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(54) **THERMAL-IMAGE BASED OBJECT DETECTION AND HEAT MAP GENERATION SYSTEMS AND METHODS**

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CPC *G06T 7/194* (2017.01); *G06T 2207/10048* (2013.01); *G06K 9/3241* (2013.01); *G06K 9/00624* (2013.01)

(57) **ABSTRACT**

An infrared (IR) imaging module may capture a background image in response to receiving IR radiation from a background of a scene and determine background calibration terms using the background image. The determined background calibration terms may be scale factors and/or offsets that equalize the pixel values of the background image to a baseline, value. IR imaging device may use the background calibration terms to capture images that have the baseline value for pixels corresponding to IR radiation received from the background and higher values (or lower values) for pixels corresponding to IR radiation received from a foreground. Such images may be used to count people and generate a heat map. The background calibration terms may be updated periodically, with the update period being increased at least for some pixels or a pixel area when a person is detected.
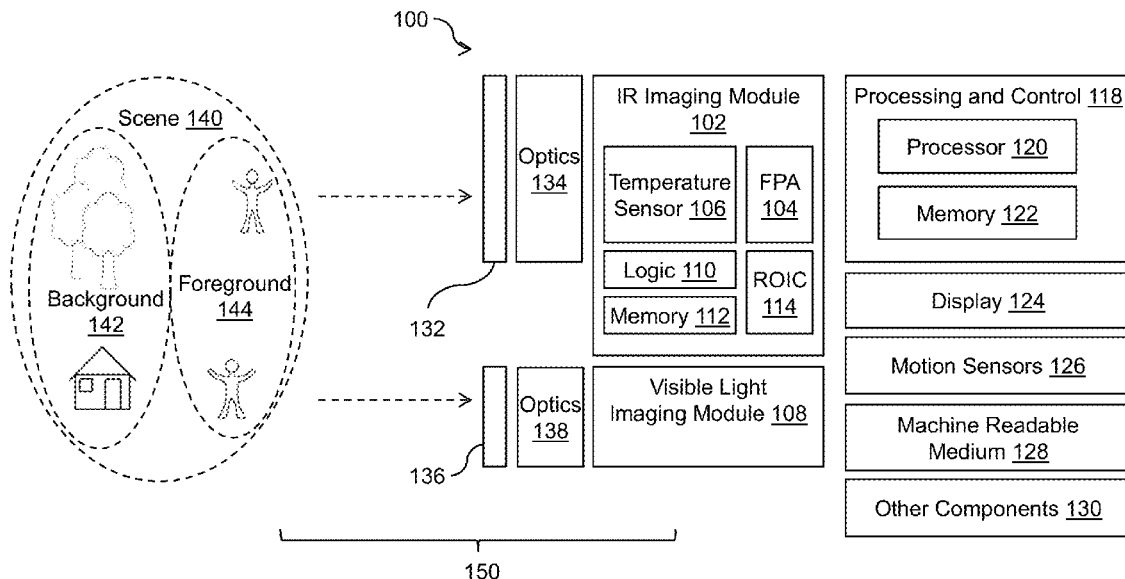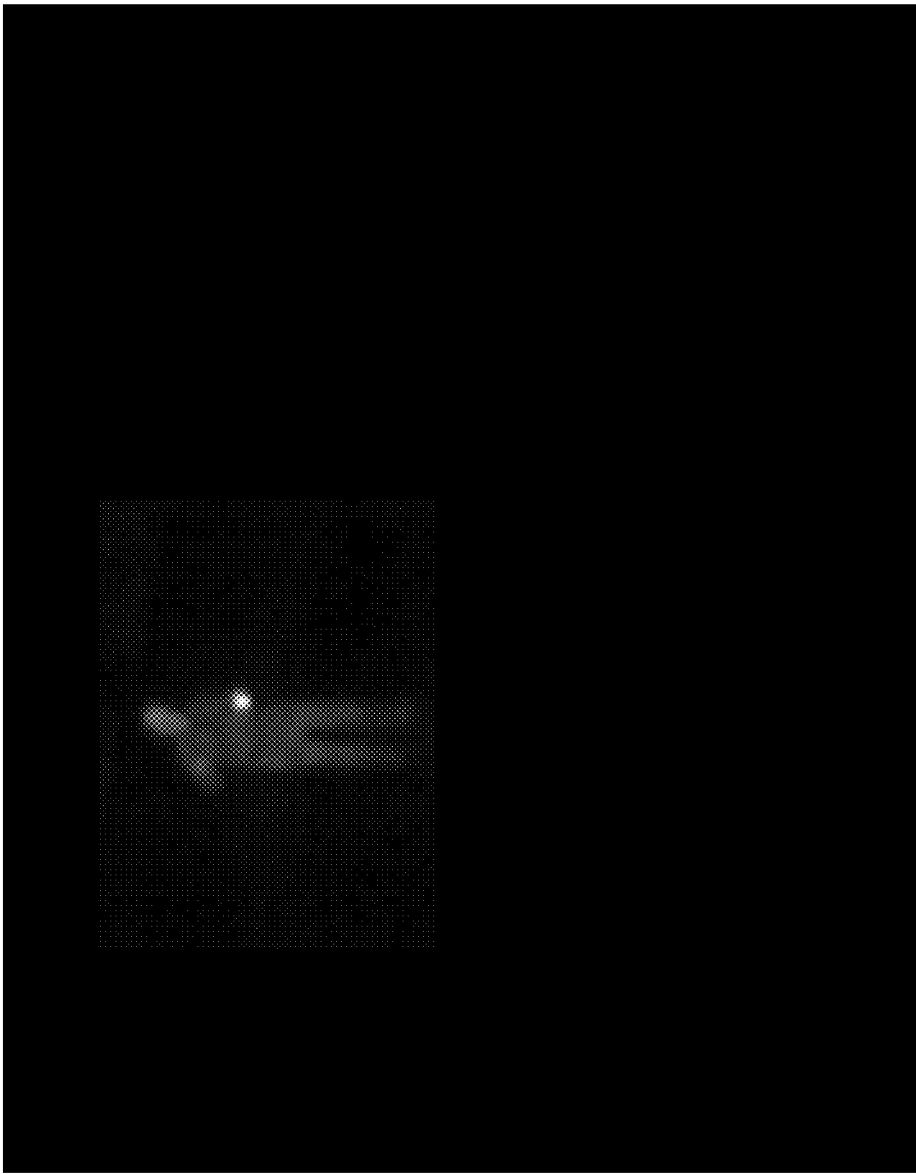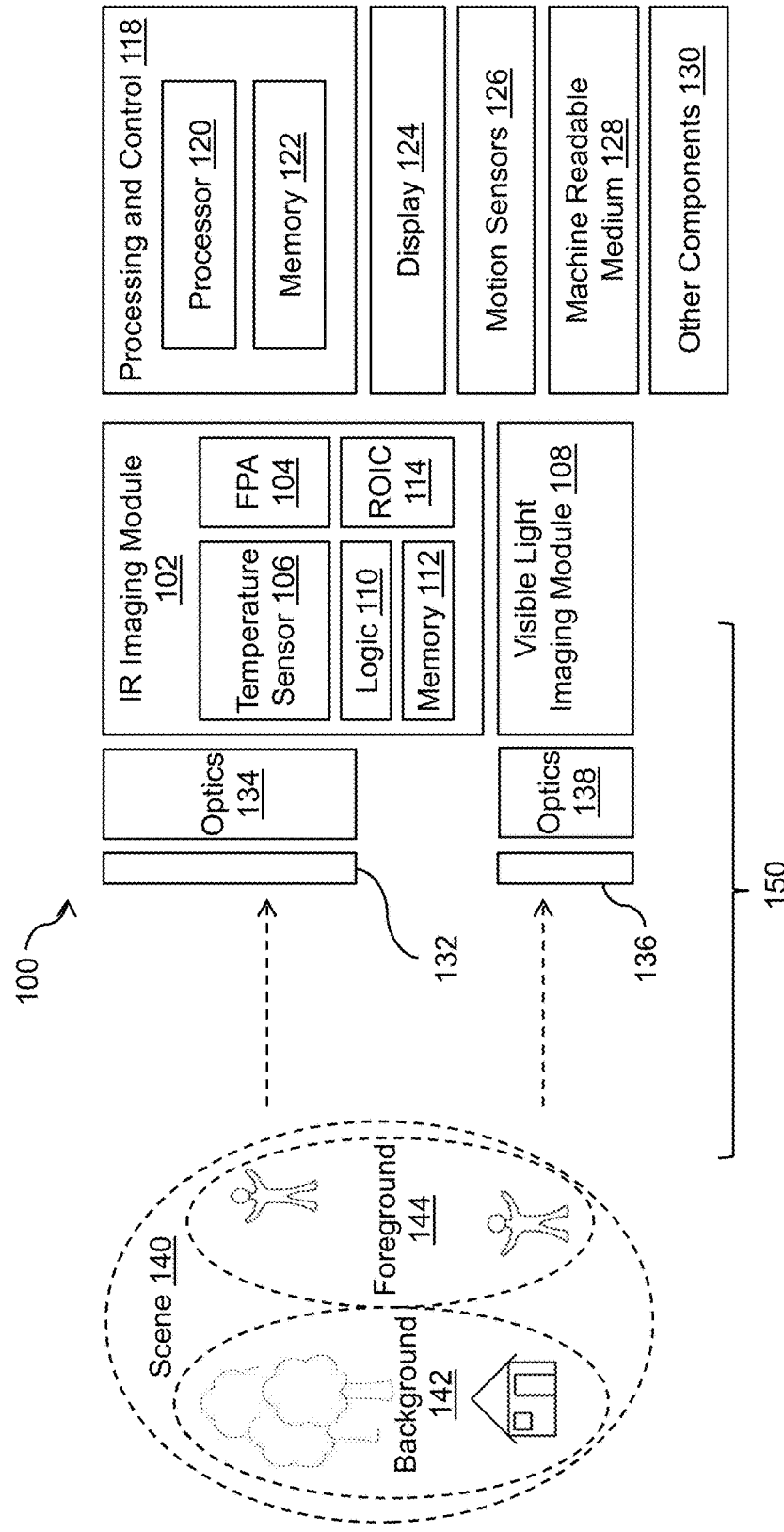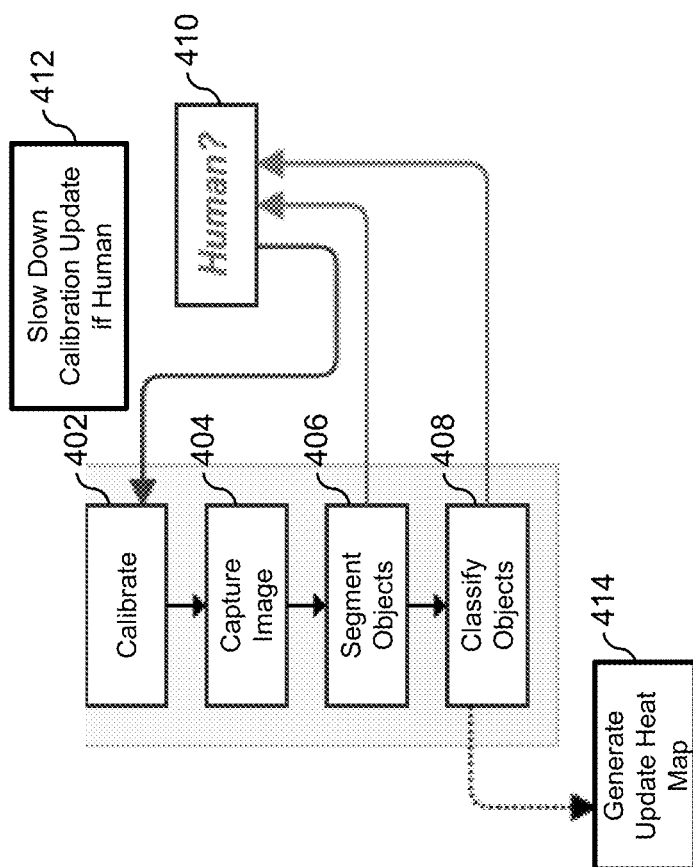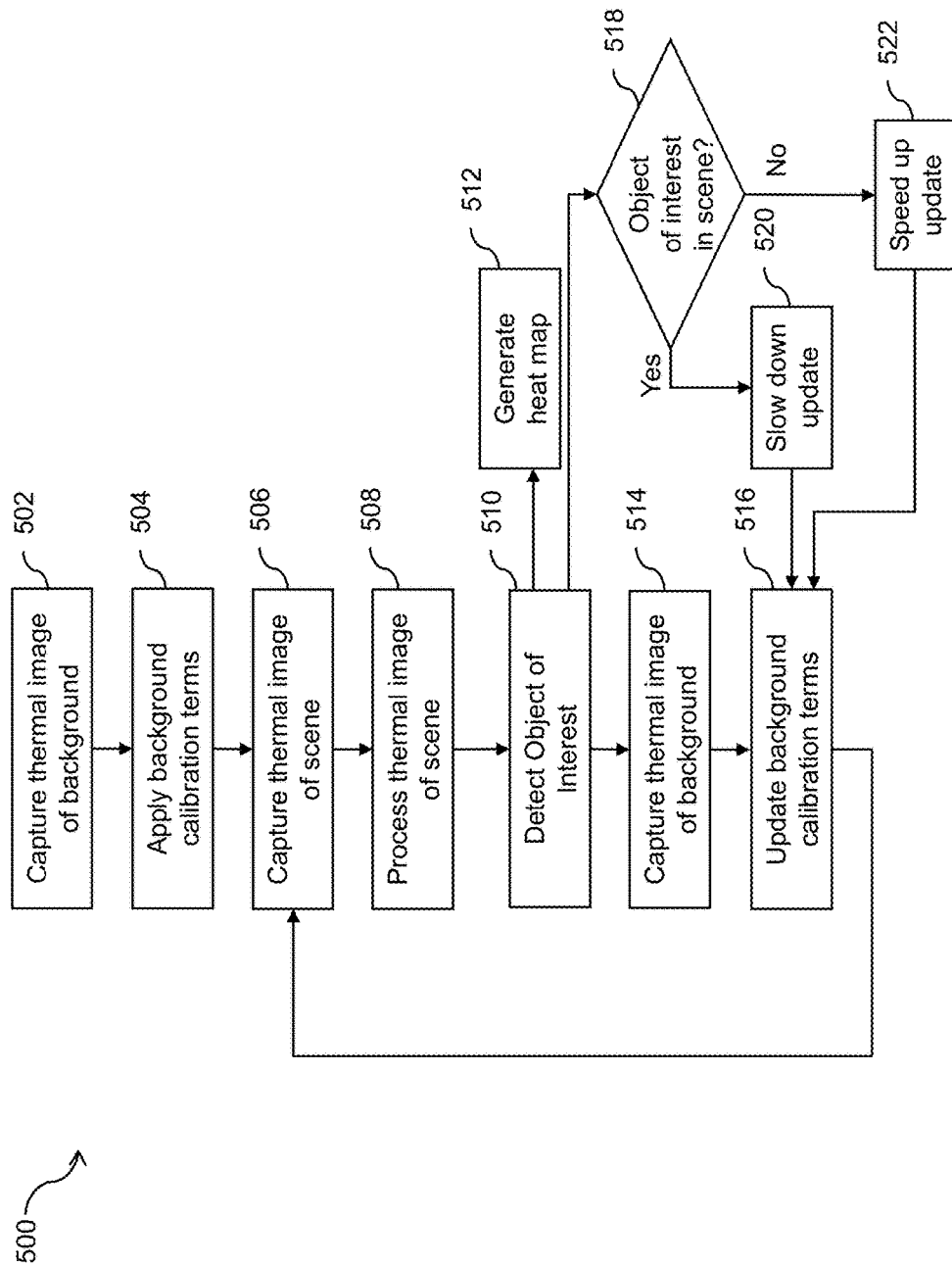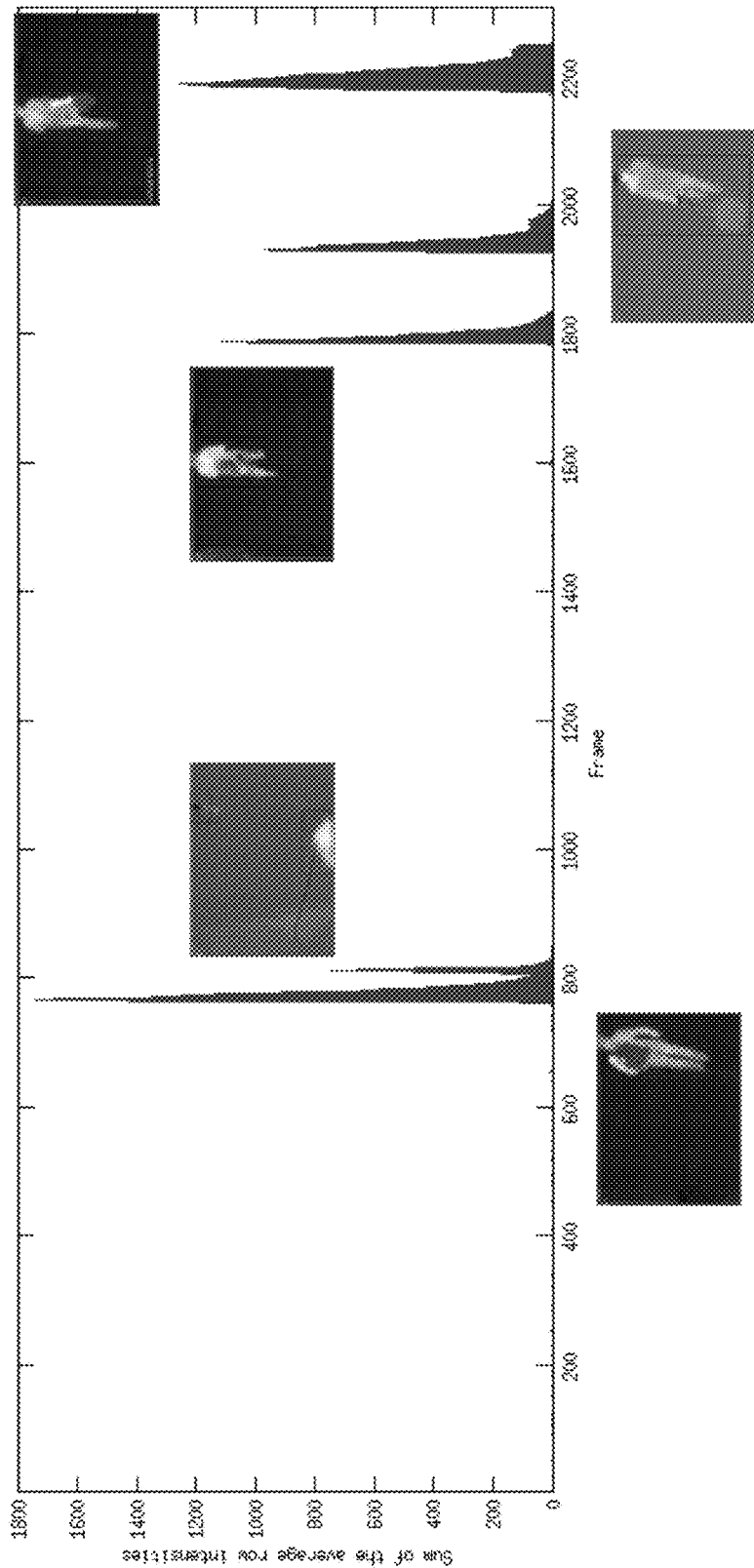
100
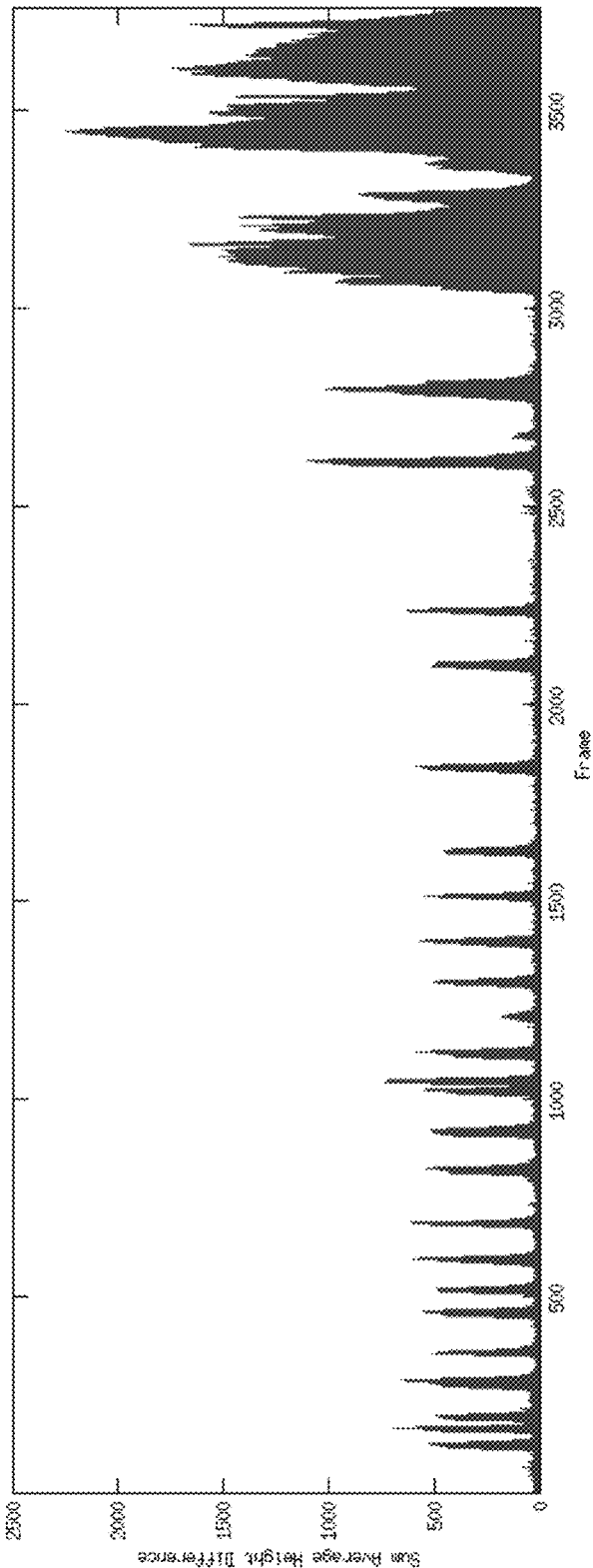

