(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 June 2014 (26.06.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/099326 A1

(51) International Patent Classification:
H04N 5/262 (2006.01) *G06T 5/00* (2006.01)

(21) International Application Number:
PCT/US2013/072564

(22) International Filing Date:
2 December 2013 (02.12.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/722,519 20 December 2012 (20.12.2012) US

(71) Applicant: **GOOGLE INC.** [US/US]; 1600 Amphitheatre Parkway, Mountain View, CA 94043 (US).

(72) Inventor: **GEISS, Ryan**; Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043 (US).

(74) Agent: **BORELLA, Michael, S.**; Mcdonnel Boehnen Hulbert &, Berghoff LLP, 300 South Wacker Drive, Chicago, IL 60606 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: DETERMINING IMAGE ALIGNMENT FAILURE

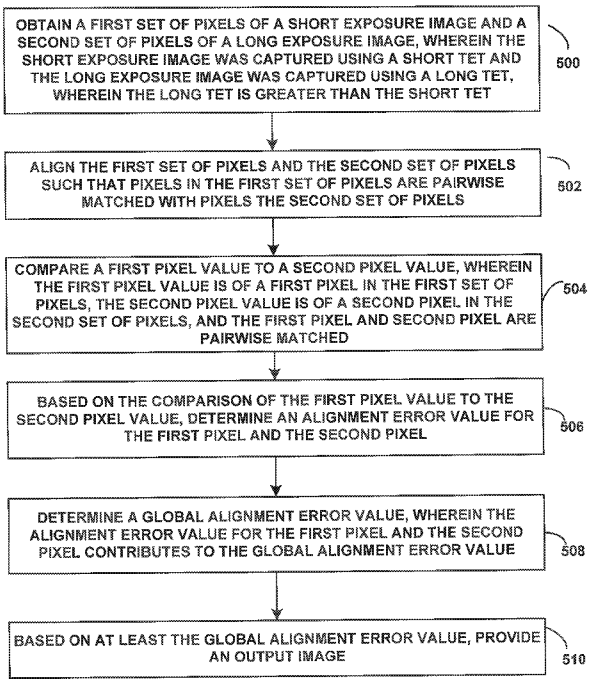


FIG. 5

(57) Abstract: A first set of pixels of a short exposure image and a second set of pixels of a long exposure image may be obtained. The short exposure image may have been captured using a short total exposure time (TET) and the long exposure image may have been captured using a long TET, The long TET may be greater than the short TET, The first set of pixels and the second set of pixels may be aligned. A first pixel value of a first pixel in the first set of pixels and a second pixel of a second pixel in the second set of pixels value may be compared. Based on the comparison, an alignment error value for the first pixel and the second pixel may be determined. Based at least on the alignment error value, an output image may be provided.

WO 2014/099326 A1

Published:

— *with international search report (Art. 21(3))*

DETERMINING IMAGE ALIGNMENT FAILURE

BACKGROUND

[0001] Generally, imaging may refer to representing the color and brightness characteristics of digital images. Low dynamic range (LDR) imaging may represent digital images (e.g., photographs and motion video) with 8 or fewer bits for each color channel of a pixel. As a result, up to 256 levels of brightness may be supported. Currently, a wide range of video output devices (e.g., computer monitors, tablet and smartphone screens, televisions, etc.) support displaying LDR images.

[0002] However, real-world scenes often exhibit a wider range of brightness than can be represented by LDR imaging. As an example scene with a wide brightness range, consider an individual standing in a dark room in front of a window. This scene may include both extremely bright regions (e.g., sunlit features outside the window) and extremely dark regions (e.g., the features in the room). Ideally, a photograph of this scene would include both the details in the bright regions and the details in the dark regions.

SUMMARY

[0003] In a first example embodiment, a first set of pixels of a short exposure image and a second set of pixels of a long exposure image may be obtained. The short exposure image may have been captured using a short total exposure time (TET) and the long exposure image may have been captured using a long TET. The long TET may be greater than the short TET. The first set of pixels and the second set of pixels may be aligned. A first pixel value of a first pixel in the first set of pixels and a second pixel of a second pixel in the second set of pixels value may be compared. Based on the comparison, an alignment error value for the first pixel and the second pixel may be

determined. Based on at least the alignment error value, an output image may be provided.

[0004] A second example embodiment may include a non-transitory computer-readable storage medium, having stored thereon program instructions that, upon execution by a computing device, cause the computing device, and/or its peripherals, to perform operations in accordance with the first example embodiment.

[0005] A third example embodiment may include a computing device, comprising at least a processor and data storage. The data storage may contain program instructions that, upon execution by the processor, cause the computing device operate in accordance with the first example embodiment.

[0006] These as well as other aspects, advantages, and alternatives will become apparent to those of ordinary skill in the art by reading the following detailed description with reference where appropriate to the accompanying drawings. Further, it should be understood that the description provided in this summary section and elsewhere in this document is intended to illustrate the claimed subject matter by way of example and not by way of limitation.

BRIEF DESCRIPTION OF THE FIGURES

[0007] Figure 1 depicts front, right side, and rear views of a digital camera device, in accordance with an example embodiment.

[0008] Figure 2 depicts a block diagram of a computing device with image capture capability, in accordance with an example embodiment.

[0009] Figure 3 depicts a flow chart, in accordance with an example embodiment.

[0010] Figure 4 depicts image alignment, in accordance with an example embodiment.

[0011] Figure 5 depicts a flow chart, in accordance with an example embodiment.

DETAILED DESCRIPTION

[0012] As image capture devices, such as cameras, become more popular, they may be employed as standalone hardware devices or integrated into various other types of devices. For instance, still and video cameras are now regularly included in wireless communication devices (e.g., mobile phones), tablet computers, laptop computers, video game interfaces, home automation devices, and even automobiles and other types of vehicles.

[0013] The physical components of a camera may include an aperture through which light enters, a recording surface for capturing the image represented by the light, and a lens positioned in front of the aperture to focus at least part of the image on the recording surface. The aperture may be fixed size or adjustable. In an analog camera, the recording surface may be photographic film. In a digital camera, the recording surface may include an electronic image sensor (e.g., a charge coupled device (CCD) or a complementary metal-oxide-semiconductor (CMOS) sensor) to transfer and/or store captured images in a data storage unit (e.g., memory).

[0014] A shutter may be coupled to or nearby the lens or the recording surface. The shutter may either be in a closed position, in which it blocks light from reaching the recording surface, or an open position, in which light is allowed to reach to recording surface. The position of the shutter may be controlled by a shutter button. For instance, the shutter may be in the closed position by default. When the shutter button is triggered (e.g., pressed), the shutter may change from the closed position to the open position for a period of time, known as the shutter cycle. During the shutter cycle, an image may be captured on the recording surface. At the end of the shutter cycle, the shutter may change back to the closed position.

[0015] Alternatively, the shuttering process may be electronic. For example, before an electronic shutter of a CCD image sensor is "opened" the sensor may be reset to remove any residual signal in its photodiodes. While the electronic shutter remains open, the photodiodes may accumulate charge. When or after the shutter closes, these charges may be transferred to longer-term data storage. Combinations of mechanical and electronic shuttering may also be possible.

