresponding source image **26-923**(**3**). The control knob **26-934** may be configured to snap to a closest discrete position **26-936** when released by a user withdrawing their finger.

[1078] In an alternative embodiment, the control knob **26-934** may be positioned between two discrete positions **26-936** to indicate that resulting image **26-942** should be generated based on two corresponding pairs of source images. For example, if the control knob **26-934** is positioned between discrete position **26-936**(**3**) and discrete position **26-936** (**4**), then the image processing subsystem **26-912** generates resulting image **26-942** from source images **26-922**(**3**) and **922**(**4**) as well as source images **26-923**(**3**) and **923**(**4**). In one embodiment, the image processing subsystem **26-912** generates resulting image **26-942** by aligning source images **26-922**(**3**) and **922**(**4**) as well as source images **26-923**(**3**) and **923**(**4**), and performing an alpha-blend between the aligned images according to the position of the control knob **26-934**. For example, if the control knob **26-934** is positioned to be one quarter of the distance from discrete position **26-936**(**3**) to discrete position **26-936**(**4**) along slide path **26-932**, then an aligned image corresponding to source image **26-922** (**4**) may be blended with twenty-five percent opacity (seventy-five percent transparency) over a fully opaque aligned image corresponding to source image **26-922**(**3**).

[1079] In one embodiment, UI control **26-930** is configured to include a discrete position **26-936** for each source image **26-922** within the first image set **26-920**(**0**). Each image set **26-920** stored within the digital photographic system **300** of FIG. **3**A may include a different number of source images **26-922**, and UI control **26-930** may be configured to establish discrete positions **26-936** to correspond to the source images **26-922** for a given image set **26-920**.

[1080] FIG. **26-6**C illustrates a system for generating a resulting image from a high dynamic range chrominance image and a high dynamic range luminance image, in accordance with one embodiment. The image sets **26-920** enable a user to generate a high dynamic range (HDR) image. For example, the sensitivity of an image sensor is limited. While some portions of the scene are bright, other portions may be dim. If the brightly lit portions of the scene are captured within the dynamic range of the image sensor, then the dimly lit portions of the scene may not be captured with sufficient detail (i.e., the signal to noise ratio at low analog values may not allow for sufficient details to be seen). In such cases, the image sets may be utilized to create HDR versions of both the chrominance image and the luminance image. In certain embodiments, luminance images may be sampled at an inherently higher analog dynamic range, and in one embodiment, one luminance image provides an HDR image for luminance.

[1081] A chrominance HDR module **26-980** may access two or more of the source images **26-922** to create an HDR chrominance image **26-991** with a high dynamic range. Similarly a luminance HDR module **26-990** may access two or more of the source images **26-923** to create an HDR luminance image **26-992** with a high dynamic range. The chrominance HDR module **26-980** and the luminance HDR module **26-990** may generate HDR images under any feasible technique, including techniques well-known in the art. The image processing subsystem **26-912** may then combine the HDR chrominance image **26-991** with the HDR luminance image **26-992** to generate the resulting image **26-942** as described above with respect to a single source image **26-922** and a single corresponding source image **26-923**.
[1082] One advantage of the present invention is that a user may photograph a scene using a single shutter release command, and subsequently select an image sampled according to a strobe intensity that best satisfies user aesthetic requirements for the photographic scene. The one shutter release command causes a digital photographic system to rapidly sample a sequence of images with a range of strobe intensity and/or color. For example, twenty or more full-resolution images may be sampled within one second, allowing a user to capture a potentially fleeting photographic moment with the advantage of strobe illumination. Furthermore, the captured images may be captured using one or more image sensors for capturing separate chrominance and luminance information. The chrominance and luminance information may then be blended to produce the resulting images.
[1083] While various embodiments have been described above with respect to a digital camera **302** and a mobile device **376**, any device configured to perform at least one aspect described herein is within the scope and spirit of the present invention. In certain embodiments, two or more digital photographic systems implemented in respective devices are configured to sample corresponding image sets in mutual time synchronization. A single shutter release command may trigger the two or more digital photographic systems.
[1084] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

Claims

1. An apparatus, comprising: an image sensor including a plurality of cells including: a first cell having a first photodiode generating a first analog signal, and a second cell having a second photodiode generating a second analog signal, for being utilized to generate at least a portion of one or more line analog signals; a line in communication with the plurality of cells, the line communicating the one or more line analog signals; at least one analog-to-digital channel in communication with the line, the at least one analog-to-digital channel capable of receiving at least one of the one or more line analog signals for conversion thereof to a first line digital signal; and circuitry in communication with the at least one analog-to-digital channel, the circuitry capable of receiving the first line digital signal, for image generation.
2. The apparatus of claim 1, wherein the apparatus is configured such that, in response to a user input to capture a photographic scene: the at least portion of a first image is generated for the photographic scene with a first brightness level, at least a portion of a second image is generated for the photographic scene with a second brightness level, and the at least portion of the first image is combined with the at least portion of the second image to generate at least one high dynamic range (HDR) image.
3. The apparatus of claim 1, wherein the apparatus is configured such that the plurality of cells are each sampled with at least three different exposure times to generate at least three analog signals for being utilized to generate at least a portion of at least three different images including the at

least portion of a first image, at least portion of a second image, and at least portion of a third image, based on which at least one high dynamic range (HDR) image is generated.