150

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7
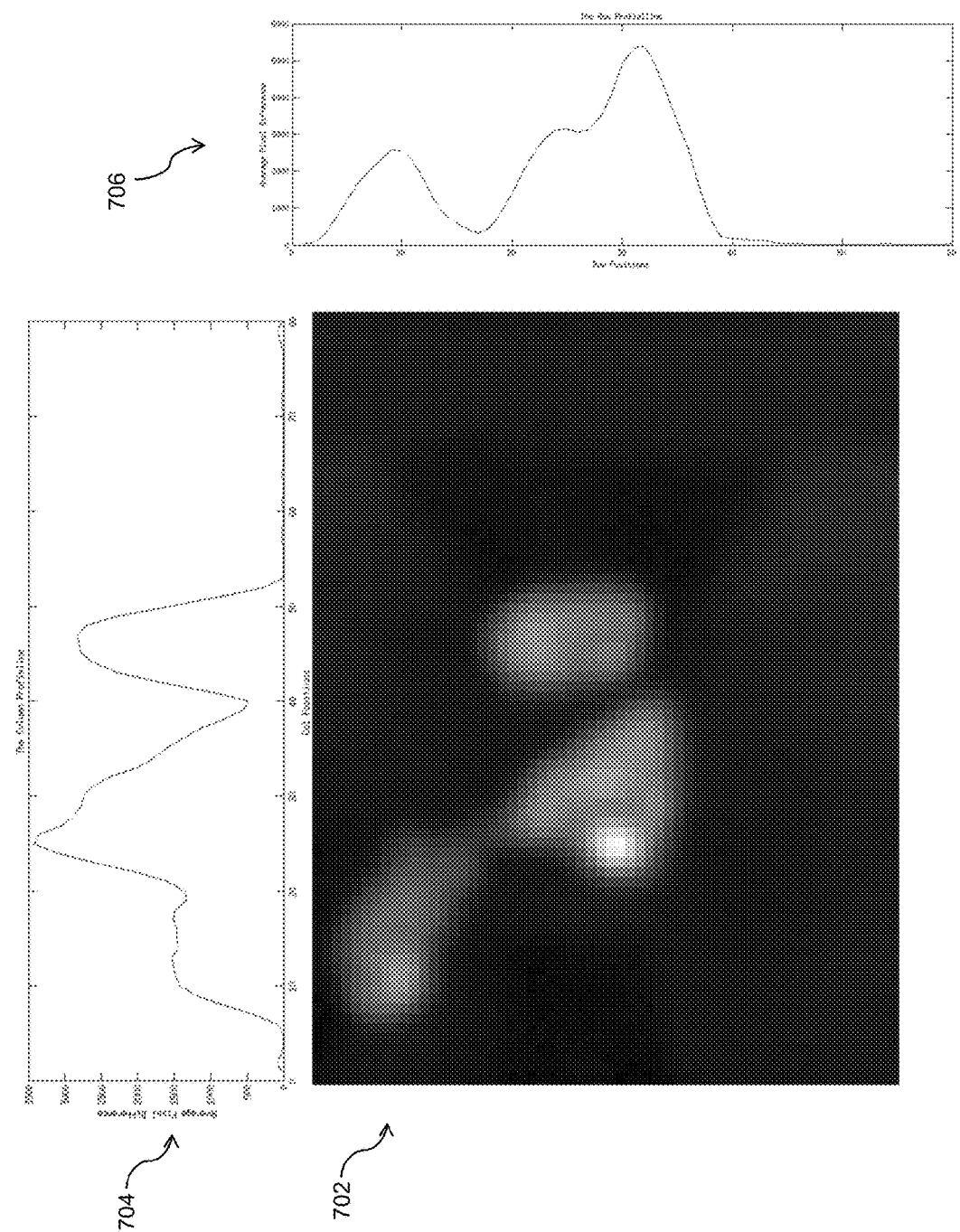
FIG. 8

THERMAL-IMAGE BASED OBJECT DETECTION AND HEAT MAP GENERATION SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Patent Application No. PCT/US2017/012397 filed Jan. 5, 2017 and entitled "THERMAL-IMAGE BASED OBJECT DETECTION AND HEAT MAP GENERATION SYSTEMS AND METHODS," which is incorporated herein by reference in its entirety.

[0002] International Patent Application No. PCT/US2017/012397 filed Jan. 5, 2017 claims priority to and the benefit of U.S. Provisional Patent Application No. 62/276,766 filed Jan. 8, 2016 and entitled "THERMAL-IMAGE BASED OBJECT DETECTION AND HEAT MAP GENERATION SYSTEMS AND METHODS," which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0003] One or more embodiments of the present invention relate generally to thermal imaging and more particularly, for example, to systems and methods for object detection and heat map generation based on thermal images.

BACKGROUND

[0004] Focal plane arrays (FPAs) that detect infrared (IR) radiation, such as thermal IR radiation, are used by IR imaging devices (e.g., IR cameras) to provide thermal images. For example, thermal radiation passing through an optical path of an IR imaging device is received by IR detectors of the FPA, which provide image data for pixels of thermal images.

[0005] Images may be processed to detect objects (e.g., count people) and/or generate a heat map. One method for object detection in an image may include performing background-foreground segmentation on an image captured by and received from an imaging device. However, background-foreground segmentation processes typically require use of a significant amount of the processing power of a processor (e.g., up to 50% of the processing power of a typical central processing unit (CPU) used with imaging devices).

[0006] IR imaging devices typically require a mechanical shutter. Mechanical components such as mechanical shutters are more prone to wear and tear, and thus adversely affect the overall reliability and longevity of IR imaging devices that rely on mechanical shutters. Further, IR imaging devices that are used in surveillance or security cameras typically require automatic mechanical shutters, which include numerous mechanical components such as a shutter blade (e.g., a shutter paddle), an actuator (e.g., a motor), and an associated drive train to move the shutter blade in and out of the optical path. Also, mechanical shutters, if integrated into or otherwise provided in an IR imaging device, may increase the size, complexity, and cost of IR imaging devices.