[0016] Regardless of type, a shutter may be activated and/or controlled by something other than a shutter button. For instance, the shutter may be activated by a softkey, a timer, or some other trigger. Herein, the term "image capture" may refer to any mechanical and/or electronic shuttering process that results in one or more photographs being recorded, regardless of how the shuttering process is triggered or controlled.

[0017] The exposure of a captured image may be determined by a combination of the size of the aperture, the brightness of the light entering the aperture, and the length of the shutter cycle (also referred to as the shutter length or the exposure length). Additionally, a digital or analog gain may be applied to the image, thereby influencing the exposure. In some embodiments, the term "total exposure length" or "total exposure time" may refer to the shutter length multiplied by the gain for a particular aperture size. Herein, the term "total exposure time," or "TET," should be interpreted as possibly being a shutter length, an exposure time, or any other metric that controls the amount of signal response that results from light reaching the recording surface.

[0018] A still camera may capture one or more images each time image capture is triggered. A video camera may continuously capture images at a particular rate (e.g., 24 images – or frames – per second) as long as image capture remains triggered (e.g., while the shutter button is held down). Some digital still cameras may open the shutter when the camera device or application is activated, and the shutter may remain in this position until the camera device or application is deactivated. While the shutter is open, the camera

device or application may capture and display a representation of a scene on a viewfinder. When image capture is triggered, one or more distinct digital images of the current scene may be captured.

[0019] Cameras – even analog cameras – may include software to control one or more camera functions and/or settings, such as aperture size, TET, gain, and so on. Additionally, some cameras may include software that digitally processes images during or after these images are captured. While it should be understood that the description above refers to cameras in general, it may be particularly relevant to digital cameras.

[0020] As noted previously, digital cameras may be standalone devices or integrated with other devices. As an example, Figure 1 illustrates the form factor of a digital camera device 100. Digital camera device 100 may be, for example, a mobile phone, a tablet computer, or a wearable computing device. However, other embodiments are possible. Digital camera device 100 may include various elements, such as a body 102, a front-facing camera 104, a multi-element display 106, a shutter button 108, and other buttons 110. Digital camera device 100 could further include a rear-facing camera 112. Front-facing camera 104 may be positioned on a side of body 102 typically facing a user while in operation, or on the same side as multi-element display 106. Rear-facing camera 112 may be positioned on a side of body 102 opposite front-facing camera 104. Referring to the cameras as front and rear facing is arbitrary, and digital camera device 100 may include multiple cameras positioned on various sides of body 102.

[0021] Multi-element display 106 could represent a cathode ray tube (CRT) display, a light emitting diode (LED) display, a liquid crystal (LCD) display, a plasma display, or any other type of display known in the art. In some embodiments, multi-element display 106 may display a digital representation of the current image being captured by front-facing camera 104 and/or rear-facing camera 112, or an image that could be captured or was recently captured by either or both of these cameras. Thus, multi-

element display 106 may serve as a viewfinder for either camera. Multi-element display 106 may also support touchscreen and/or presence-sensitive functions that may be able to adjust the settings and/or configuration of any aspect of digital camera device 100.

[0022] Front-facing camera 104 may include an image sensor and associated optical elements such as lenses. Front-facing camera 104 may offer zoom capabilities or could have a fixed focal length. In other embodiments, interchangeable lenses could be used with front-facing camera 104. Front-facing camera 104 may have a variable mechanical aperture and a mechanical and/or electronic shutter. Front-facing camera 104 also could be configured to capture still images, video images, or both. Further, front-facing camera 104 could represent a monoscopic, stereoscopic, or multiscopic camera. Rear-facing camera 112 may be similarly or differently arranged. Additionally, front-facing camera 104, rear-facing camera 112, or both, may be an array of one or more cameras.

[0023] Either or both of front facing camera 104 and rear-facing camera 112 may include or be associated with an illumination component that provides a light field to illuminate a target object. For instance, an illumination component could provide flash or constant illumination of the target object. An illumination component could also be configured to provide a light field that includes one or more of structured light, polarized light, and light with specific spectral content. Other types of light fields known and used to recover three-dimensional (3D) models from an object are possible within the context of the embodiments herein.

[0024] Either or both of front facing camera 104 and rear-facing camera 112 may include or be associated with an ambient light sensor that may continuously or from time to time determine the ambient brightness of a scene that the camera can capture. In some devices, the ambient light sensor can be used to adjust the display brightness of a screen associated with the camera (e.g., a viewfinder). When the determined ambient brightness

is high, the brightness level of the screen may be increased to make the screen easier to view. When the determined ambient brightness is low, the brightness level of the screen may be decreased, also to make the screen easier to view as well as to potentially save power. Additionally, the ambient light sensor's input may be used to determine a TET of an associated camera, or to help in this determination.

[0025] Digital camera device 100 could be configured to use multi-element display 106 and either front-facing camera 104 or rear-facing camera 112 to capture images of a target object. The captured images could be a plurality of still images or a video stream. The image capture could be triggered by activating shutter button 108, pressing a softkey on multi-element display 106, or by some other mechanism. Depending upon the implementation, the images could be captured automatically at a specific time interval, for example, upon pressing shutter button 108, upon appropriate lighting conditions of the target object, upon moving digital camera device 100 a predetermined distance, or according to a predetermined capture schedule.

[0026] As noted above, the functions of digital camera device 100 – or another type of digital camera – may be integrated into a computing device, such as a wireless communication device, tablet computer, laptop computer and so on. For purposes of example, Figure 2 is a simplified block diagram showing some of the components of an example computing device 200 that may include camera components 224.

[0027] By way of example and without limitation, computing device 200 may be a cellular mobile telephone (e.g., a smartphone), a still camera, a video camera, a fax machine, a computer (such as a desktop, notebook, tablet, or handheld computer), a personal digital assistant (PDA), a home automation component, a digital video recorder (DVR), a digital television, a remote control, a wearable computing device, or some other type of device equipped with at least some image capture and/or image processing capabilities. It should be understood that computing device 200 may represent a physical

camera device such as a digital camera, a particular physical hardware platform on which a camera application operates in software, or other combinations of hardware and software that are configured to carry out camera functions.

[0028] As shown in Figure 2, computing device 200 may include a communication interface 202, a user interface 204, a processor 206, data storage 208, and camera components 224, all of which may be communicatively linked together by a system bus, network, or other connection mechanism 210.

