US 20100265316A1

(19) **United States**
(12) **Patent Application Publication**
Sali et al.
(10) **Pub. No.: US 2010/0265316 A1**
(43) **Pub. Date: Oct. 21, 2010**

(54) **THREE-DIMENSIONAL MAPPING AND IMAGING**

(75) Inventors: **Erez Sali**, Savyon (IL); **Assaf Avraham**, Givatayim (IL)

Correspondence Address:
D. Kligler I.P. Services LTD
P.O. Box 25
Zippori 17910 (IL)

(73) Assignee: **PRIMESENSE LTD.**, Tel Aviv (IL)

(21) Appl. No.: **12/758,047**

(22) Filed: **Apr. 12, 2010**

Related U.S. Application Data

(60) Provisional application No. 61/169,728, filed on Apr. 16, 2009, now abandoned, provisional application No. 61/171,087, filed on Apr. 21, 2009.

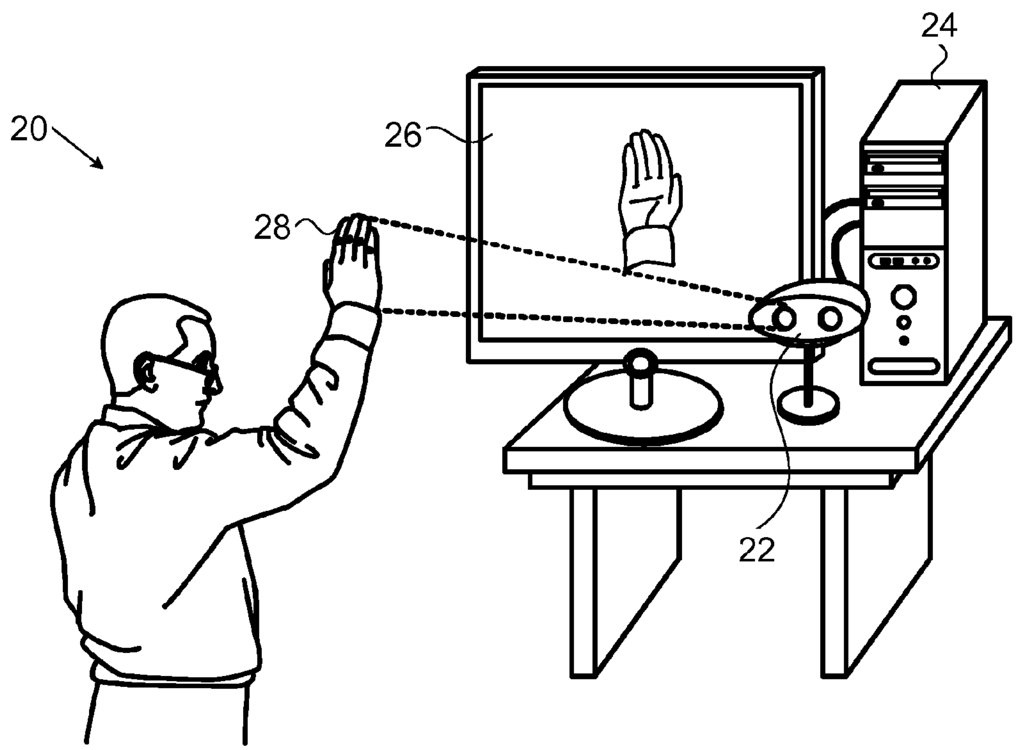
Publication Classification

(51) **Int. Cl.**
H04N 13/02 (2006.01)

(52) **U.S. Cl.** **348/46**; 348/E13.074

(57) **ABSTRACT**

Imaging apparatus includes an illumination subassembly, which is configured to project onto an object a pattern of monochromatic optical radiation in a given wavelength band. An imaging subassembly includes an image sensor, which is configured both to capture a first, monochromatic image of the pattern on the object by receiving the monochromatic optical radiation reflected from the object and to capture a second, color image of the object by receiving polychromatic optical radiation, and to output first and second image signals responsively to the first and second images, respectively. A processor is configured to process the first and second signals so as to generate and output a depth map of the object in registration with the color image.