SUMMARY

[0007] Systems, devices, and methods for heat map and people counting are provided. In one or more embodiments, device includes an infrared (IR) imaging module configured to capture thermal images; a memory configured to store background calibration terms; and a logic device configured to receive a thermal image of a background from the IR imaging module, determine the background calibration terms based on the thermal image of the background, and apply the background calibration terms. The background calibration terms bring each pixel value of the thermal image of the background to a baseline pixel value, and the IR imaging module is configured to provide a thermal image of a scene including the baseline pixel value for pixels corresponding to the background and pixel values different from the baseline pixel value for pixels corresponding to a foreground according to the applied background calibration terms.

[0008] In some embodiments, the logic device is further configured to receive additional thermal images of the background from the IR imaging module, and update the background calibration terms periodically according to a time interval based on the additional thermal images. In some embodiments, the device further includes a processor configured to determine foreground pixels in the thermal image of the scene, determine segments based on the foreground pixels, detect one or more objects of interest indicated by at least one of the segments, and, in response to detecting the one or more objects of interest, increase the time interval.

[0009] In some embodiments, the processor is configured to update the background calibration terms in response to detecting no objects of interest during the time interval. In some embodiments, the increased time interval is applied only to select pixels that are a part of the at least one of the segments, and the processor is configured to update the background calibration terms corresponding to the select pixels according to the increased time interval.

[0010] In some embodiments, the one or more objects of interest comprise one or more people. For example, the processor may be configured to detect the one or more people based on a volume of the at least one of the segments, an average pixel intensity, or both. In another example, the processor may be configured to detect the one or more people based on a volume, contours, an aspect ratio, and/or a histogram of oriented gradients of the at least one of the segments. In some embodiments, the processor is further configured to generate a heat map indicating where the one or more people are located, walking to, and/or looking at based on the thermal image of the scene.

[0011] In some embodiments, the logic device is configured to apply the background calibration terms to a readout integrated circuit of the IR imaging module, to the thermal image of the scene, or both. In some embodiments, the background calibration terms comprise gain terms and/or offset terms. In some embodiments, the IR imaging module is a 14-bit shutterless IR imaging module configured to capture 14-bit thermal images.

[0012] In one or more embodiments, a method includes capturing a thermal image of a background, acquiring background calibration terms based on the thermal image of the background, applying the background calibration terms, and capturing a thermal image of a scene. The background calibration terms bring each pixel value of the thermal image of the background to a baseline pixel value, and the thermal image of the scene includes the baseline pixel value for pixels corresponding to the background and pixel values different from the baseline pixel value for pixels corresponding to a foreground.

[0013] In some embodiments, the method further includes capturing additional thermal images of the background, and updating the background calibration terms applied to the IR imaging module periodically according to a time interval based on the additional thermal images. In some embodiments, the method further includes determining foreground pixels in the thermal image of the scene, determining segments based on the foreground pixels, detecting one or more objects of interest indicated by at least one of the segments, and, in response to the detecting, increasing the time interval.

[0014] In some embodiments, the updating is in response to detecting no objects of interest during the time interval. In some embodiments, the increasing of the time interval is applied only to select pixels that are a part of the at least one of the segments, and wherein the updating comprises updating the background calibration terms corresponding to the select pixels according to the increased time interval.

[0015] In some embodiments, the one or more objects of interest comprise one or more people. For example, the detecting of the one or more people may be based on a volume of the at least one of the segments, an average pixel intensity, or both. In another example, the detecting of the one or more people may be based on a volume, contours, an aspect ratio, and/or a histogram of oriented gradients of the at least one of the segments. In some embodiments, the method further includes generating a heat map indicating where the one or more people are located, walking to, and/or looking at based on the thermal image of the scene.

[0016] In some embodiments, the applying comprises applying the background calibration terms to a readout integrated circuit, to the thermal image of the scene, or both. In some embodiments, the applying comprises applying gain terms and/or offset terms. In some embodiments, the thermal image of the background and the thermal image of the scene are 14-bit thermal images.

[0017] The scope of the invention is defined by the claims. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 illustrates an example thermal image of a scene captured by an infrared (IR) imaging device that has been calibrated by performing flat-field correction (FFC) with a shutter.

[0019] FIG. 2 illustrates an example thermal image of a scene captured by an IR imaging device that has been calibrated using a background.

[0020] FIG. 3 illustrates an exemplary IR imaging device in accordance with an embodiment of the disclosure.

[0021] FIG. 4 illustrates a flow diagram of a process to generate a heat map and detect objects in accordance with an embodiment of the disclosure.

[0022] FIG. 5 illustrates another flow diagram of a process to generate a heat map and detect objects in accordance with an embodiment of the disclosure.

[0023] FIG. 6 illustrates images captured using a side-fired IR imaging device and a graph of average pixel intensities of the captured images in accordance with an embodiment of the disclosure.

[0024] FIG. 7 illustrates a graph of average pixel intensity of images captured using an overhead IR imaging device in accordance with an embodiment of the disclosure.

[0025] FIG. 8 illustrates an image captured using an overhead IR imaging device and graphs of average pixel intensities of the captured image in accordance with an embodiment of the disclosure.

[0026] Embodiments of the invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

[0027] Systems, devices, and methods for heat map and people counting are provided. An infrared (IR) imaging device may capture a background image in response to IR radiation from a background. The IR imaging device may perform aspects of processes used for non-uniformity correction (NUC), such as a flat-field correction (FFC) process, to determine the calibration terms. However, instead of using an image of a shutter that is used for an FFC process, the IR imaging device determines calibration terms using the background image. IR imaging device may use the background calibration terms to capture images that have the baseline pixel value for pixels corresponding to IR radiation received from the background and higher pixel values for pixels corresponding to IR radiation received from a foreground. The images captured by the IR imaging device may be used to count people and generate a heat map.

[0028] IR imaging devices may include a focal plane array (FPA) that detects IR radiation from a scene. The individual IR detectors of the FPA may not respond uniformly to an incident IR radiation. Factors contributing to such non-uniformity may include, for example, variations in the physical characteristics (i.e., dimensions and locations), IR radiation absorption coefficient, resistance, temperature coefficient of resistance (TCR), heat capacity, and/or thermal conductivity of the individual IR detectors. Further non-uniform out-of-field IR radiation from surrounding mechanical components may contribute to the non-uniformity. In order to compensate for the non-uniformities and obtain a desirable signal-to-noise ratio, NUC techniques are used to calibrate the FPA such that each IR detector provides a consistent pixel value in response to IR radiation of the same intensity level.

[0029] An FFC process may be used to perform the NUC. The FFC process may include selectively inserting a shutter into an optical path of the FPA, and calibrating IR detectors of an FPA based on IR radiation from the shutter. The shutter blocks the IR radiation from the scene and provides a uniform temperature source, which may approximate a thermal black body and thereby provide a flat-field source of IR radiation. The shutter emits uniform IR radiation to each IR detector of the FPA, and in response to the IR detectors receiving the uniform IR radiation, an IR imaging device captures an image of the shutter and processes the image to acquire FFC terms (e.g., FFC values or an FFC map). The IR imaging device may use the FFC terms to achieve a desirable signal-to-noise ratio for images taken after the FFC process. After calibration of the FPA based on the uniform IR radiation from the shutter, the IR imaging device may capture images of a scene in which non-uniformities are compensated for by application of the FC terms.

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[0030] In an example, the IR imaging device may apply the FFC terms, such as gain and/or offset terms for each pixel corresponding to a respective IR detector, to a component of the IR imaging device such as a readout integrated circuit (ROIC) and/or an input image. By applying the FFC terms, in response to the FPA receiving IR radiation from the scene, the IR imaging device may provide an output image that compensates for non-uniformities. In another example, the FFC terms may be stored as a NUC image. The IR imaging device may capture an input image in response to IR radiation from the scene, and a logic device may subtract the NUC image from the raw image to generate an output image that compensates for non-uniformities. Accordingly, the FPA may take one or more data frames (e.g., one or more snapshots) of the shutter to calibrate its response to provide a more uniform response for IR radiation of the same intensity level.

[0031] An IR imaging device that use an FFC process with a shutter as described above may capture images to count objects and generate heat maps. A process for heat map generation and object detection may include performing FFC with the shutter, capturing an image of a background, generating a background model using the image of the background, and performing background/foreground segmentation based on the background model. After the background model is generated, an image of a scene is captured using the IR imaging device and processed using the background model to identify pixels that potentially correspond to foreground objects. After further processing of the identified pixels, objects may be detected and indicated in the captured image of the scene. FIG. 1 illustrates an example thermal image captured by an IR imaging device that uses a shutter to perform FFC, in which object detection process has been performed to detect objects indicated by rectangles.

[0032] The FFC process as described above may be performed, rather than using a shutter, using instead an image of an empty scene in accordance with one or more embodiments of the disclosure. An IR imaging device may perform a calibration process (corresponding to the FFC process described above) without a shutter using an image of a scene that only includes a background. The background contains varying temperature sources, so it does not provide a uniform temperature source. In response to the IR detectors receiving varying IR radiation from the background, the IR imaging device captures a background image and processes the background image to acquire background calibration terms (e.g., background calibration values or a background calibration map). Applying the background calibration terms reduce each the pixel value of the background image, which corresponds to IR radiation received from the background, to a baseline pixel value (e.g., zero). Accordingly, the background calibration terms are such that they flatten out the variation of IR radiation levels.