[0029] Communication interface 202 may function to allow computing device 200 to communicate, using analog or digital modulation, with other devices, access networks, and/or transport networks. Thus, communication interface 202 may facilitate circuit-switched and/or packet-switched communication, such as plain old telephone service (POTS) communication and/or Internet protocol (IP) or other packetized communication. For instance, communication interface 202 may include a chipset and antenna arranged for wireless communication with a radio access network or an access point. Also, communication interface 202 may take the form of or include a wireline interface, such as an Ethernet, Universal Serial Bus (USB), or High-Definition Multimedia Interface (HDMI) port. Communication interface 202 may also take the form of or include a wireless interface, such as a Wifi, BLUETOOTH®, global positioning system (GPS), or wide-area wireless interface (e.g., WiMAX or 3GPP Long-Term Evolution (LTE)). However, other forms of physical layer interfaces and other types of standard or proprietary communication protocols may be used over communication interface 202. Furthermore, communication interface 202 may comprise multiple physical communication interfaces (e.g., a Wifi interface, a BLUETOOTH® interface, and a wide-area wireless interface).

[0030] User interface 204 may function to allow computing device 200 to interact with a human or non-human user, such as to receive input from a user and to provide

output to the user. Thus, user interface 204 may include input components such as a keypad, keyboard, touch-sensitive or presence-sensitive panel, computer mouse, trackball, joystick, microphone, and so on. User interface 204 may also include one or more output components such as a display screen which, for example, may be combined with a presence-sensitive panel. The display screen may be based on CRT, LCD, and/or LED technologies, or other technologies now known or later developed. User interface 204 may also be configured to generate audible output(s), via a speaker, speaker jack, audio output port, audio output device, earphones, and/or other similar devices.

[0031] In some embodiments, user interface 204 may include a display that serves as a viewfinder for still camera and/or video camera functions supported by computing device 200. Additionally, user interface 204 may include one or more buttons, switches, knobs, and/or dials that facilitate the configuration and focusing of a camera function and the capturing of images (e.g., capturing a picture). It may be possible that some or all of these buttons, switches, knobs, and/or dials are implemented as functions on a presence-sensitive panel.

[0032] Processor 206 may comprise one or more general purpose processors – e.g., microprocessors – and/or one or more special purpose processors – e.g., digital signal processors (DSPs), graphics processing units (GPUs), floating point units (FPUs), network processors, or application-specific integrated circuits (ASICs). In some instances, special purpose processors may be capable of image processing, image alignment, and merging images, among other possibilities. Data storage 208 may include one or more volatile and/or non-volatile storage components, such as magnetic, optical, flash, or organic storage, and may be integrated in whole or in part with processor 206. Data storage 208 may include removable and/or non-removable components.

[0033] Processor 206 may be capable of executing program instructions 218 (e.g., compiled or non-compiled program logic and/or machine code) stored in data storage 208

to carry out the various functions described herein. Therefore, data storage 208 may include a non-transitory computer-readable medium, having stored thereon program instructions that, upon execution by computing device 200, cause computing device 200 to carry out any of the methods, processes, or functions disclosed in this specification and/or the accompanying drawings. The execution of program instructions 218 by processor 206 may result in processor 206 using data 212.

[0034] By way of example, program instructions 218 may include an operating system 222 (e.g., an operating system kernel, device driver(s), and/or other modules) and one or more application programs 220 (e.g., camera functions, address book, email, web browsing, social networking, and/or gaming applications) installed on computing device 200. Similarly, data 212 may include operating system data 216 and application data 214. Operating system data 216 may be accessible primarily to operating system 222, and application data 214 may be accessible primarily to one or more of application programs 220. Application data 214 may be arranged in a file system that is visible to or hidden from a user of computing device 200.

[0035] Application programs 220 may communicate with operating system 222 through one or more application programming interfaces (APIs). These APIs may facilitate, for instance, application programs 220 reading and/or writing application data 214, transmitting or receiving information via communication interface 202, receiving and/or displaying information on user interface 204, and so on.

[0036] In some vernaculars, application programs 220 may be referred to as "apps" for short. Additionally, application programs 220 may be downloadable to computing device 200 through one or more online application stores or application markets. However, application programs can also be installed on computing device 200 in other ways, such as via a web browser or through a physical interface (e.g., a USB port) on computing device 200.

[0037] Camera components 224 may include, but are not limited to, an aperture, shutter, recording surface (e.g., photographic film and/or an image sensor), lens, and/or shutter button. Camera components 224 may be controlled at least in part by software executed by processor 206.

[0038] Captured digital images may be represented as a one-dimensional, two-dimensional, or multi-dimensional array of pixels. Each pixel may be represented by one or more values that may encode the respective pixel's color and/or brightness. For example, one possible encoding uses the YCbCr color model. In this color model, the Y channel may represent the brightness of a pixel, and the Cb and Cr channels may represent the blue chrominance and red chrominance, respectively, of the pixel. For instance, each of these channels may take values from 0 to 255 (i.e., the tonal range that a single 8-bit byte can offer). Thus, the brightness of a pixel may be represented by a 0 or a value near zero if the pixel is black or close to black, and by a 255 or a value near 255 if the pixel is white or close to white. However, the value of 255 is a non-limiting reference point, and some implementations may use different maximum values (e.g., 1023, 4095, etc.).

[0039] Nonetheless, the YCbCr color model is just one possible color model, and other color models such as a red-green-blue (RGB) color model or a cyan-magenta-yellow-key (CMYK) may be employed with the embodiments herein. Further, the pixels in an image may be represented in various file formats, including raw (uncompressed) formats, or compressed formats such as Joint Photographic Experts Group (JPEG), Portable Network Graphics (PNG), Graphics Interchange Format (GIF), and so on.

[0040] Some pixel encodings – including the YCbCr color model – use 8 bits to represent the brightness of each pixel. Doing so is referred to as LDR imaging. As a result, only 256 levels of brightness may be supported. However, real-world scenes often exhibit a wider dynamic range of brightness than can be reasonably represented by LDR imaging. For example, a scene of an individual standing in a dark room in front of a

window may include both extremely bright regions and extremely dark regions. However, use of LDR imaging to capture an image of such a scene may result in loss of detail in the bright region and/or the dark region based on the TET with which the image was captured.

[0041] A short TET may result in a reasonably accurate representation of the bright regions of a scene, but underexposure of the dark regions. Conversely, a long TET may result in a reasonably accurate representation of the dark regions, but may overexpose the bright regions. In the example scene introduced above, if the TET is too long, the features in the room may appear properly-exposed, but the features outside the window may appear whitewashed. But if the TET is too short, the features outside the window may appear normal but the features in the room may appear darkened. Either of these outcomes is undesirable. For some scenes, there may not be a single TET that results in a captured image representing the details in both bright regions and dark regions with acceptable detail.

[0042] Camera devices may support an auto-exposure (AE) mode in which, prior to output image capture, the camera determines the TET based on the brightness of the scene. For example, the user may observe the scene in the camera's viewfinder before triggering image capture. During this period, the camera may make an initial estimate of the proper TET, capture a preview image with that TET, and then evaluate the pixels in the captured image. Then, as one possible implementation, if a majority (or some other sufficient fraction) of the pixels in the preview image are over-exposed, the camera may decrease the TET and capture another preview image. If a majority (or some other sufficient fraction) of the pixels in this preview image are under-exposed, the camera may increase the TET and capture yet another preview image.