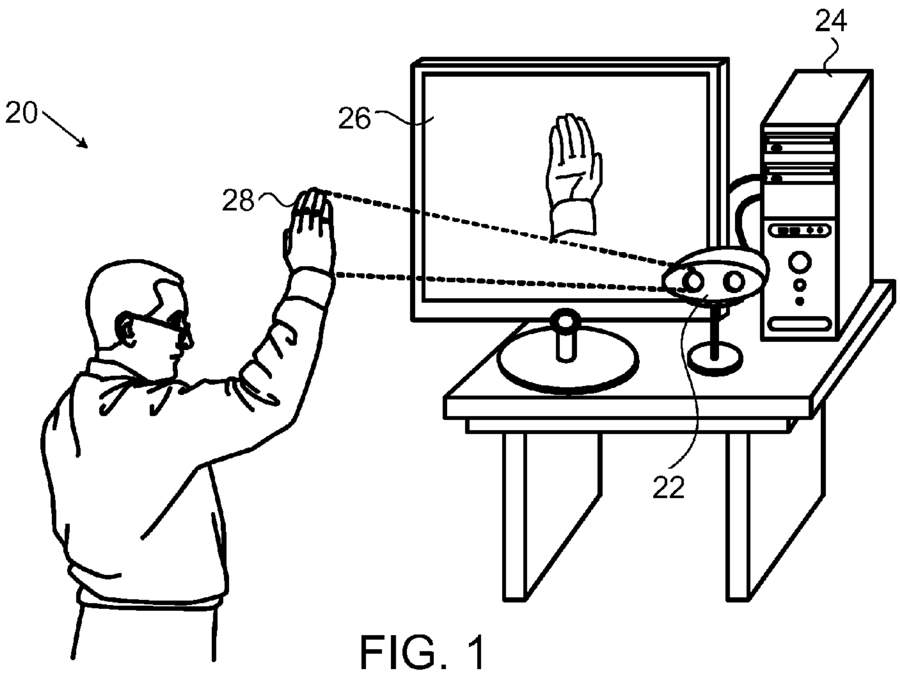

20
24
26
28
22

FIG. 1

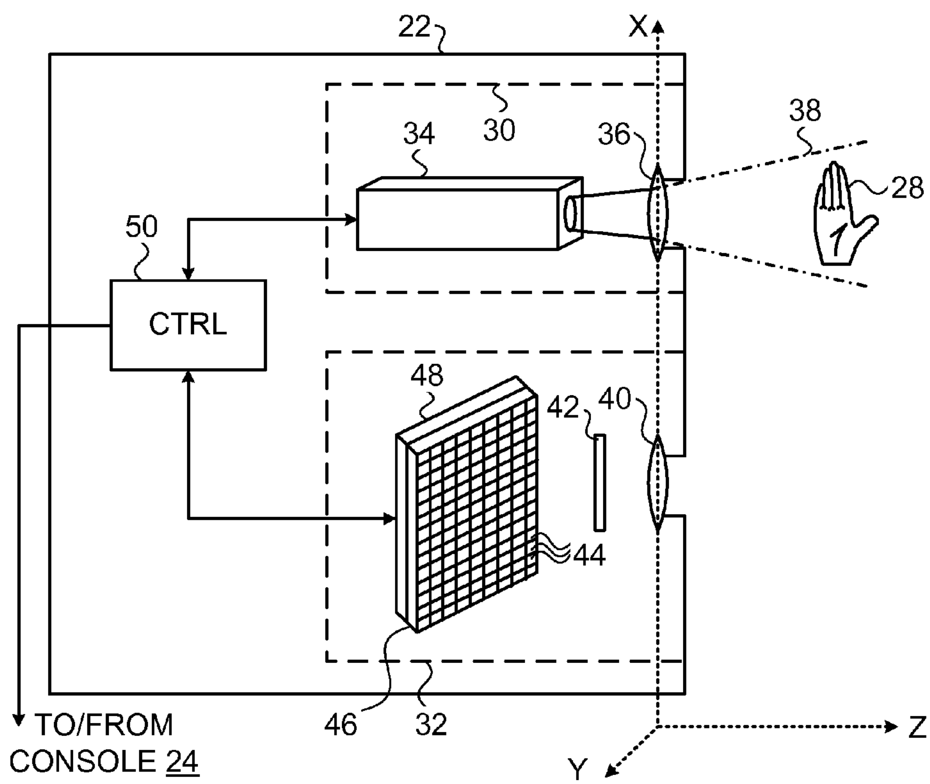

22
X
30
34
36
38
28
50
CTRL
48
42
40
44
46
32
TO/FROM
CONSOLE 24
Z
Y

FIG. 2

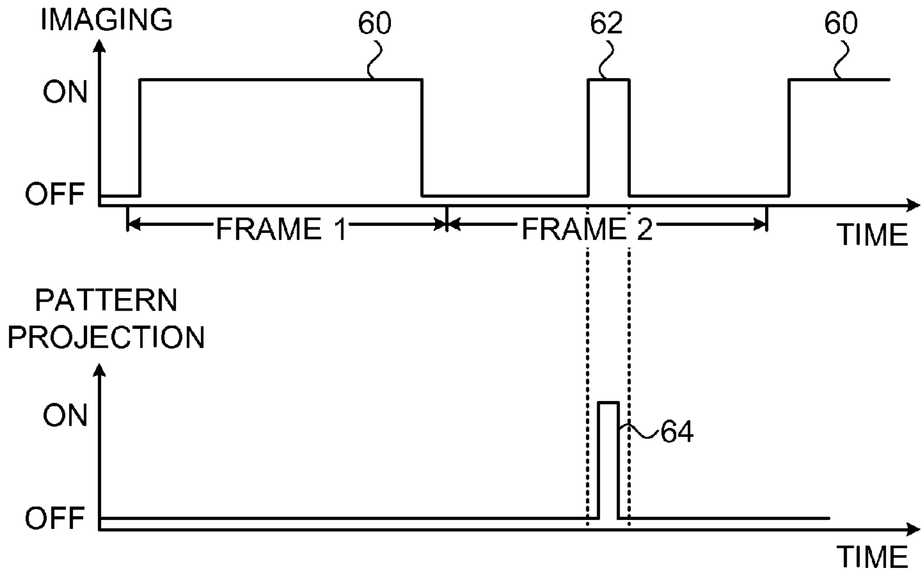

IMAGING
60
62
60
ON
OFF
FRAME 1
FRAME 2
TIME
PATTERN
PROJECTION
ON
64
OFF
TIME

FIG. 3

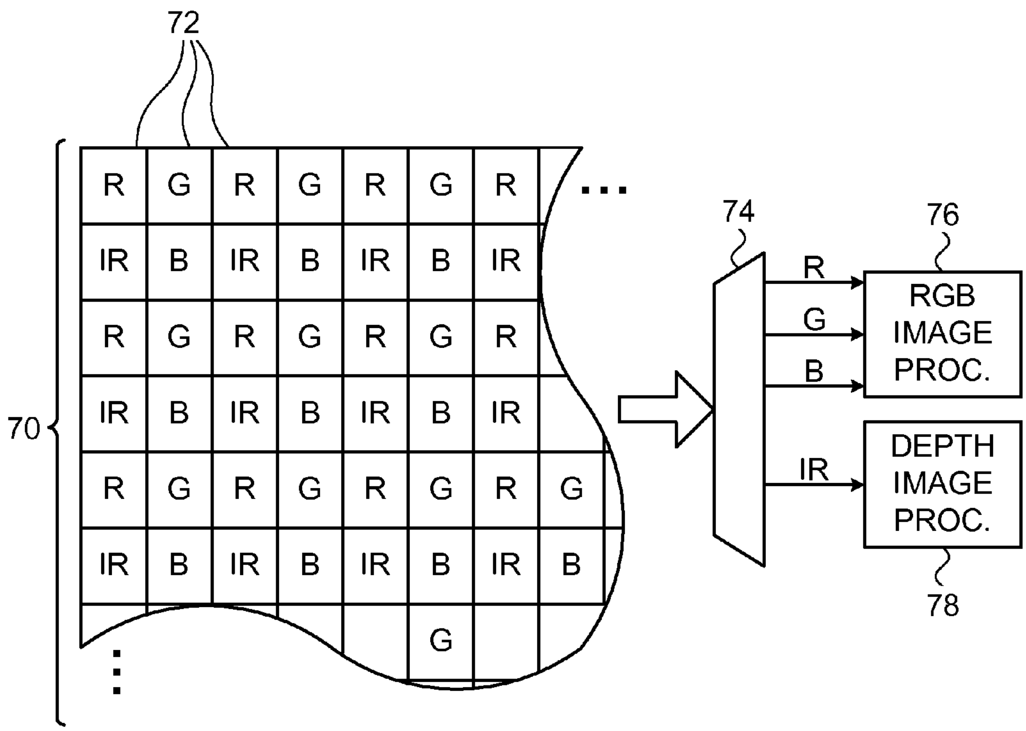

72
R G R G R G R
IR B IR B IR B IR
R G R G R G R
IR B IR B IR B IR
R G R G R G R G
IR B IR B IR B IR B
G
70
74
76
R
G
B
RGB
IMAGE
PROC.
IR
DEPTH
IMAGE
PROC.
78

FIG. 4

THREE-DIMENSIONAL MAPPING AND IMAGING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application 61/169,728, filed Apr. 16, 2009, and of U.S. Provisional Patent Application 61/171,087 filed Apr. 21, 2009, both of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates generally to mapping of an object in three dimensions, and specifically to combining such mapping and imaging functions.

BACKGROUND OF THE INVENTION

[0003] Various methods are known in the art for optical three-dimensional (3D) mapping, i.e., generating a 3D profile of the surface of an object by processing an optical image of the object. This sort of 3D profile is also referred to as a depth map or depth image, and 3D mapping is also referred to as depth mapping. Some methods of 3D mapping are based on projecting patterned light onto the object, and then analyzing an image of the pattern on the object. The pattern may be random or quasi-random, or it may alternatively have a well-defined geometrical structure (commonly known as "structured light").

[0004] One type of patterned light that may be used in depth mapping is a speckle pattern. For example, PCT International Publication WO 2007/043036, whose disclosure is incorporated herein by reference, describes a system and method for object reconstruction in which a coherent light source and a generator of a random speckle pattern project onto the object a coherent random speckle pattern. An imaging unit detects the light response of the illuminated region and generates image data. Shifts of the pattern in the image of the object relative to a reference image of the pattern are used in real-time reconstruction of a 3D map of the object. Further methods for 3D mapping using speckle patterns are described, for example, in PCT International Publication WO 2007/105205, whose disclosure is also incorporated herein by reference.