[0033] The IR imaging device may calibrate the FPA based on IR radiation from the background. When IR imaging device captures images of a scene including the background and a foreground (e.g., an object or a person), the output image will have no or little scene-background information and provide scene-foreground information. Pixels of the output image corresponding to IR radiation received from the background will have values that are at or close to the baseline pixel value (e.g., zero). All the scene-background information is removed due to the application of the background calibration terms. On the other hand, pixels of the output image corresponding to IR radiation received from the foreground will have higher or lower pixel values than the baseline pixel value. Accordingly, the IR imaging device that has been calibrated using the background image may provide output images that directly show the foreground or show the foreground with far less processing compared to IR imaging device that perform background-foreground segmentation techniques on images captured using an FFC process with a shutter. FIG. 2 illustrates an example thermal image of a scene including a background and a person in the foreground captured by an IR imaging device that has been calibrated using an image of the background (i.e., the scene without the person) according to one or more embodiments of the disclosure.

[0034] In some embodiments, an IR imaging device may apply the background calibration terms, such as gain and/or offset terms for each pixel corresponding to a respective IR detector, to a component of the IR imaging device such as an ROIC and/or an input image. Each of the IR detectors of FPA may provide a consistent pixel value (e.g., a low pixel value such as zero, or other baseline or reference value) in response to corresponding IR radiation received from the background. By applying the background calibration terms, the IR imaging device generates an output image that show little or no background and show the foreground objects with high pixel intensity. The IR imaging device may further update previously acquired background calibration terms.

[0035] In other embodiments, an IR imaging device may store the background calibration terms as a background calibration image. The IR imaging device may capture an input image in response to IR radiation from the scene, and a logic device may subtract the background calibration image from the input image. By subtracting the background calibration image, the IR imaging device generates an output image that show little or no background and show the foreground objects with high pixel intensity. The IR imaging device may further update a previously stored background calibration image.

[0036] A processor that receives the example thermal image of FIG. 2 output by an IR imaging module calibrated using an image of the background is able to detect foreground objects by simply determining where the high pixel values are located in the image. In contrast, a processor that receives the example thermal image of FIG. 1 output by an IR imaging module calibrated using a shutter must perform significantly more processing (e.g., using complex algorithms) to detect foreground objects.

[0037] FIG. 3 illustrates a block diagram of an IR imaging device 100 in accordance with an embodiment of the invention. IR imaging device 100 includes an IR imaging module 102 with a focal plane array (FPA) 104 configured to detect IR radiation and provide IR image data (e.g., thermal image data). IR imaging module 102 may also be coupled to or include a temperature sensor 106 configured to detect a temperature of FPA 104. IR imaging device 100 may also include a visible light module 108.

[0038] IR imaging module 102 may include or be coupled to a logic device 110 and/or a non-volatile memory 112. Logic device 110 may include programmable logic devices (PLDs), microcontrollers, application specific integrated circuits (ASICs), and/or other logic devices. Logic device 110 may be configured to perform processes specific to or associated with IR imaging module 102 as further described herein, and may store and access data in non-volatile

memory **112**. IR imaging module **102** may also include or be coupled to an integrated circuit such as an ROIC **114**.

[0039] IR imaging device **100** may also include a processing and control block **118** including a processor **120** and a memory **122**, a display **124**, one or more motion sensors **126**, a machine readable medium **128**, and/or other components **130**. IR imaging device **100** may further include a window **132** and/or one or more optics blocks **134** for IR imaging module **102** and a window **136** and/or one or more optics blocks **138** for visible light imaging module **108**.

[0040] IR imaging device **100** may represent any type of IR camera or thermal imaging system not limited to any specific embodiment disclosed herein, and may be implemented as desired for particular applications. In this regard, the components illustrated in FIG. **3** may be implemented as a standalone IR camera in one embodiment, while in another embodiment the components of FIG. **3** may be distributed among a plurality of different devices. Thus, in one example, all or part of processing and control block **118** may be implemented by one or more external computer systems that interface with IR imaging device **100** (e.g., over a network or other appropriate communication medium). In another example, all or part of processing and control block **118** may be implemented in a host device such as a smart phone or other mobile device, with other components of FIG. **3** being implemented in a device attachment configured to be attached to the host device, for example, according to one or more aspects disclosed in U.S. patent application Ser. No. 13/901,428, filed May 23, 2013, and entitled "Device Attachment with Infrared imaging Sensor," and International Patent Application No. PCT/US2013/062433, filed Sep. 27, 2013, and entitled "Device Attachment with Infrared imaging Sensor," all of which are incorporated herein by reference in their entirety. In some embodiments, IR imaging device **100** may be implemented with greater, fewer, and/or different components than those illustrated in FIG. **3** as appropriate for particular applications.

[0041] FPA **104** of IR imaging module **102** may be configured to detect IR radiation from a scene **140** for a field of view (FOV) of FPA **104**, and provide IR image data (e.g., via analog or digital signals) representing the IR radiation in response to detecting the IR radiation. FPA **104** may be implemented using any suitable type of IR detectors (e.g., quantum wells, microbolometers, thermopiles, or other types of detector elements responsive to IR radiation) that are arranged in a suitable pattern (e.g., a rectangular array, a square array, a one-dimensional array, or other arrangements) as may be desired for particular implementations. ROIC **114**, which may be coupled to or integrated with FPA **104**, is configured to generate analog or digital signals corresponding to the intensity of IR radiation received at each IR detector of FPA **104** and to interface with other components such as processing and control block **118**. Further examples of ROICs **114** and IR detectors (e.g., microbolometer circuits) of FPA **104** may be found in U.S. patent application Ser. No. 09/021,714, filed Feb. 10, 1998, and entitled "Methods and Circuitry for Correcting Temperature-Induced Errors in Microbolometer Focal Plane Array," now U.S. Pat. No. 6,028,309, issued Feb. 22, 2000, which is incorporated herein by reference in its entirety.

[0042] IR imaging module **102** may capture IR image data (e.g., a thermal image) using FPA **104**. In the illustrated embodiment of FIG. **3**, IR radiation from scene **140** passes along an optical path **150** through window **132** and one or

more optics blocks **134** to reach IR imaging module **102** (e.g., a vacuum package assembly). Optics block **134** may be implemented, for example, with athermalized optics including one or more lenses (e.g., lens elements), and configured to focus the IR radiation onto FPA **104** provided in IR imaging module **102**. In one example, IR imaging module **102** and optics block **134** may be sealed inside a chamber including window **132** (e.g., a heated or temperature controlled protective window) positioned between optics block **134** and scene **140**. In another example, one or more lenses of optics block **134** may be selectively inserted into optical path **150**. Accordingly, IR imaging device **100** may be operated with various lenses (e.g., 25 mm, 35 mm, 50 mm, 140 mm, or other size) as may be desired for particular applications. The different types of lenses may contribute to different non-uniformities in the propagation of IR radiation along optical path **150**. Although window **132** and optics block **134** are shown in the embodiment of FIG. **3**, window **132**, optics block **134**, or both may be omitted, or combined with IR imaging module **102**, according to various other embodiments.

[0043] IR imaging device **100** may include visible light imaging module **108** that is configured to capture visible light image data (e.g., a visible light image). In the illustrated embodiment of FIG. **3**, visible light from scene **140** may pass along optical path **150** through window **136** and one or more optics blocks **138** to reach visible light imaging module **108**. Window **136** (e.g., a protective window) may be positioned between optics block **138** and visible light imaging module **108**. Although window **136** and optics block **138** are shown in the embodiment of FIG. **3**, window **136**, optics block **138**, or both may be omitted, or combined with visible light imaging module **108**, according to various other embodiments.

[0044] In IR imaging devices that use a shutter to perform FFC, a logic device may receive thermal image data captured by IR detectors of an FPA while the shutter is closed, and processes the thermal image data to perform FFC to compensate for non-uniformities (e.g., different gains and dark currents) associated with the IR detectors of the FPA and other non-uniformities associated with optics blocks or other portions of the IR imaging device. The shutter emits uniform IR radiation to each IR detector of the FPA such that pixel values corresponding to each IR detector may be compared. The logic device may thereby acquire FFC terms (e.g., gain and/or offset terms) that may be used. The FFC terms may be applied to an IR imaging module (e.g., a ROIC of the IR imaging module) and/or an input image to provide corrected thermal images of a scene that account for non-uniformities of the FPA. When the IR imaging module captures an image subsequent to the acquisition of the FFC terms, uniform IR radiation throughout the FOV will create a uniform output image. The determination of FFC terms are further described as an example in U.S. patent application Ser. No. 12/391,156, filed Feb. 23, 2009, and entitled "Flat field correction for IR cameras," now U.S. Pat. No. 8,373, 757 entitled "Flat field correction for IR cameras," issued Feb. 12, 2013, which is incorporated herein by reference in its entirety.

[0045] IR imaging module **102** may capture an image of an empty scene, rather than the image of the shutter as described above, and the image of the empty scene may be used to acquire calibration terms in accordance with one or more embodiments of the disclosure. A scene **140** may

include a background **142** and a foreground **144**. The empty scene refers to background **142**. Foreground **144** may include objects such as people. The objects in foreground **144** may be moving objects and/or objects that have moved into scene **140** since IR imaging device **100** acquired or updated background calibration terms using the image of background **142**.