[0043] For instance, if the majority of the pixels in the captured image exhibit a brightness value above a high threshold level (e.g., 240), the camera may decrease the

TET. On the other hand, if a majority of the pixels exhibit a brightness level below a low threshold level (e.g., 96), the camera may increase the TET.

[0044] Alternatively or additionally, a target average pixel value for some or all of the scene's pixels may be determined. If the actual average pixel value is above the target average pixel value, the TET may be decreased, and if the actual average pixel value is below the target average pixel value, the TET may be increased. The target average pixel value can also be tuned differently depending on how much contrast there is in the scene. For example, in a low-contrast scene, the target average pixel value may be bright (e.g., 200). But in a high-contrast scene, the target average pixel value may be lower (e.g., 128).

[0045] This process may continue until the camera determines that an image should be captured and stored (e.g., the user activates the shutter button). During this process, if the characteristics of the scene are relatively unchanging, the camera usually converges on an estimated "best" TET based on the brightness of the scene. In some embodiments, the image displayed on the camera's viewfinder may omit information from one or more of the captured preview images or combine information from two or more of the captured preview images.

[0046] In some cases, the camera might not treat all pixels equally when determining an "average" brightness of the scene. Using a technique described as "center-weighted averaging," pixels near the middle of the scene may be considered to be more important. Thus, these pixels may be weighted more than pixels illustrating other areas of the scene. Alternatively, pixels in other locations of an image may be given more weight. For instance, if the camera detects a human face (or some other object of interest) in a particular location other than the center of the image, the camera may give a higher weight to the associated pixels.

[0047] In this way, AE algorithms may seek to determine a TET that produces a large number (e.g., the largest number) of properly-exposed pixels. However, given the

range limitations of LDR imaging, even images captured in AE mode may contain portions that are whitewashed or darkened. Thus, as noted above, some scenes there may be no single "best" TET.

[0048] AE algorithms may differ from the description above. For instance, some may be more complex, treating different colors differently, considering the spatial and/or structural components of a scene, and/or measuring contrast between regions. The embodiments herein, however, may operate with any AE algorithm now known or developed in the future.

[0049] High dynamic range (HDR) imaging has been proposed as a way of compensating for the deficiencies of LDR imaging. In a possible implementation, HDR imaging may involve a camera capturing multiple images of a scene at various TETs, and then digitally processing these captured images to make a single image that contains a reasonable representation of the details in most or all regions of the scene, including those that are very bright and very dark. However, determining TETs for capturing images can be problematic. In particular, difficulty in adjusting TETs for a particular scene has created limitations in HDR imaging. The methods and implementations described herein may provide computational efficiency, robustness to artifacts, and/or enhanced image quality.

[0050] In the following, the term "LDR image" may refer to an image captured using LDR imaging, and the term "LDR scene" may refer to a scene that has been determined to be reasonably represented using LDR imaging. Similarly, the term "HDR image" may refer to an image captured using HDR imaging, and the term "HDR scene" may refer to a scene that has been determined to be reasonably represented using HDR imaging. Furthermore, the term "LDR imaging" may be used interchangeably with the term "LDR image acquisition," and the term "HDR imaging" may be used interchangeably with the term "HDR image acquisition."

[0051] Figure 3 depicts a flow chart, in accordance with an example embodiment. At a high level, flow chart 300 represents an imaging pipeline for a digital camera device 302. For instance, flow chart 300 may represent a number of steps performed by digital camera device 302 to determine whether to use LDR or HDR image acquisition for a particular scene, determine one or more TETs with which to capture images of the scene, and whether and/or how to combine the captured images into an output image that is a reasonably satisfactory representation of the scene. In this way, digital camera device 302 can dynamically adapt to the lighting pattern of the scene, whether that pattern is dark, bright, or some combination of both. Digital camera device 302 may have the same or similar capabilities as digital camera device 100 in Figure 1.

[0052] Flow chart 300 may represent a series of steps performed by digital camera device 302 when a shutter button is triggered. Alternatively or additionally, flow chart 300 may represent steps that are continuously performed when a viewfinder of digital camera device 302 is displaying a representation of a scene. Thus, in some embodiments, the features of flow chart 300 may be performed in a way that is not apparent to the user. For instance, the user may trigger the shutter once, with the intention of capturing a single image. However, digital camera device 302 may capture multiple images in each of first image capture 306 and second image capture 314, and provide an output image 318 that is a combination of one or more images captured during second image capture 314.

[0053] It should be noted that not all steps depicted in Figure 3 need be performed by digital camera device 302. Some steps, such as image processing 308 and combining images 316, for example, could be performed by a different device. For instance, representations of one or more images captured during first image captures 306 and second image capture 314 could be transmitted from a capturing device to a remote computing device. The remote computing device could them perform image processing

308 and combining images 316, possibly transmitting some or all of the results thereof to the capturing device.

[0054] Additionally, training image database 304 may be included in digital camera device 302 or alternatively, training image database 304 may be part of a separate device or system that may be accessed by digital camera device 302. In some embodiments, training image database 304 may include representations of training images that can be used to help determine the structure of a payload burst used in second image capture 314.

[0055] In first image capture 306, a first group of images of a scene may be captured using a "metering burst sweep." In a metering burst sweep, each image in the group may be captured with a different TET. In some instances, the metering burst sweep may capture consecutive images across a range of TETs (e.g., 1 – 300 milliseconds, 0.1 – 500 milliseconds, or some other range). Using such ranges of TETs, the metering burst sweep may capture a series of images with TETs designed to cover this range according to a linear, logarithmic, and/or exponential distribution of TETs, among other possibilities.

[0056] As an example, Figure 3 depicts first image capture 306 including three digital images of a scene, each captured with a different TET. The three images exhibit diverse levels of brightness due to the different TETs used to capture the images. In other examples, more or fewer images may be captured during first image capture 306. These captured images may provide parameters for digital camera device 302 to use when capturing subsequent images of the scene.

[0057] The metering burst sweep can be used to determine the characteristics of the scene so that a subsequent payload burst structure for second image capture 314 can be selected. Therefore, in step 308, the images captured at step 306 may be processed. Particularly, step 308 may include merging one or more of the images captured at step 306 in a combined image 310. Step 308 may also include forming a histogram 312 from the

merged images, and then using the histogram, and possibly some or all of the information in training image data 304, to classify the scene (e.g., as an LDR scene or an HDR scene), determine the structure of the payload burst based on the classification of the scene, and determine the TETs to use when capturing images according to the payload burst. In some embodiments, the captured images, shown as a result of first image capture 306, may be downsampled prior to merging. Further, the histogram may be an LDR histogram, HDR histogram, a log HDR histogram, or some other form of histogram.

[0058] In step 314, the second group of images may be captured. The number of images captured and the arrangement of TETs used to capture these images may be referred to as a "payload burst." For example, in Figure 3 second image capture 314 includes three images of a scene, each captured with a TET identified in step 308. It should be understood that the TETs identified in step 308 may be the same or different than the TETs used to capture images in step 306. Additionally, it is possible that all three images in second image capture 314 are captured with the same or similar TETs.