[0005] Other methods of optical 3D mapping project different sorts of patterns onto the object to be mapped. For example, PCT International Publication WO 2008/120217, whose disclosure is incorporated herein by reference, describes an illumination assembly for 3D mapping that includes a single transparency containing a fixed pattern of spots. A light source transilluminates the transparency with optical radiation so as to project the pattern onto an object. An image capture assembly captures an image of the pattern on the object, and the image is processed so as to reconstruct a 3D map of the object.

[0006] U.S. Patent Application Publication 2010/0007717, which is assigned to the assignee of the present patent application and whose disclosure is incorporated herein by reference, describes a device having a first input port for receiving color image data from a first image sensor and a second input port for receiving depth-related image data from a second image sensor. Processing circuitry generates depth maps using the depth-related image data, and then registers and synchronizes the depth maps with the color images.

[0007] The description above is presented as a general overview of related art in this field and should not be construed as an admission that any of the information it contains constitutes prior art against the present patent application.

SUMMARY

[0008] Embodiments of the present invention that are described hereinbelow provide devices and methods that may be used to generate concurrently color images and depth maps of a scene.

[0009] There is therefore provided, in accordance with an embodiment of the present invention, imaging apparatus, including an illumination subassembly, which is configured to project onto an object a pattern of monochromatic optical radiation in a given wavelength band. An imaging subassembly includes an image sensor, which is configured both to capture a first, monochromatic image of the pattern on the object by receiving the monochromatic optical radiation reflected from the object and to capture a second, color image of the object by receiving polychromatic optical radiation, and to output first and second image signals responsively to the first and second images, respectively. A processor is configured to process the first and second signals so as to generate and output a depth map of the object in registration with the color image.

[0010] Typically, the given wavelength band of the monochromatic optical radiation includes an infrared (IR) band, which may have a bandwidth that is no greater than 20 nm. In a disclosed embodiment, the imaging subassembly includes an IR bandpass filter, which is configured to inhibit IR radiation that is outside the given wavelength band from reaching the image sensor.

[0011] In disclosed embodiments, the image sensor includes an array of detector elements, and the imaging subassembly includes a mosaic filter including a pattern of filter elements overlaid respectively on the detector elements. In some embodiments, the filter elements include first filter elements configured to pass different, respective polychromatic wavelength bands, and second filter elements configured to pass the given wavelength band of the monochromatic optical radiation, wherein the first image signal is generated by the detector elements that are overlaid by the first filter elements, while the second image signal is generated by the detector elements that are overlaid by the second filter elements. Typically, the first filter elements include red, green and blue filter elements, and the second filter elements include infrared (IR) filter elements, which are interleaved with the first filter elements in a rectilinear pattern.

[0012] In other embodiments, the filter elements include at least first, second and third filter elements, which are interleaved in the pattern and are configured to pass different, respective first, second and third polychromatic wavelength bands and are also configured pass the given wavelength band of the monochromatic radiation.

[0013] In some embodiments, the image sensor is configured to output the first and second image signals in respective first and second image frames in an alternating sequence, and the illumination subassembly is configured to project the pattern during the first image frames but not during the second image frames. Typically, the frames have a given frame duration, and the imaging subassembly includes a shutter, which is configured to limit an exposure period of the image sensor to less than half of the frame duration during the first image frames, and the illumination subassembly is configured to project the pattern in a pulse that is synchronized with the exposure period.

[0014] In a disclosed embodiment, the imaging subassembly is configured to capture a third image representative of a background radiation level in the given wavelength band, and wherein the processor is configured to subtract the third image from the first image in order to generate the depth map.

[0015] There is also provided, in accordance with an embodiment of the present invention, a method for imaging, including projecting onto an object a pattern of monochromatic optical radiation in a given wavelength band. An image sensor captures both a first, monochromatic image of the pattern on the object by receiving the monochromatic optical radiation reflected from the object and a second, color image of the object by receiving polychromatic optical radiation, and outputs first and second image signals responsively to the first and second images, respectively. The first and second signals are processed so as to generate a depth map of the object in registration with the color image.

[0016] The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a schematic pictorial illustration of a system for 3D mapping and imaging, in accordance with an embodiment of the present invention;

[0018] FIG. **2** is a schematic top view of an imaging assembly, in accordance with an embodiment of the present invention;

[0019] FIG. **3** is a timing diagram that schematically illustrates operation of illumination and imaging components in a system for 3D mapping and imaging, in accordance with an embodiment of the present invention; and

[0020] FIG. **4** is a block diagram that schematically illustrates components of an imaging assembly, in accordance with an alternative embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Overview

[0021] In many applications, it is necessary or at least desirable to capture both a 3D depth map and a 2D color image of a scene of interest. For example, in a gesture-based computer interface, the computer may use both the depth map and the color image in sensing and interpreting user gestures, as well as in presenting images to the user on the computer display screen. In systems that use pattern-based depth mapping with color imaging, at least two image sensors are typically required: one to capture images of the pattern (which may be projected using infrared radiation), and the other to capture color images. The above-mentioned US 2010/0007717 describes a system of this sort, in which a processing circuit registers the depth maps with the color images.