[0046] FPA **104** may detect IR radiation received from scene **140** that only includes background **142** along optical path **150** for a FOV. In response, ROIC **114** may generate thermal image data (e.g., a thermal image) of background **142**. Logic device **110** may receive the thermal image data from ROIC **114**, and acquire background calibration terms (e.g., background calibration values or a calibration map) by processing the thermal image data to determine background calibration terms. The background calibration terms may be acquired using the FFC process described above but without the shutter. As the FFC process is being performed using the thermal image data of background **142** instead of thermal image data from a shutter, pixel values corresponding to IR radiation received from background **142** will be calibrated (e.g., by gain and offset) to a baseline pixel value (e.g., zero).

[0047] Logic device **110** may apply the background calibration terms such that when IR imaging module **102** captures an image of background **142** subsequent to the application of background calibration terms, each pixels value of the image of background **142** is calibrated to be equal or approximately equal in value (e.g., each pixel value is or close to zero or some other baseline pixel value). Logic device **110** may apply the background calibration terms to ROIC **114** such that image data generated by ROIC **114** in response to FPA **104** receiving IR radiation is calibrated to background **142**. For example, IR imaging module **102** may capture an input image by ROIC **114** generating the input image in response to FPA **104** receiving IR radiation, and ROIC **114** or logic device **110** may send the input image to processor **120** as an output image. Additionally, or alternatively, logic device **110** may apply the background calibration terms to the input image to generate output image to be sent to processor **120**. For example, IR imaging module **102** may capture an input image by ROIC **114** generating the input image in response to FPA **104** receiving IR radiation, and logic device **110** may apply background calibration terms to the input image to generate an output image, which may be sent to processor **120**.

[0048] When IR imaging module **102** captures an image of scene **140** including background **142** and foreground **144**, the output image may have high pixel values for pixels corresponding to IR radiation received from foreground **144** (e.g., representing objects that are hotter than background **144**), and pixel values at or close to the baseline pixel value (e.g., zero or low pixel values below a predetermined threshold) for pixels corresponding to IR radiation received from background **142**, for example. Accordingly, the image may be referred to as a foreground image since the foreground pixels have high pixel values and all the background pixels have pixel values at or close to the baseline pixel value (e.g., zero or low pixel values below a predetermined threshold). Similarly, in another example, the output image may have higher or lower pixel values for pixels corresponding to IR radiation received from foreground **144** (e.g., representing objects that are hotter or colder than back-

ground **144**), and pixel values at or close to the baseline pixel value for pixels corresponding to IR radiation received from background **142**.

[0049] The background calibration terms may be updated periodically to account for changes in background **142**. After a time period from the last determination of the background calibration terms, IR imaging module **102** may capture one or more images of background **142**, determine updated background calibration terms, and apply the updated background calibration terms as discussed above. Processor **120** may dynamically adjust a time period between each update based on foreground information (e.g., presence of people, human activity, human movement, etc.). Processor **120** may process the output image received from IR imaging module **102** to determine foreground pixels and segment objects. When people are detected in the image, processor **120** slows down background update, such as by lengthening the time period between updates, so that the people are not included as part of background **142**. Further, background calibration terms for different pixels or pixel areas may be updated at different rates, for example, depending on detected objects or motion in corresponding pixels or pixel areas. Processor **120** may further process the output image received from IR imaging module **102** to generate heat maps and classify objects in foreground **144**.

[0050] In some embodiments, IR imaging module **102** may be configured to provide thermal images as image data representing the IR radiation intensity for each pixel using high bit-depth digital values. In one implementation, IR imaging module **102** may provide thermal images having 14-bit values to represent IR radiation intensity for each pixel of the thermal images captured with background calibration terms applied. Such an IR imaging module may also be herein referred to as a 14-bit thermal imaging module. Furthermore, IR imaging module **102** according to one or more embodiments may be configured to provide the high bit-depth thermal images without compressing (e.g., for automatic gain control and/or to provide a suitable dynamic range for displaying on a screen) or otherwise mapping to lower bit-depth images. Thus, in such embodiments, more detailed pixel information may be provided by the high bit-depth pixels, thereby advantageously facilitating more accurate and efficient detection and classification of objects using the pixels of the thermal images provided by IR imaging module **102**.

[0051] Processor **120** may include one or more processing systems configured with appropriate software (e.g., one or more computer programs for execution by processor **120**) stored in memory **122** and/or on machine readable medium **128** to instruct processor **120** to perform one or more of the operations described herein. The one or more processing systems of processor **120** may include logic devices, microcontrollers, application specific integrated circuits (ASICs), programmable logic devices (PLDs), or other suitable processing systems.

[0052] Memory **122** may include one or more memory devices to store data and information, including IR imaging data (e.g., thermal imaging data), IR images (e.g., thermal images), background calibration terms, radiometric calibration terms, and/or other calibration terms. The one or more memory devices may include various types of memory including volatile and non-volatile memory devices, such as RAM (Random Access Memory), flash memory, EEPROM

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(Electrically-Erasable Read-Only Memory), ROM (Read Only Memory), a hard disk drive, or other suitable memory devices.

[0053] Processor **120** and memory **122** may be implemented in accordance with any desired combination of one or more processors and/or one or more memories as desired for particular implementations. In some embodiments, processor **120** is communicatively coupled to logic device **110** that is separate from processor **120**. In other embodiments, logic device **110** is implemented, at least in part, by processor **120**, and memory **112** is implemented, at least in part, by memory **122**.

[0054] Machine-readable medium **128** may include one or more mediums including a compact disc, such as a CD-ROM, a digital video disc, a flash drive, or other suitable medium. Machine-readable medium **128** may be a non-transitory machine-readable medium storing machine-readable instructions, which may be executed by processor **120** to cause IR imaging device **100** to perform one or more processes described herein. Memory **122** and/or machine readable medium **128** may configured to store a plurality of calibration terms, such as calibration maps (e.g., calibration terms associated with coordinates of a map, the coordinates representing pixel locations on captured thermal images).

[0055] Display **124** may be used to display captured and/or processed IR images and/or other images, data, and information. Motion sensors **126** may be implemented by one or more motion detectors, accelerometers, gyroscopes, or other appropriate devices that may be used to detect movement of IR imaging device **100** and/or objects or people in foreground **144**.

[0056] Motion sensors **126** may be monitored by and provide information to processing and control block **118** to detect motion. In various embodiments, motion sensors **126** may be implemented as part of IR imaging device **100** (as shown in FIG. **3**), IR imaging module **102**, or other devices attached to or otherwise interfaced with IR imaging device **100**.

[0057] Other components **130** of IR imaging device **100** may include various components as desired for particular implementations of IR imaging device **100**. In some embodiments, other components **130** may include one or more indicator lights, such as LED indicators, that are configured to turn on or off to indicate various conditions or an operating status associated with IR imaging device **100**. For example, one or more indicator lights may be used to indicate the power status (e.g., on, off, ready-state, or in other power modes) of IR imaging device **100**, and/or to indicate the calibration term acquisition state (e.g., whether the acquisition of calibration terms is complete or in progress). In some embodiments, one or more audible indicators (e.g., beepers or speakers) or vibrational indicators may be used in addition to or in place of the one or more indicator lights. In some embodiments, other components **130** may include a power block including a circuit board power subsystem (e.g., a power board) for IR imaging device **100**. The power block may provide various power conversion operations and desired power supply voltages, power on-off switching, and/or various other operations, such as providing an interface to a battery or external power supply, as would be understood by one skilled in the art.

[0058] As IR imaging device **100** according to some embodiments includes no shutter for IR imaging module **102**, IR imaging device **100** may not need motors or solenoids, which allow for miniaturization such that it is suitable for various devices, for example, compact security or surveillance cameras, hand-held thermal cameras, or goggle thermal cameras. IR imaging device **100** may have no electronic motion control, which allows IR imaging device **100** to have high reliability, power savings, and noiseless operation. IR imaging device **100** in other embodiments may include a shutter for IR imaging module **102**, but capturing of an image to be used for calibration (e.g., an image of background **142**) and determining of background calibration terms are still performed as discussed above without the shutter blocking the optical path from scene **140** to FPA **104** (e.g., with the shutter open).

[0059] FIG. **4** illustrates a flow diagram of a process **400** to detect objects and generate heat maps in accordance with an embodiment of the disclosure. At block **402**, background calibration terms are acquired and applied. In some embodiments, an IR imaging device such as IR imaging device **100** (shown in FIG. **3**) captures and processes image data of a background such as background **142** (shown in FIG. **3**) to determine background calibration terms. IR imaging module **102** (shown in FIG. **3**) may generate background image data in response to FPA **104** (shown in FIG. **3**) receiving IR radiation from a scene such as scene **140** (shown in FIG. **3**) that only includes background **142**. The background image data may include a high bit-depth input image, such as an uncompressed 14-bit input image, as discussed above for IR imaging module **102**.

[0060] A logic device such as logic device **110** (shown in FIG. **3**), which may be integrated with or coupled to IR imaging module **102**, may process the background image data to determine background calibration terms that bring each pixel value of background image data to a baseline pixel value. The background calibration terms may include gain and offset terms for each pixel that are to be applied to values of corresponding pixels of input image data to provide the output image data.

[0061] Logic device **110** may store the background calibration terms in a non-volatile memory such as memory **112** (shown in FIG. **3**), which may be integrated with or coupled to IR imaging module **102**. If previously acquired background calibration terms are stored in the memory **112**, the previously acquired background calibration terms are updated.

[0062] Logic device **110** may apply the background calibration terms to IR imaging module **102** (e.g., to ROIC **114**). Additionally, or alternatively, logic device **110** may apply the background calibration terms to input image data (e.g., input image) when it receives the input image data from ROIC **114** at block **404**, described further below. Advantageously, the application of the background calibration terms effectively eliminates the need for background models that are typically required for IR imaging devices that perform background-foreground segmentation processes on images captured using an FFC process using a shutter.