[0059] In step 316, images from the second group of images may be combined. Combining images may include aligning two or more of the images. In some instances, images may be aligned globally (i.e., aligning whole images as opposed to portions of images), locally (i.e., aligning portions of images), or possibly both globally and locally. Further, combining two or more images may also include merging them to form an output image 318. This merging may be carried out in accordance with any image fusion technique now known or developed in the future.

[0060] Merging the images in the second group of images may result in output image 318 being sharper and/or better-exposed than any of the individual images in the second group. For instance, if some of the images in second image capture 314 are captured with the same or similar TETs, these images may be merged to reduce noise in one or more sections of the images. Alternatively or additionally, if the images in second

image capture 314 are captured with two or more different TETs, at least some images with different exposure times may be merged according to HDR procedures. Regardless, the output image may be stored on a computer-readable medium and/or displayed on an output medium such as the multi-element display 106 of Figure 1.

[0061] In some embodiments, the arrangements of various possible payload burst structures may be determined based on the TETs determined in step 308, as well as an understanding of combining images step 316. While numerous arrangements of payload burst structures may be possible, three examples are described herein.

Scene Type	Payload Burst Structure
LDR	T T T T
HDR	L S L L S L L S L L
HDR (with fallback)	L S L L S L L F F F

Table 2

[0062] Table 2 illustrates these examples. In the first example, the scene type is LDR. In this example, the payload burst structure includes four images captured sequentially, and may be referred to as an "LDR burst structure." Each "T" in the Payload Burst Structure column of Table 2 may represent a captured image. Each of these images may be captured using the same or a similar TET that was determined in step 308. In some embodiments, fewer or more images may be captured in an LDR payload burst. For example, as few as one, or as many as ten or more images may be included.

[0063] Regardless of the number of images captured, some of these images may be aligned and combined in step 316. For instance, if m images are captured in the payload burst, the sharpest one of these images may be selected as a "primary image," and the remaining m-1 images may be considered "secondary images." In some implementations, the sharpness of an image may be measured by the image's resolution and/or boundaries

between zones of different tones and/or colors in the image. Alternatively or additionally, other sharpness measurements may be used.

[0064] Further, zero or more of the m-1 secondary images may then be aligned and merged with the sharpest image. For instance, alignment may be attempted between each of the secondary images and the sharpest image, respectively. If the alignment fails for parts of a respective secondary image, those parts may be discarded, and not combined with the primary image. In this way, the sharpest image may be de-noised with information from some or all of the secondary images.

[0065] In the second example, the scene type is HDR. In this example, the payload burst structure includes ten images captured according to a pattern of long and short TETs, and may be referred to as an "HDR burst structure." In the Payload Burst Structure column of Table 2, each "L" may represent an image captured with the long TET, each "S" may represent an image captured with the short TET. Thus, the pattern of "L S L L S L L S L L" may indicate that the first image of the payload burst is captured using the long TET, the second image is captured using the short TET, the third and fourth images are captured using the long TET, the fifth image is captured using the short TET, the sixth and seventh images are captured using the long TET, the eighth image is captured using the short TET, the ninth image is captured using the long TET, and the tenth image is captured using the long TET.

[0066] The long and short TETs may be determined based on the results of image processing 308. Thus, the long and short TETs may be selected so that the resulting images captured with these TETs can be combined using HDR procedures. The long TET may be used to capture the details in dark sections of the scene, while the short TET may be used to capture the details in bright sections of the scene.

[0067] Examples of short TET values may include TETs of 1 millisecond, 2 milliseconds, and/or 8 milliseconds, while examples of long TET values may include

TETs of 20 milliseconds, 40 milliseconds, and/or 80 milliseconds. However, short and long TETs may take on different values.

[0068] Despite the payload burst in the second example having a particular structure in Table 1, other structures may be used. For example, payload burst structures of "L S L S L S L S L S" or "L L S L L S L L S L" could potentially provide suitable patterns of long and short TETs. Further, some payload burst structures may include fallback TETs (denoted by an "F"). Thus, additional example payload bursts may include "S L L L S L L L F F" or "S L S L S L F F F F" structures.

[0069] In some embodiments, a payload burst structure may include more or fewer than ten images. Generally speaking, the determining the length of the payload burst structure involves a tradeoff. On one hand, a long payload burst (i.e., a payload burst with a large number of image captures) is desirable because the likelihood of one or more of the captured image being well-exposed and sharp is increased. On the other hand, if the payload burst is too long, the likelihood of ghosting due to movement in the scene is also increased. Additionally, darker scenes may benefit from images captured using a longer TET, so that more light can reach the recording surface. Therefore, the payload burst structure may be based, possibly in part, on these considerations.

[0070] In the third example, the scene type is also HDR. However, in this example, the associated payload burst structure (which also may be referred to as an HDR burst structure) includes seven images captured according to a pattern of long and short TETs, followed by three fallback TETs. Each "F" may represent an image captured with the fallback TET, and the fallback TET may take on a value different from both the long and short TETs.

[0071] Regardless of the type of payload burst structure, the images of an HDR scene may be aligned and combined. Images captured using the short TET may be

referred to as "short images" for convenience, and images captured with the long TET may be referred to as "long images" for convenience.

[0072] In some embodiments, the sharpest short image may be selected, from the short images, as the primary short image. Zero or more of the remaining secondary short images may then be aligned and merged with the primary short image. For instance, alignment may be attempted between each of the secondary short images and the primary short image, respectively. If the alignment fails for parts of the respective secondary short image, those parts may be discarded, and not combined with the primary short image. In this way, the sharpest short image may be denoised with information from some of the secondary short images.

[0073] The same or a similar process may be undertaken for the long images. For example, the sharpest long image may be selected, from the long images, as the primary long image. Zero or more of the remaining secondary long images may then be aligned and merged with the primary long image. Alignment may be attempted between each of the secondary long images and the primary long image, respectively. If the alignment fails for parts of the respective secondary long image, those parts may be discarded, and not combined with the primary long image.

[0074] The resulting combined short image (e.g., the sharpest short image possibly denoised by information from zero or more secondary short images) and the resulting combined long image (e.g., the sharpest long image possibly denoised by information from zero or more secondary long images) may then be aligned. If the alignment succeeds, these two images (e.g., both LDR images) may be combined according to HDR procedures. For instance, they may be combined into an HDR image, and the HDR image may then be tonemapped so that its brightness falls within a range commensurate with the display abilities of convention video output devices (e.g., pixel values between 0 and 255, inclusive). The resulting tonemapped HDR image may be designated as output image

318. In some embodiments, if the signal-to-noise ratio of part or all of output image 318 is still lower than a threshold value, a de-noising procedure may be applied to further reduce noise. Additionally, output image 318 may also be sharpened, possibly after applying the de-noising procedure. In general, various types of HDR fusion algorithms, such as Exposure Fusion or Local Laplacian Filters, may be used to merge short and long images. If fallback TETs are used in the payload burst structure, these HDR fusion algorithms may be applied to one or more fallback images as well.