[0022] Embodiments of the present invention, on the other hand, provide systems and methods for capturing depth maps and color images concurrently using a single image sensor. In these systems, an illumination subassembly projects a pattern of monochromatic optical radiation onto an object. The term "monochromatic" is used broadly, in the context of the present patent application and in the claims, to refer to radiation in a band of wavelengths that is substantially narrower than the full polychromatic range of visible light. Thus, the monochromatic radiation typically has a bandwidth that is no more than 100 nm at full-width-half-maximum (FWHM). The wavelength band of the monochromatic pattern is typically chosen to be in the infrared (IR) so as to avoid interfering with the color imaging function and to avoid visual disturbance to the user. The wavelength band of the monochromatic radiation may be considerably narrower than 100 nm, for example, 20 nm or less, in order to facilitate the use of narrowband filters to separate the monochromatic radiation from the ambient radiation (and particularly from wideband ambient IR radiation).

[0023] The image sensor captures both monochromatic images of the pattern on the object (due to the monochromatic radiation reflected from the object) and color images of the object (due to reflection of ambient light or other visible lighting from the object). Although the same image sensor captures both images, it outputs separate monochrome and color image signals.

[0024] In some embodiments, the separation is achieved by temporal multiplexing, whereby the image sensor outputs monochrome and color image frames in an alternating sequence. In such embodiments, the illumination subassembly projects the monochromatic pattern during the monochrome image frames but not during the color image frames.

[0025] In other embodiments, the separation is achieved by spatial multiplexing. In these embodiments, the array of detector elements of the image sensor is overlaid by a mosaic array of filter elements, which includes both color filter elements (such as red, green and blue) for the detector elements used in sensing the color image and monochromatic filter elements (typically IR) for the detector elements that sense the projected pattern.

[0026] A processor receives and processes the signals output by the image sensor so as to generate and output both the depth maps and the color images. The use of a single image sensor for both functions reduces the cost, size and complexity of the system, while at the same time ensuring that the depth maps are perfectly registered with the color images.

System Description

[0027] FIG. **1** is a schematic, pictorial illustration of a system **20** for 3D mapping and imaging, in accordance with an embodiment of the present invention. In this example, an imaging assembly **22** is configured to capture and process 3D maps and images of an object **28** (in this case the hand of a user, who may also be the operator of the system). The maps and images may be used by a host computer console **24** as part of a 3D user interface, presented on a display **26**, which enables the user to interact by means of gestures with games and other applications running on the computer. (This sort of functionality is described, for example, in U.S. Patent Application Publication 2009/0183125, whose disclosure is incorporated herein by reference.) This particular application of system **20** is shown here only by way of example, however, and the mapping and imaging capabilities of system **20** may be used for other purposes, as well, and applied to substantially any suitable type of 3D object.

[0028] In the example shown in FIG. **1**, imaging assembly **22** projects a pattern of optical radiation onto the body (or at least parts of the body) of the user, and captures an image of the pattern that appears on the body surface. The term "optical radiation," as used in the context of the present patent application and in the claims, refers to any of ultraviolet, visible, and/or IR radiation. In the present embodiment, the radiation that is projected by assembly **22** is narrowband radiation in the IR range, but other wavelength bands may alternatively be used.

[0029] A processor in assembly **22**, whose functionality is described in greater detail hereinbelow, processes the image of the pattern in order to generate a depth map of the body. The depth map comprises an array of 3D coordinates, including a depth (Z) coordinate value of the body surface at each point (X,Y) within a predefined field of view. (In the context of an array of image-related data, these (X,Y) points are also referred to as pixels.) In the embodiments that are described hereinbelow, the processor computes the 3D coordinates of points on the surface of the user's body by triangulation, based on transverse shifts of spots in the pattern, as described in the above-mentioned PCT publications WO 2007/043036, WO 2007/105205 and WO 2008/120217. This technique is referred to herein as "pattern-based depth mapping."

[0030] In addition, imaging assembly **22** captures 2D color images of the user. The 2D color images are inherently registered and synchronized with the depth maps, thus providing the basis to reconstruct a 3D color image of the user. Assembly **22** generates a data stream that includes the depth maps and image data for output to computer console **24**.

[0031] FIG. **2** is a schematic top view of imaging assembly **22**, in accordance with an embodiment of the present invention. Here the X-axis is taken to be the horizontal direction along the front of assembly **22**, the Y-axis is the vertical direction (out of the page in this view), and the Z-axis extends away from assembly **22** in the general direction of the object being imaged by the assembly.