4. The apparatus of claim 1, wherein the apparatus includes a mobile device including: a touch screen; one or more non-transitory memories; and one or more processors in communication with the touch screen, the one or more non-transitory memories, the image sensor, and the circuitry, wherein the one or more processors execute instructions in the one or more non-transitory memories, to cause the apparatus to: display, utilizing the touch screen, a photographic scene; receive, utilizing the touch screen, user input in connection with the photographic scene; based on the user input, identify a point of interest in the photographic scene; based on the identification of the point of interest in the photographic scene, identify information associated with the point of interest; based on the information associated with the point of interest, set one or more parameters for generating one or more analog signals, to generate a first digital image and a second digital image both including the point of interest in the photographic scene utilizing the at least one analog-to-digital channel; and generate a resulting HDR image based on combining at least a portion of the first digital image and at least a portion of the second digital image.

5. The apparatus of claim 4, wherein the apparatus is configured such that zero-interframe time exists between the generation of the first digital image and the second digital image.

6. The apparatus of claim 4, wherein the apparatus is configured such that one or more other analog signals is generated to generate a third digital image and a fourth digital image both including the point of interest in the photographic scene that are combined to generate another resulting HDR image, where yet another resultant HDR image is generated based on a combination of at least a portion of the resulting HDR image and at least a portion of the another resulting HDR image.

7. The apparatus of claim 4, wherein the apparatus is configured such that the at least portion of the first digital image and the at least portion of the second digital image are each generated by having one or more gains applied while being generated.

8. The apparatus of claim 1, wherein the apparatus includes a mobile device including: a touch screen; one or more non-transitory memories; and one or more processors in communication with the touch screen, the one or more non-transitory memories, the image sensor, and the circuitry, wherein the one or more processors execute instructions in the one or more non-transitory memories, to cause the apparatus to: display, utilizing the touch screen, a photographic scene; automatically identify a human face in the photographic scene; based on the identification of the human face in the photographic scene, identify information associated with the human face; based on the information associated with the human face, set one or more parameters for generating one or more analog signals, to generate a first digital image and a second digital image both including the human face in the photographic scene, utilizing the at least one analog-to-digital channel; and generate a resulting HDR image based on combining at least a portion of the first digital image and at least a portion of the second digital image.

9. The apparatus of claim 8, wherein the apparatus is configured such that the one or more parameters include an exposure parameter.

10. The apparatus of claim 1, wherein the apparatus includes a mobile device including: a touch screen; one or more non-transitory memories; and one or more processors in communication with the touch screen, the one or more non-transitory memories, the image sensor, and the circuitry, wherein the one or more processors execute instructions in the one or more non-transitory memories, to cause the apparatus to: display, utilizing the touch screen, a photographic scene; receive, utilizing the touch screen, user input in connection with the photographic scene; based on the user input, identify a point of interest in the photographic scene; generate one or more analog signals, to generate a first digital image and a second digital image both including the point of interest in the photographic scene, utilizing the at least one analog-to-digital channel; based on the identification of the point of interest in the photographic scene, identify information associated with the point of interest; based on the information associated with the point of interest, identify at least one of: at least a portion of the first digital image or at least a portion of the second digital image; and generate a resulting HDR image based on combining at least part of the first digital image and at least part of the second digital image, utilizing the least one of: the at least portion of the first digital image or the at least portion of the second digital image, that is identified based on the information associated with the point of interest.

11. The apparatus of claim 1, wherein the apparatus includes a mobile device including: a touch screen; one or more non-transitory memories; and one or more processors in communication with the touch screen, the one or more non-transitory memories, the image sensor, and the circuitry, wherein the one or more processors execute instructions in the one or more non-transitory memories, to cause the apparatus to: display, utilizing the touch screen, a photographic scene; automatically identify a human face in the photographic scene; based on the identification of the human face in the photographic scene, identify information associated with the human face; generate one or more analog signals, to generate a first digital image and a second digital image both including the human face in the photographic scene, utilizing at least one of the first analog-to-digital channel or the second analog-to-digital channel; based on the identification of the human face in the photographic scene, identify information associated with the human face; based on the information associated with the human face, identify at least one of: at least a portion of the first digital image or at least a portion of the second digital image; and generate a resulting HDR image based on combining at least part of the first digital image and at least part of the second digital image, utilizing the least one of: the at least portion of the first digital image or the at least portion of the second digital image, that is identified based on the information associated with the human face.

12. The apparatus of claim 1, wherein the apparatus is configured such that a first one of the one or more line analog signals is generated by sampling the first analog signal a first time and a second one of the one or more line analog signals is generated by sampling the first analog signal a second time.