[0075] If the alignment fails between the combined short image and the combined long image, then the HDR processing fails. However, if fallback images were captured, one or more of the fallback images may be used to form output image 318. For instance, the sharpest fallback image may be selected. Zero or more of the remaining secondary fallback images may be aligned and combined with the sharpest fallback image carried out in a similar fashion as the processes described above for the short and long images. For payload burst structures without fallback images in which alignment fails, the combined long or short image may be used to form output image 318.

[0076] Generally speaking, image alignment may involve computational methods for arranging two or more images over one another so that they "match." Once the images are aligned, various functions can be performed, such as image enhancement (e.g., noise reduction), image stabilization (e.g., to compensate for the shaking of a video camera), pattern matching (e.g., identification of common elements in two or more images), and object recognition (e.g., finding a specific object in two or more images), as well as other functions.

[0077] Given the various uses of image alignment, it is advantageous to be able to perform image alignment in an efficient and robust fashion. In practice, a global alignment (i.e., translating the whole image by a number of pixels on the x-axis and by a potentially different number of pixels on the y-axis) may be performed. Alternatively,

instead of or in addition to aligning the whole image according to these x and y offsets, it may be advantageous to break the image into a number of smaller tiles, where each tile is an i x j pixel block, and align these tiles separately according to respective individual offsets. The size of each tile may be as small as a 1 x 1 pixel block (i.e., one pixel). The result the alignment might include some tiles being offset differently than others.

[0078] Numerous image alignment techniques may be used with the embodiments herein. For instance, one possible option is to use optical flow, which performs both global (e.g., image level) alignment and local (e.g., tile level and/or pixel level) alignment. Other techniques include using affine transforms or homography for global alignment, followed by any type of local alignment. An affine transform may result in one of the images being shifted, scaled, and rotated as it is aligned to the other image. A homography transform may result in one of the images being shifted, scaled, rotated, and warped as it is aligned to the other image. The local alignment may involve using row and/or column sums, Fourier transforms, brute force, or other techniques to refine the global alignment.

[0079] Figure 4 depicts an example alignment of a short image 400 and a long image 402. Short image 400 may be a combined short image, and/or long image 402 may be a combined long image. Short image 400 and long image 402 may have been captured, perhaps during second image capture 314, as part of a payload burst of images of a scene.

[0080] Optionally, short image 400 and long image 402 may be divided into i x j pixel tiles, and associated pair of tiles may be aligned with one another. For instance, tile 404 from the upper left hand corner of short image 400 and tile 406 from the upper left hand corner of long image 402 may be selected for alignment with one another. As shown in Figure 4, either tile 404 or tile 406 may be shifted vertically or horizontally during the alignment process. This may occur due to movement in the scene or movement of the camera device between when short image 400 and long image 402 are captured.

Nonetheless, the resulting overlap area 408 between short image 400 and long image 402 may encompass only subsets of each image. The illustrated procedure of aligning individual tiles may be repeated for all pairs of tiles in short image 400 and long image 402.

[0081] Alternatively, overlap area 408 may encompass more than just a tile of short image 400 or long image 402. For instance, tile 404 may be selected from short image 400. Then, tile 404 may be "slid" around and/or placed in a series of locations in long image 402 until a sufficient match between the contents of tile 404 and a corresponding region of long image 402 is found. Then, a pixel by pixel pairwise alignment of tile 404 with this region may be performed.

[0082] As part of the alignment process, various checks may be performed to determine the accuracy of the alignment. If these checks indicate that the alignment is reasonably accurate (e.g., one or more values that measure alignment error are within pre-determined tolerances), then the images may be merged according to the alignments of each pair of tiles. As noted above, the merging process may use various types of HDR fusion algorithms, such as Exposure Fusion and/or Local Laplacian Filters.

[0083] Moreover, due to short image 400 and long image 402 having been captured with different TETs, additionally checks may be performed. For instance, suppose that short image 400 was captured with short TET $T1$, and long image 402 was captured with long TET $T2$. The ratio $m = {}^{T2}/_{T1}$ may be calculated.

[0084] As indicated by overlap area 408, at least some pixels in tile 404 may be aligned with at least some pixels in tile 406 or with pixels in long image 402. For instance, the pixel from short image 400 that appears in the upper left hand corner of overlap area 408 may be aligned with the pixel from long image 402 that appears in the

upper left hand corner of overlap area 408. Additional aligned pairs of pixels from short image 400 and long image 402 may be aligned accordingly.

[0085] For each respective pair of aligned pixels, suppose that the pixel from short image 400 has a pixel value of $P1$ and the pixel from long image 402 has a pixel value of $P2$. These pixel values may be values of a particular color channel for the pixel, the result of applying a function to one or more color channels of the pixel, or may be derived in some other fashion. Due to the value of $T2$ being m times that of $T1$, the value of $P2$ should be approximately m times that of $P1$. Therefore, this relationship between $P1$ and $P2$ can be tested. If $P2 \approx m \times P1$ within a tolerance, then the alignment of the pixel from short image 400 and the pixel from long image 402 may be considered to have succeeded. Otherwise the alignment of these pixels may be considered to have failed. Therefore, in some embodiments, $e = |P2 - m \times P1|$ may be calculated. If e is less or equal to than a threshold error value the alignment of the two pixels may be considered successful.

[0086] In other embodiments, the error e for each pair of aligned pixels may be summed and a global alignment value, e', for an entire tile or an entire image may be calculated. If e' is greater than a global alignment error threshold, the alignment of the tiles (or images) may be considered to have failed. However, if e' is less than or equal to the global alignment error threshold, the alignment of the tiles (or images) may be considered to have succeeded. Alternatively or additionally, the error for some pixels may be weighted differently than for other pixels.

[0087] For example, pixels near the "blend zone" of an image may be weighted more than other pixels in the image. The blend zone may refer to a border, in the long exposure, between the pixels that are less than 255 (or some other pixel value threshold), and the pixels that are saturated at 255. Thus, on one side of the blend zone, pixels primarily from images captured with one TET may be used in the combined image. On

the other side, pixels primarily from images captured using another TET may be used in the combined image. Therefore, near the blend zone, the pixels in the final image will probably end up as a mix of the two sources (wherein the two sources may be the combined long image and the combined short image). However, away from the blend zone, the pixels that end up in the final image may be from just one of the two sources. Thus, misalignments away from the blend zone may be significantly less important than misalignments near the blend zone. Consequently, pixels away from the blend zone may have a low weighting, while pixels near the blend zone may have a higher weighting.

[0088] If short image 400 and long image 402 are LDR images, the pixel values of each pixel in both images may fall within a range of values, such as 0-255. If $P2$ is at the high end of this range (e.g., if $P2 = 255$), then the associated pixel in long image 402 may be whitewashed. In other words, the location of the scene represented by this pixel may have been so bright that it exceeded the image sensor's ability to accurately represent its brightness. Thus, the ground truth brightness of the pixel might not be known, and the relation $P2 \approx m \times P1$ might not hold.