[0032] For 3D mapping, an illumination subassembly **30** illuminates the object with an appropriate pattern, such as a speckle pattern. For this purpose, subassembly **30** typically comprises a suitable radiation source **34**, such as a diode laser, light-emitting diode (LED) or other light source, along with optics for creating the pattern. The optics may comprises, for example, a diffuser, a diffractive optical element, a microlens array, or another sort of transparency, as described in the above-mentioned PCT publications. As noted above, radiation source **34** typically emits monochromatic IR radiation in a narrow band, although other radiation bands, in the visible or ultraviolet range, for example, may also be used. Projection optics **36** projects the pattern in a beam **38** onto object **28**.

[0033] An image capture subassembly **32** captures images of the pattern on the surface of object **28** and also captures color images of the object. Subassembly **32** typically comprises objective optics **40**, which image the object surface onto an image sensor **48**, such as a CMOS or CCD image sensor. The image sensor comprises an array of detector elements overlaid by a mosaic filter **46**, which comprises an array of filter elements **44** aligned with respective detector elements. Features of this mosaic filter are described further hereinbelow. To enhance the contrast of the images captured by image sensor **48**, a bandpass filter **42** may be used to block ambient IR radiation, while passing only visible light and the IR wavelength band of radiation source **34**. Alternatively, mosaic filter elements **44** may also be configured to perform this IR bandpass filtering function. Typically, subassembly **32** comprises one or more mechanisms for adapting its image capture function to the intensity of the light reflected from the object including, for example, an electronic or mechanical shutter, automatic gain control (AGC), and/or a variable iris.

[0034] A control processor **50** controls the timing and other functions of subassemblies **30** and **32**, and also receives and processes image signals from subassembly **32**. Processor **50** typically comprises an embedded microprocessor, which is programmed in software (or firmware) to carry out the processing functions that are described hereinbelow. The software may be provided to the processor in electronic form, over a network, for example; alternatively or additionally, the software may be stored on tangible computer-readable media, such as optical, magnetic, or electronic memory media. Processor also comprises suitable input and output interfaces and may comprise dedicated and/or programmable hardware logic circuits for carrying out some or all of its functions. Details of some of these processing functions and circuits that may be used to carry them out are presented in the above mentioned U.S. Patent Application Publication 2010/0007717.

[0035] Briefly put, processor **50** compares the monochrome images provided by subassembly **32** to a reference image of the pattern projected by subassembly **30** onto a reference plane at a known distance from assembly **22**. (The reference image may be captured as part of a calibration procedure and stored in a memory, for example.) The processor matches the local patterns in the captured image to those in the reference image and thus finds the transverse shift for each pixel, or group of pixels, within the plane. Based on these transverse shifts and on the known distance between the optical axes of subassemblies **30** and **32**, the processor computes a depth (Z) coordinate for each pixel and thus creates a depth map. In addition, as noted above, processor **50** processes the color image signals from image sensor **48** to produce color images in registration with the depth maps. Processor **50** outputs the depth and color image data via a port, such as a USB port, to console **24**.

[0036] Alternatively, other system configurations may be used for the purposes described herein and are considered to be within the scope of the present invention. For example, image capture subassembly **32** may comprise multiple image sensors. As another example, processor **50** may output raw data received from image sensor **48**, and the processing functions described above may be carried out by an external computer, such as console **24**.

Time Multiplexing of Depth Maps and Color Images

[0037] In some embodiments of the present invention, filter comprises standard polychromatic mosaic filter, such as a Bayer red-green-blue (RGB) mosaic filter. In this sort of filter, there are three different types of filter elements **44**, arranged in a rectilinear pattern, which filter the optical radiation to be received by the image sensor by passing different, respective visible wavelength bands, for example:

R	G	R	G	...
G	B	G	B	...
R	G	R	G	...
G	B	G	B	...
...	...	...	...	...

[0038] The filter elements, however, also tend to pass IR radiation, including the IR wavelength band of the monochromatic radiation. (For example, see the spectral response curves of the KAC-9628 image sensor, produced by Eastman Kodak Image Sensor Solutions, Rochester, N.Y.) In conventional cameras, an additional IR cutoff filter in front of the image sensor prevents IR radiation from reaching the detector elements, and thus compensates for the relative transparency of the mosaic filter elements in the IR.

[0039] In the present embodiment, however, bandpass filter **42** permits IR radiation in the narrow wavelength band of radiation source **34** to reach image sensor **48**, in addition to visible light. In this embodiment, it is desirable that the filter bandwidth be as narrow as possible, in order to limit the amount of ambient IR radiation that passes through to the image sensor. Furthermore, controller **50** drives radiation source **34** in an intermittent, pulsed mode, in a way that minimizes IR interference with the color image, as described below.

[0040] FIG. **3** is a timing diagram that schematically illustrates operation of illumination subassembly **30** and imaging subassembly **32** in this embodiment. The upper plot illustrates the operation of image sensor **48** over a sequence of standard image frames. The image sensor captures and outputs color images in the odd-numbered frames (FRAME **1**, FRAME **3**, . . .), interleaved in alternation with IR pattern images in the even-numbered frames (FRAME **2**, FRAME **4**, . . .). Alternatively, other interleaving ratios may be used and may, for example, provide a larger proportion of color frames or of IR frames in the sequence.