[0063] In other embodiments, the background calibration terms may be stored as background image data in a memory (e.g., memory **112**, memory **122**, or machine readable medium **128** shown in FIG. **3**). IR imaging device **100** (e.g., using logic device **110** or processor **120** shown in FIG. **3**) may subtract the background image data from the input image data for each pixel when it receives the input image data from ROIC **114** at block **404**, described further below.

[0064] At block **404**, IR imaging device **100** captures and handles new input image data. IR imaging module **102** may capture input image data in response to FPA **104** receiving IR radiation from scene **140**. The input image data may include a high bit-depth input image, such as for example an uncompressed 14-bit input image, as discussed above for IR imaging module **102** of FIG. **3**. In some embodiments, ROIC **114** of IR imaging module **102** sends input image data to processor **120** as output image data (e.g., output image). In other embodiments, logic device **110** of IR imaging module **102** may process the input image data using background calibration terms to generate output image data that is sent to processor **120**. Pixels of the output image data that correspond to background **142** have pixel values at or close to a baseline pixel value (e.g., zero or close to zero) while pixels of the output image data corresponding to foreground **144** have higher or lower pixel values.

[0065] At block **406**, IR imaging device **100** creates segmented objects. Processor **120** of IR imaging device **100** may perform spatial foreground detection on the output image data received from IR imaging module **102** based on the background pixels having values at or close to the baseline pixel value and the foreground pixels having a higher pixel value. For example, processor **120** may determine the foreground from the output image by determining pixel values that are above the baseline pixel value or a predetermined threshold (to eliminate pixel values that are above zero due to noise). Advantageously, the foreground is extracted simply by determining where the high pixel values are located (e.g., by applying a threshold), which effectively eliminates the need for background-foreground segmentation processes that require processing intensive and complex algorithms.

[0066] Processor **120** may segment the determined foreground to create objects. Advantageously, the foreground contains less artificial foreground pixels and object segmentation is more accurate compared to the foreground and object segmentation obtained by IR imaging devices that perform background-foreground segmentation processes on images captured using an FFC process with a shutter.

[0067] At block **408**, IR imaging device **100** classifies the segmented objects (e.g., by determining whether a segmented object is or is not a human). Processor **120** of IR imaging device **100** may classify the segmented objects based on a volume of the segmented objects as each human will have a similar volume, the contours of the segmented objects, and/or the aspect ratio of the segmented objects. Further, a feature descriptor such as a histogram of oriented gradients (HoG) may be used to detect humans (e.g., using the Dalal-Triggs method).

[0068] In an example, IR imaging device **100** may be side-fired (IR imaging device **100** captures images of people from the side), and the average pixel intensities of images captured by IR imaging device **100** may be used to count a number of people as shown in FIG. **6**. As shown in FIG. **6**, each time a person moves within the FOV of IR imaging device **100**, the average pixel intensities (or pixel value differences from the baseline value) represented by the y-axis peaks and dissipates as the person moves out of the FOV. Because each person has an approximately similar pixel volume or a pixel volume within a predetermined pixel volume range in the captured image, the average pixel intensity may be proportional to the number of people in the FOV. Accordingly, the average pixel intensity (e.g., a sum of

the average row intensities) may be used to determine a number of people in the FOV of IR imaging device **100**. The average pixel intensities will be at or close to the baseline pixel value (e.g. zero) when there are no people within the FOV.

[0069] In another example, IR imaging device **100** may be overhead (IR imaging devices **100** captures images of people from above), and the average pixel intensities of images captured by IR imaging device **100** may be used to count a number of people as shown in FIG. **7**. As shown in FIG. **7**, the average pixel intensities represented by the y-axis are higher when there are people in the FOV of IR imaging device. The average pixel intensity may be proportional to the number of people in the FOV. Accordingly, the average pixel intensity (e.g., a sum of average pixel value differences from the baseline values) may be used to determine a number of people in the FOV of IR imaging device **100**.

[0070] In a further example, IR imaging device **100** may be overhead (IR imaging devices **100** captures images of people from above), and IR imaging device **100** may capture an image of one or more people as shown in an image **702** in FIG. **7**. A horizontal profile **702** such as column profile may be determined from image **704**. Horizontal profile **702** shows horizontal location (e.g., column position) represented by the x-axis vs. average pixel intensity represented by the y-axis. Further, a vertical profile **706** such as row profile may be determined from image **702**. Vertical profile **706** shows vertical location (e.g., row position) represented by the x-axis vs. average pixel intensity represented by the y-axis. IR imaging device **100** may combine horizontal profile **704** and vertical profile **706** to perform spatial two-dimensional segmentation and foreground detection. Accordingly, the average pixel intensities may advantageously be used to separate objects from each other. As can be observed in the two profile lines of horizontal profile **704** and vertical profile **706**, objects may be separated from each other based on the local minimums. IR imaging device **100** may further take into account the expected volume of each person given the perspective of IR imaging device **100** (e.g., side-fired, overhead, at a certain angle from above, etc.).

[0071] At block **410**, IR imaging device **100** may determine whether an object in foreground **144** is detected at block **406** (e.g., presence of a foreground object). Additionally, or alternatively, IR imaging device **100** may determine whether a classified object in foreground **144** is detected at block **408** (e.g., the presence of a human, human activity, or human motion).

[0072] At block **412**, if a foreground (e.g., a human) is detected at block **410**, the update of the applied background calibration terms is slowed down. If no human is detected for a predetermined time period (e.g., no human activity or motion for 1 minute), IR imaging module **102** may capture an image of background **142**, acquire updated background calibration terms, and update the background calibration terms. Processor **120** may control or modulate when logic device **110** acquires and updates background calibration terms. Accordingly, the background calibration terms are updated using a feedback mechanism that includes slowing down the update when people are detected and performing the update if no people are detected for a predetermined time period. The feedback mechanism used for updating of the calibration terms may be referred to as temporal foreground

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detection and, thus, IR imaging device **100** combines spatial foreground detection discussed above with temporal foreground detection.

[0073] In some embodiments, if human activity is detected at block **410**, the update of the background calibration terms is slowed down only for pixels that are a part of the object segment determined to indicate a human. In this manner, update of background calibration terms may be adaptive—some pixels are updated faster. Background calibration terms for some pixels are acquired and updated while background calibration terms for pixels that are or were recently a part of an object segment determined to indicate a human is not updated. In further embodiments, such adaptive updating of background calibration terms may only occur when the object segment is determined to indicate a human with a confidence level that is above a threshold confidence level.

[0074] Although blocks **408-412** have been described in relation to detecting people, other objects of interest and moving objects may be detected in other embodiments. In further embodiments, blocks **408-412** may also perform fire detection.

[0075] At block **414**, IR imaging device **100** generates or updates a heat map (e.g., a map or other data structure for presenting information associated with objects in a scene). Processor **120** of IR imaging device **100** may generate a heat map using the output image data from ROIC **114** at block **404**, segmented objects at block **406**, and/or classified objects at block **408**. Processor **120** may display the heat map on a display such as display **124** (shown in FIG. **3**).

[0076] Various features may be shown on the heat map. The object segments and classification from blocks **406-408** may be shown on the heat map. When an object in scene **140** moves, an object segment corresponding to the object may move on the heat map when the heat map is updated. Advantageously, recognizing high pixel values of pixels or pixel areas of an image may replace complex tracking algorithms typically used for object tracking processes.

[0077] Features shown on the heat map may include features in real-time or near real-time such as where people are located, where people are facing, what people are looking at, how many people are present, or other feature at the moment. Features shown on the heat map may include features determined over a period of time such as where people tend to walk through, where people spend more time, what people tend look at, or other feature based on trends. In some embodiments, the heat map may utilize horizontal profile **704** and vertical profile **706** shown in FIG. **7** to determine one or more features shown on the heat map. In an example, IR imaging device **100** may advantageously be used at a retail location to provide information such as where customers are located, where customers are moving within the store, where they are looking at, the most common trajectories of the customers, and other useful information.

[0078] A shutterless IR imaging device such as IR imaging device **100** that applies background calibration terms, which are based on IR radiation received from an empty scene, advantageously provides a stable image for extraction and segmentation in blocks **406-408**. The process described above in relation to FIG. **4** not only produces more accurate segmentation but also produces less ghost artifacts. Further, there may be a longer mean time between failures (MTBF) compared to IR imaging devices that use a shutter for FFC, since the shutter and related mechanical components are not needed in one or more embodiments of the disclosure. In addition, further advantages of more accurate, efficient, and otherwise improved foreground extraction and segmentation may be achieved as discussed above for embodiments that utilize a higher bit-depth image, such as a 14-bit image provided without further compression, automatic gain control (AGC), or other mapping to a lower bit-depth image. Since the often complex AGC and/or other compression/mapping processes need not be performed in such embodiments, even further saving of the processing power may be achieved for a processor such as processor **120**.

[0079] In some embodiments, IR imaging device **100** may also perform one or more processes described at blocks **402-414** using visible light imaging module **108**. Such object detection process using visible light imaging module **108** may be combined or otherwise mixed with the object detection and heat map generation process performed using IR imaging module **102**. For example, IR imaging device **100** may generate a heat map that includes information from thermal image captured by IR imaging module **102** and visible light image captured by visible light imaging module **108**. By utilizing more than one imaging module, fewer artifacts may be included in the foreground pixels and the foreground pixels may be segmented more accurately, which in turn allows for more accurate classification of the segments.