[0089] However, when $P2 = 255$, $m \times P1$ should be at least 255. Therefore a check of the two pixel values can still be performed. If $m \times P1$ is greater than or equal 255, then a low value of e, e.g., 0, may be used for these pixels. However, if $m \times P1$ is less than 255, then e may be calculated as $|P2 - m \times P1|$. In this way, whitewashed pixels may be taken into account when calculating alignment error.

[0090] It should be understood that values other than 255 may be used as the high end of a range of pixel values. Further, the mathematical calculations described above can be replaced with different, but equivalent, calculations that would lead to the same results. For instance, $m = {}^{T1}/_{T2}$ may be calculated, and then the relation $P1 \approx m \times P2$ might be

expected to hold. Each of these variations is contemplated herein as alternate embodiments.

[0091] In some embodiments, the pixel value multiplied by m may be first reverse tonemapped from an LDR value to a linear value, and then multiplied by m. The resulting product may then be tonemapped back to an LDR value before being compared to the other pixel value. This process helps maintain the linearity of the multiplicative relationship between the two pixel values.

[0092] Furthermore, in some embodiments, an optional partial two-dimensional high-pass filter may be applied to one or more of the short and/or long images prior to checking for alignment error. Doing so may concentrate the error measurement on edge mismatches, rather than subtle and/or steady differences in color due to image sensor response being slightly non-linear.

[0093] Moreover, individual image sensors may be non-linear in distinct ways. For instance, some image sensors may exhibit more non-linearity at low brightness levels, while other image sensors may exhibit more non-linearity at higher brightness levels. Accordingly, for each image sensor, a map of this non-linearity may be obtained. Then, by placing this map in one or more lookup tables, the individual non-linear characteristics of each image sensor may be taken into account. For instance, prior to comparing $P1$ and $P2$, each of these pixel values may be looked up in one of the tables and adjusted to remove image sensor non-linearity.

[0094] Additionally, any of the embodiments disclosed herein can optionally be enhanced by performing a multi-resolution analysis of the target image. Generally speaking, such a multi-resolution analysis involves, for a given tile, downsampling the pixels in the given tile a number of times.

[0095] Downsampling can be implemented by, for example, dividing the given tile into 2 x 2 blocks, and replacing each of these blocks by a single pixel. The value of this

replacement pixel can be based on the values of the pixels in the block. For instance, the value of the replacement pixel may be determined by taking an average of the values of the four pixels in the block, resulting in a "fuzzier," lower-resolution downsampled tile of one-quarter the size of the full tile. Thus, if a 64 x 64 tile is downsampled one level, the result is a 32 x 32 tile. If the 64 x 64 tile is downsampled two levels (or the 32 x 32 tile is downsampled one level), the result is a 16 x 16 tile, and so on. Nonetheless, a tile can be downsampled in other ways. For example, a 3 x 3 block or a 4 x 4 block can be replaced by a single pixel, and more than just one or two levels of downsampling can be performed for a tile. In some embodiments, the tiles may be rectangular instead of square.

[0096] A downsampled tile, perhaps the downsampled tile at the downsampling level with the lowest resolution, may be compared to a similarly-downsampled search area of a target image. As a result, one or more low-error alignments for the downsampled tile may be identified. For instance, the n lowest-error alignments may be identified.

[0097] Then, one of these alignments is selected, perhaps the lowest-error translation, and the alignment procedures are repeated using the next-highest level of the downsampled tile and the downsampled search area for the alignment. If the result is a low-error alignment, the alignment procedure can be repeated with an even higher level of the downsampled tile. However, if the result is not a low-error alignment, another of the n lowest-error alignments may be selected, the alignment procedures are repeated using the next-highest level of the downsampled tile and the downsampled search area for this alignment.

[0098] Figure 5 depicts a flow chart, in accordance with an example embodiment. At step 500, a first set of pixels of a short exposure image and a second set of pixels of a long exposure image may be obtained. The short exposure image may have been captured using a short TET and the long exposure image may have been captured using a long TET. The long TET may be greater than the short TET.

[0099] At step 502, the first set of pixels and the second set of pixels may be aligned such that pixels in the first set of pixels are pairwise matched with pixels the second set of pixels. At step 504, a first pixel value may be compared to a second pixel value. The first pixel value may be of a first pixel in the first set of pixels, and the second pixel value is of a second pixel in the second set of pixels. The first pixel and second pixel may be pairwise matched. The first set of pixels may represent an i x j pixel block of the short exposure image, and the second set of pixel may represent an i x j pixel block of the long exposure image.

At step 506, based on the comparison of the first pixel value to the second pixel value, an alignment error value for the first pixel and the second pixel may be determined. At step 508, a global alignment error value may be determined. The alignment error value for the first pixel and the second pixel may contribute to the global alignment error value. At step 510, based on at least the global alignment error value, an output image may be provided.

[00100] In some embodiments, it may be determined that the global alignment error value is less than or equal to a threshold tolerance. Based on the global alignment error value being less than or equal to the threshold tolerance, it may be determined that the alignment of the short exposure image and the long exposure image has succeeded. In response to determining that the alignment of the short exposure image and the long exposure image has succeeded, the short exposure image and the long exposure image may be merged into a combined image, and the combined image may be provided as the output image.

[00101] In alternative embodiments, it may be determined that the global alignment error value is greater than a threshold tolerance. Based on the global alignment error value being greater than the threshold tolerance, it may be determined that the alignment of the short exposure image and the long exposure image has failed. Further, a

fallback exposure image may be obtained. The fallback exposure image may have been captured using a fallback TET. In some embodiments, the fallback TET may be between the short TET and the long TET, though the fallback TET could be less than the short TET or greater than the long TET. In response to determining that the alignment of the short exposure image and the long exposure image has failed, the fallback exposure image, or a merged image from multiple fallback exposure images, may be provided as the output image. On the other hand, one of the short exposure image, the long exposure image, a merged image from multiple short exposure images, or a merged image from multiple long exposure images may be provided as the output image.

[00102] In some embodiments, m may be a ratio of the long TET to the short TET, and comparing the first pixel value to the second pixel value may involve multiplying the first pixel value by m to provide a multiplied pixel value. Comparing the first pixel value to the second pixel value may also involve (i) determining that the multiplied pixel value is greater than or equal to a high threshold pixel value, (ii) determining that the second pixel value is equal to the high threshold pixel value, and (iii) based on the multiplied pixel value being greater than or equal to the high threshold pixel value and the second pixel value being equal to the high threshold pixel value, determining the alignment error value for the first pixel and the second pixel to be zero. In some cases the high threshold pixel value may be between 240 and 256, inclusive, or may fall within some other range. In some embodiments, the multiplied pixel value may be set to the maximum value of the short exposure pixel's range (e.g., 255), before comparing the multiplied pixel value to the long exposure pixel.

[00103] Alternatively or additionally, comparing the first pixel value to the second pixel value may also involve calculating an absolute value difference of the multiplied pixel value and the second pixel value, and determining the alignment error value for the first pixel and the second pixel to be the absolute value difference.

[00104] The steps depicted in Figure 5 may be carried out by a camera device, such as digital camera device 100, a computing device, such as computing device 200, and/or by two or more distinct devices. Further, the flow chart depicted in Figure 5 may be modified according to the variations disclosed in this specification and/or the accompanying drawings.