[0041] In each frame, the detector elements of the image sensor capture light and integrate photoelectrons over an exposure period **60** or **62**. The exposure period is controlled by a shutter, such as electronic shutter integrated with the image sensor, as is known in the art. Exposure period **60** is variable, depending on the level of visible light, and may be nearly as long as the frame duration, as shown in FIG. **3**. Exposure period **62** in the IR frames, however, is typically less than half the frame duration, and may be considerably shorter.

[0042] The lower plot in FIG. **3** illustrates the operation of radiation source **34**, under the control of processor **50**. The radiation source is turned off during the color image frames, so that the pattern is not projected during these frames, and the only IR radiation reaching image sensor **48** is ambient radiation within the passband of filter **42**. Processor **50** drives radiation source **34** to emit a pulse **64** of IR radiation during each IR frame, in synchronization with exposure period **62**. Because the shuttered exposure period and IR pulse are short, relative to the frame duration, image sensor **48** captures relatively little ambient IR radiation, and the signal/background ratio of the pattern images is enhanced.

[0043] To reduce the effect of ambient light still further, it is possible to capture an ambient light image while the patterned IR radiation is off, which is representative of the background IR radiation level. This ambient light image can be subtracted from the IR pattern image in order to gain additional enhancement of the signal/background ratio.

[0044] Thus, processor **50** receives an interleaved sequence of alternating color and IR image frames. It processes the IR frames, as described above, in order to detect the pattern of the IR radiation reflected from object **28** and thus to create a depth map of the object. Because the color images and depth maps are created using the same image sensor and optics, they are inherently aligned without requiring any further adjustment by the processor. The processor thus outputs an alternating sequence of color images and depth maps or, alternatively, a sequence of frames in which the pixels have both color and depth values.

Spatial Multiplexing of Depth and Color Image Capture

[0045] FIG. **4** is a block diagram that schematically illustrates components of imaging assembly **22**, in accordance with an alternative embodiment of the present invention. In this embodiment, image sensor **48** has a mosaic filter **70** with a non-standard arrangement of filter elements **72**: The filter includes IR filter elements interleaved with the three types of polychromatic (R, G and B) filter elements. These IR filter elements may, for example, take the place of one of the two green elements in each group of four filter elements in the standard Bayer layout shown above. The IR filter elements are designed to pass IR radiation in the wavelength band emitted by radiation source **34**. It is desirable in this embodiment, too, that filter **42** pass visible light and only the wavelength band of radiation source **34** in the IR range. It is also desirable that the R, G and B filter elements block IR radiation, in contrast, for example, to conventional mosaic filter elements used in devices such as the Kodak image sensor described above.

[0046] A switching circuit **74**, which may be integrated into the image sensor chip or processor **50**, or may comprise a separate component, demultiplexes the IR pixels from the R, G and B pixels. Thus, in effect, the image sensor simultaneously outputs a color image and an IR pattern image in each frame. Processor **50** comprises a RGB image processor **76**, which combines the color pixels into a color output image, and a depth image processor **78**, which generates a depth map based on the IR pixels. The resolution of the color image and of the depth map may be lower than those achieved by the preceding embodiment, but on the other hand, the color images and depth maps are both output at the full frame rate of the image sensor.

[0047] As another alternative (not shown in the figures), the mosaic filter may include an additional set of IR filter elements, having a passband of similar width to that of the IR filter elements that capture the patterned radiation, but offset from the wavelength of the IR radiation source. The detector elements associated with these additional IR filter elements thus capture an IR background image, with intensity close to the intensity of the ambient background in the IR pattern image. This background image may then be subtracted from the pattern image in order to enhance the signal/background ratio.

[0048] It will be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

1. Imaging apparatus, comprising:

an illumination subassembly, which is configured to project onto an object a pattern of monochromatic optical radiation in a given wavelength band;

an imaging subassembly comprising an image sensor, which is configured both to capture a first, monochromatic image of the pattern on the object by receiving the monochromatic optical radiation reflected from the object and to capture a second, color image of the object by receiving polychromatic optical radiation, and to output first and second image signals responsively to the first and second images, respectively; and

a processor, which is configured to process the first and second signals so as to generate and output a depth map of the object in registration with the color image.

2. The apparatus according to claim **1**, wherein the given wavelength band of the monochromatic optical radiation comprises an infrared (IR) band.

3. The apparatus according to claim **2**, wherein the IR band has a bandwidth that is no greater than 20 nm.

4. The apparatus according to claim **2**, wherein the imaging subassembly comprises an IR bandpass filter, which is configured to inhibit IR radiation that is outside the given wavelength band from reaching the image sensor.

5. The apparatus according to claim **1**, wherein the image sensor comprises an array of detector elements, and wherein the imaging subassembly comprises a mosaic filter comprising a pattern of filter elements overlaid respectively on the detector elements.