[0080] FIG. **5** illustrates another flow diagram of a process **500** to generate a heat map and detect objects in accordance with an embodiment of the disclosure. At block **502**, IR imaging module **102** of IR imaging device **100** (shown in FIG. **3**) captures a thermal image of an empty scene, such as scene **140** that includes background **142** but no foreground **144** (shown in FIG. **3**).

[0081] At block **504**, IR imaging device **100** (e.g., using logic device **110** shown in FIG. **3**) acquires background calibration terms based on the thermal image of background **142** in response to IR radiation received from background **142**. IR imaging device **100** may store the background calibration terms in a memory, such as memory **112** (shown in FIG. **3**). IR imaging device **100** may apply the background calibration terms to IR imaging module **102**. Alternatively, or additionally, IR imaging module **102** may apply the background calibration terms to an input image received from IR imaging module **102** at block **506**.

[0082] The background calibration terms may include gain terms and offset terms for each IR detector of FPA **104** corresponding to a value of a pixel in the thermal image. The background calibration terms for each pixel may bring the value of each pixel to a baseline value (e.g., zero) such that when the background calibration terms are applied, a thermal image captured by IR imaging module **102** in response to IR radiation from the same background **142** will include pixels all having the baseline pixel value (e.g., zero) or low values close to the baseline value (e.g., approximately zero).

[0083] At block **506**, IR imaging module **102** captures a thermal image of a scene, such as scene **140** including background **142** and foreground **144**. Foreground **144** may include various objects that were not present in scene **140** when background **142** was captured at block **502**. The various objects may include one or more objects of interest. The objects of interest may be people, animals, moving objects, automobiles, fire, or other objects of interest to an operator. For example, for IR imaging device **100** used at a retail location, the objects of interest may be customers. The

operator may be interested in how they are moving within the store, how they are moving, and where they are looking at.

[0084] At block **508**, IR imaging device **100** (e.g., using processor **120** shown in FIG. **3**) processes the thermal image of scene **140** captured at block **506**. IR imaging device **100** may determine foreground pixels in the thermal image of scene **140**, for example, by detecting foreground as further described above in relation to block **404** in FIG. **4**. IR imaging device **100** may determine segments (e.g., segment objects) based on the foreground pixels, for example, by creating the segments as further described above in relation to block **406** in FIG. **4**.

[0085] At block **510**, IR imaging device **100** (e.g., using processor **120**) detects one or more objects of interest indicated by at least one of the segments or determine that no objects of interest are in the thermal image of scene **140**. For example, IR imaging device **100** may perform the detection by classifying the segments as further described above in relation to block **408** in FIG. **4**.

[0086] At block **512**, IR imaging device **100** (e.g., using processor **120**) generates a heat map, as further described in relation to block **412** in FIG. **4**. The heat map may indicate where the one or more people are located, walking to, and/or looking at based on the thermal image of scene **140**. The heat map may be in grayscale, as shown in FIG. **2**, or in color. In certain embodiments, the heat map may be combined or mixed with a visible image captured using visible light imaging module **108** to provide more information to an operator.

[0087] In an example, IR imaging device **100** is used at a retail location, and generates a heat map that indicate where customers are located, where customers are moving within the store, where they are looking at. The heat map may further indicate the most common trajectories of the customers.

[0088] At block **514**, IR imaging module **102** captures a thermal image of an empty scene such as background **142** after a time interval, which may be a predetermined time period. At block **516**, IR imaging device **100** (e.g., using logic device **110** and/or processor **120**) updates the background calibration terms after the time interval, for example, by acquiring and applying updated background calibration terms based on the thermal image captured at block **514**.

[0089] At block **518**, IR imaging device **100** (e.g., using processor **120**) determines whether one or more objects of interest are in scene **140** based on the process at block **510**. In some embodiments, IR imaging device **100** updates the background calibration terms only when no objects of interest are detected during the time interval.

[0090] At block **520**, if it is determined that there are one or more objects of interest in scene **140** at block **518**, IR imaging device **100** (e.g., using logic device **110** and/or processor **120**) slows down the update process at block **516**, such as by increasing the time interval at blocks **514-516**. In some embodiments, IR imaging device **100** applies the increased time interval only to select pixels that are a part of the segments determined to indicate an object of interest. IR imaging device **100** may update the background calibration terms corresponding to the select pixels (e.g., background calibration terms for IR detectors corresponding to the select pixels) according to the increased time interval. IR imaging device **100** may update the background calibration terms corresponding to the rest of the pixels (e.g., background

calibration terms for IR detectors corresponding to the rest of the pixels) according to a previous time interval or a default time interval. At block **522**, if it is determined that there are no objects of interest in scene **140** at block **518**, IR imaging device **100** (e.g., using logic device **110** and/or processor **120**) speeds up the update process at block **516**, such as by decreasing the time interval at blocks **514-516**.

[0091] Where applicable, the various described embodiments may be implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein may be combined into composite components including software, hardware, and/or both without departing from the spirit of the disclosure. Where applicable, the various hardware components and/or software components set forth herein may be separated into sub-components including software, hardware, or both without departing from the spirit of the disclosure. In addition, where applicable, it is contemplated that software components may be implemented as hardware components, and vice-versa. In some embodiments, such hardware components (e.g., processing and control block **118**) may be implemented as one or more appropriate processors and/or processing devices (e.g., logic device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), or other device) that may be used to execute appropriate instructions, such as software instructions implementing any of the processes described herein.

[0092] Software in accordance with the various described embodiments, such as program code and/or data, may be stored on one or more machine readable mediums. It is also contemplated that software identified herein may be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein may be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

[0093] Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the invention. Accordingly, the scope of the invention is defined only by the following claims.

We claim:

1. A device, comprising:

an infrared (IR) imaging module configured to capture thermal images;

a memory configured to store background calibration terms; and

a logic device configured to:

receive a thermal image of a background from the IR imaging module;

determine the background calibration terms based on the thermal image of the background, wherein the background calibration terms bring each pixel value of the thermal image of the background to a baseline pixel value; and

apply the background calibration terms, wherein the IR imaging module is configured to provide a thermal image of a scene comprising the baseline pixel value for pixels corresponding to the background and pixel values different from the baseline pixel value for

pixels corresponding to a foreground according to the applied background calibration terms.

2. The device of claim **1**, wherein the logic device is further configured to:

receive additional thermal images of the background from the IR imaging module; and

update the background calibration terms periodically according to a time interval based on the additional thermal images.

3. The device of claim **2**, further comprising a processor configured to:

determine foreground pixels in the thermal image of the scene;

determine segments based on the foreground pixels;

detect one or more objects of interest indicated by at least one of the segments; and

in response to detecting the one or more objects of interest, increase the time interval.

4. The device of claim **3**, wherein the processor is configured to update the background calibration terms in response to detecting no objects of interest during the time interval.

5. The device of claim **3**, wherein the increased time interval is applied only to select pixels that are a part of the at least one of the segments, and wherein the processor is configured to update the background calibration terms corresponding to the select pixels according to the increased time interval.

6. The device of claim **3**, wherein the one or more objects of interest comprise one or more people, and wherein the processor is configured to detect the one or more people based on a volume of the at least one of the segments, an average pixel intensity, or both.

7. The device of claim **6**, wherein the processor is further configured to generate a heat map indicating where the one or more people are located, walking to, and/or looking at based on the thermal image of the scene.

8. The device of claim **1**, wherein the logic device is configured to apply the background calibration terms to a readout integrated circuit of the IR imaging module, to the thermal image of the scene, or both.

9. The device of claim **1**, wherein the background calibration terms comprise gain terms and/or offset terms.

10. The device of claim **1**, wherein the IR imaging module is a 14-bit shutterless IR imaging module configured to capture 14-bit thermal images.

11. A method comprising:

capturing a thermal image of a background;

acquiring background calibration terms based on the thermal image of the background, wherein the back-

ground calibration terms bring each pixel value of the thermal image of the background to a baseline pixel value;

applying the background calibration terms; and

capturing a thermal image of a scene comprising the baseline pixel value for pixels corresponding to the background and pixel values different from the baseline pixel value for pixels corresponding to a foreground.

12. The method of claim **11**, further comprising:

capturing additional thermal images of the background; and

updating the background calibration terms periodically according to a time interval based on the additional thermal images.

13. The method of claim **12**, further comprising:

determining foreground pixels in the thermal image of the scene;

determining segments based on the foreground pixels;

detecting one or more objects of interest indicated by at least one of the segments; and

in response to the detecting, increasing the time interval.

14. The method of claim **13**, wherein the updating is in response to detecting no objects of interest during the time interval.

15. The method of claim **13**, wherein the increasing of the time interval is applied only to select pixels that are a part of the at least one of the segments, and wherein the updating comprises updating the background calibration terms corresponding to the select pixels according to the increased time interval.

16. The method of claim **13**, wherein the one or more objects of interest comprise one or more people, and wherein the detecting of the one or more people is based on a volume of the at least one of the segments, an average pixel intensity, or both.

17. The method of claim **16**, further comprising generating a heat map indicating where the one or more people are located, walking to, and/or looking at based on the thermal image of the scene.

18. The method of claim **11**, wherein the applying comprises applying the background calibration terms to a readout integrated circuit, to the thermal image of the scene, or both.

19. The method of claim **11**, wherein the applying comprises applying gain terms and/or offset terms.

20. The method of claim **12**, wherein the thermal image of the background and the thermal image of the scene are 14-bit thermal images.

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