6. The apparatus according to claim **5**, wherein the filter elements comprise first filter elements configured to pass different, respective polychromatic wavelength bands, and second filter elements configured to pass the given wavelength band of the monochromatic optical radiation, and

wherein the first image signal is generated by the detector elements that are overlaid by the first filter elements, while the second image signal is generated by the detector elements that are overlaid by the second filter elements.

7. The apparatus according to claim **6**, wherein the first filter elements comprise red, green and blue filter elements, and the second filter elements comprise infrared (IR) filter elements, which are interleaved with the first filter elements in a rectilinear pattern.

8. The apparatus according to claim **5**, wherein the filter elements comprise at least first, second and third filter elements, which are interleaved in the pattern and are configured to pass different, respective first, second and third polychromatic wavelength bands and are also configured pass the given wavelength band of the monochromatic radiation.

9. The apparatus according to claim **1**, wherein the image sensor is configured to output the first and second image signals in respective first and second image frames in an alternating sequence, and wherein the illumination subassembly is configured to project the pattern during the first image frames but not during the second image frames.

10. The apparatus according to claim **9**, wherein the frames have a given frame duration, and wherein the imaging subassembly comprises a shutter, which is configured to limit an exposure period of the image sensor to less than half of the frame duration during the first image frames, and wherein the illumination subassembly is configured to project the pattern in a pulse that is synchronized with the exposure period.

11. The apparatus according to claim **9**, wherein the imaging subassembly comprises at least first, second and third filter elements, which are configured to filter the optical radiation received by the image sensor by passing different, respective first, second and third polychromatic wavelength bands, and which are also configured pass the given wavelength band of the monochromatic radiation.

12. The apparatus according to claim **1**, wherein the imaging subassembly is configured to capture a third image representative of a background radiation level in the given wavelength band, and wherein the processor is configured to subtract the third image from the first image in order to generate the depth map.

13. A method for imaging, comprising:

projecting onto an object a pattern of monochromatic optical radiation in a given wavelength band;

capturing, using an image sensor, both a first, monochromatic image of the pattern on the object by receiving the monochromatic optical radiation reflected from the object and a second, color image of the object by receiving polychromatic optical radiation;

outputting from the image sensor first and second image signals responsively to the first and second images, respectively; and

processing the first and second signals so as to generate a depth map of the object in registration with the color image.

14. The method according to claim **13**, wherein the given wavelength band of the monochromatic optical radiation comprises an infrared (IR) band.

15. The method according to claim **14**, wherein the IR band has a bandwidth that is no greater than 20 nm.

16. The method according to claim **14**, wherein capturing the first and second images comprises filtering the optical radiation impinging on the image sensor so as to inhibit IR radiation that is outside the given wavelength band from reaching the image sensor.

17. The method according to claim **13**, wherein the image sensor comprises an array of detector elements, and wherein capturing the first and second images comprises filtering the optical radiation impinging on the image sensor using a mosaic filter, which comprises a pattern of filter elements overlaid respectively on the detector elements.

18. The method according to claim **17**, wherein the filter elements comprise first filter elements configured to pass different, respective polychromatic wavelength bands, and second filter elements configured to pass the given wavelength band of the monochromatic optical radiation, and

wherein the first image signal is generated by the detector elements that are overlaid by the first filter elements, while the second image signal is generated by the detector elements that are overlaid by the second filter elements.

19. The method according to claim **18**, wherein the first filter elements comprise red, green and blue filter elements, and the second filter elements comprise infrared (IR) filter elements, which are interleaved with the first filter elements in a rectilinear pattern.

20. The method according to claim **17**, wherein the filter elements comprise at least first, second and third filter elements, which are interleaved in the pattern and are configured to pass different, respective first, second and third polychromatic wavelength bands and are also configured pass the given wavelength band of the monochromatic radiation.

21. The method according to claim **13**, wherein outputting the first and second image signals comprises outputting the first and second image signals in respective first and second image frames in an alternating sequence, and wherein projecting the pattern comprises operating a radiation source to provide the pattern during the first image frames but not during the second image frames.

22. The method according to claim **21**, wherein the frames have a given frame duration, and wherein capturing the first image comprises limiting an exposure period of the image sensor to less than half of the frame duration during the first image frames, and wherein operating the radiation source comprises projecting the pattern in a pulse that is synchronized with the exposure period.

23. The method according to claim **21**, wherein capturing the first and second images comprises filtering the optical radiation using at least first, second and third filter elements, which are configured to filter the optical radiation received by the image sensor by passing different, respective first, second and third polychromatic wavelength bands, and which are also configured pass the given wavelength band of the monochromatic radiation.

24. The method according to claim **13**, and comprising capturing a third image representative of a background radiation level in the given wavelength band, and outputting a third image signal responsively to the third image, and wherein processing the first and second signals comprises subtracting the third image signal from the first image signal in order to generate the depth map.

* * * * *