[00105] The above detailed description describes various features and functions of the disclosed systems, devices, and methods with reference to the accompanying figures. In the figures, similar symbols typically identify similar components, unless context indicates otherwise. The illustrative embodiments described in the detailed description, figures, and claims are not meant to be limiting. Other embodiments can be utilized, and other changes can be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[00106] With respect to any or all of the message flow diagrams, scenarios, and flow charts in the figures and as discussed herein, each step, block and/or communication may represent a processing of information and/or a transmission of information in accordance with example embodiments. Alternative embodiments are included within the scope of these example embodiments. In these alternative embodiments, for example, functions described as steps, blocks, transmissions, communications, requests, responses, and/or messages may be executed out of order from that shown or discussed, including in substantially concurrent or in reverse order, depending on the functionality involved. Further, more or fewer steps, blocks and/or functions may be used with any of the message flow diagrams, scenarios, and flow charts

discussed herein, and these message flow diagrams, scenarios, and flow charts may be combined with one another, in part or in whole.

[00107] A step or block that represents a processing of information may correspond to circuitry that can be configured to perform the specific logical functions of a herein-described method or technique. Alternatively or additionally, a step or block that represents a processing of information may correspond to a module, a segment, or a portion of program code (including related data). The program code may include one or more instructions executable by a processor for implementing specific logical functions or actions in the method or technique. The program code and/or related data may be stored on any type of computer-readable medium, such as a storage device, including a disk drive, a hard drive, or other storage media.

[00108] The computer-readable medium may also include non-transitory computer-readable media such as computer-readable media that stores data for short periods of time like register memory, processor cache, and/or random access memory (RAM). The computer-readable media may also include non-transitory computer-readable media that stores program code and/or data for longer periods of time, such as secondary or persistent long term storage, like read only memory (ROM), optical or magnetic disks, and/or compact-disc read only memory (CD-ROM), for example. The computer-readable media may also be any other volatile or non-volatile storage systems. A computer-readable medium may be considered a computer-readable storage medium, for example, or a tangible storage device.

[00109] Moreover, a step or block that represents one or more information transmissions may correspond to information transmissions between software and/or hardware modules in the same physical device. However, other information transmissions may be between software modules and/or hardware modules in different physical devices.

[00110] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. A method comprising:

obtaining, by a computing device, a first set of pixels of a short exposure image and a second set of pixels of a long exposure image, wherein the short exposure image was captured using a short total exposure time (TET) and the long exposure image was captured using a long TET, wherein the long TET is greater than the short TET;

aligning the first set of pixels and the second set of pixels such that pixels in the first set of pixels are pairwise matched with pixels the second set of pixels;

comparing a first pixel value to a second pixel value, wherein the first pixel value is of a first pixel in the first set of pixels, the second pixel value is of a second pixel in the second set of pixels, and the first pixel and second pixel are pairwise matched;

based on the comparison of the first pixel value to the second pixel value, determining an alignment error value for the first pixel and the second pixel; and

determining a global alignment error value, wherein the alignment error value for the first pixel and the second pixel contributes to the global alignment error value;

based on at least the global alignment error value, providing an output image.

2. The method of claim 1, further comprising:

determining that the global alignment error value is less than or equal to threshold tolerance;

based on the global alignment error value being less than or equal to the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has succeeded; and

in response to determining that the alignment of the short exposure image and the long exposure image has succeeded, merging the short exposure image and the long exposure image into a combined image, and providing the combined image as the output image.

3. The method of claim 1, further comprising:

determining that the global alignment error value is greater than a threshold tolerance; and

based on the global alignment error value being greater than the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has failed.

4. The method of claim 3, further comprising:

obtaining a fallback exposure image, wherein the fallback exposure image was captured using a fallback TET, and wherein the fallback TET is between the short TET and the long TET; and

in response to determining that the alignment of the short exposure image and the long exposure image has failed, providing at least the fallback exposure image as the output image.

5. The method of claim 1, wherein m is a ratio of the long TET to the short TET, and wherein comparing the first pixel value to the second pixel value comprises multiplying the first pixel value by m to provide a multiplied pixel value.

6. The method of claim 5, wherein comparing the first pixel value to the second pixel value further comprises:

determining that the multiplied pixel value is greater than or equal to a high threshold pixel value;

determining that the second pixel value is equal to the high threshold pixel value; and

based on the multiplied pixel value being greater than or equal to the high threshold pixel value and the second pixel value being equal to the high threshold pixel value, determining the alignment error value for the first pixel and the second pixel to be zero.

7. The method of claim 6, wherein the high threshold pixel value is between 240 and 256, inclusive.

8. The method of claim 5, wherein comparing the first pixel value to the second pixel value further comprises:

calculating an absolute value difference of the multiplied pixel value and the second pixel value; and

determining the alignment error value for the first pixel and the second pixel to be the absolute value difference.

9. The method of claim 1, wherein the first set of pixels represents an i x j pixel block of the short exposure image, and wherein the second set of pixels represents an i x j pixel block of the long exposure image.

10. An article of manufacture including a non-transitory computer-readable medium, having stored thereon program instructions that, upon execution by a computing device, cause the computing device to perform operations comprising:

obtaining a first set of pixels of a short exposure image and a second set of pixels of a long exposure image, wherein the short exposure image was captured using a short total exposure time (TET) and the long exposure image was captured using a long TET, wherein the long TET is greater than the short TET;

aligning the first set of pixels and the second set of pixels such that pixels in the first set of pixels are pairwise matched with pixels the second set of pixels;

comparing a first pixel value to a second pixel value, wherein the first pixel value is of a first pixel in the first set of pixels, the second pixel value is of a second pixel in the second set of pixels, and the first pixel and second pixel are pairwise matched;

based on the comparison of the first pixel value to the second pixel value, determining an alignment error value for the first pixel and the second pixel; and

determining a global alignment error value, wherein the alignment error value for the first pixel and the second pixel contributes to the global alignment error value;

based on at least the global alignment error value, providing an output image.

11. The article of manufacture of claim 10, wherein the operations further comprise:

determining that the global alignment error value is less than or equal to threshold tolerance;

based on the global alignment error value being less than or equal to the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has succeeded; and

in response to determining that the alignment of the short exposure image and the long exposure image has succeeded, merging the short exposure image and the long exposure image into a combined image, and providing the combined image as the output image.

12. The article of manufacture of claim 10, wherein the operations further comprise:

determining that the global alignment error value is greater than a threshold tolerance; and

based on the global alignment error value being greater than the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has failed.

13. The article of manufacture of claim 12, wherein the operations further comprise:

obtaining a fallback exposure image, wherein the fallback exposure image was captured using a fallback TET, and wherein the fallback TET is between the short TET and the long TET; and

in response to determining that the alignment of the short exposure image and the long exposure image has failed, providing at least the fallback exposure image as the output image.

14. The article of manufacture of claim 10, wherein m is a ratio of the long TET to the short TET, and wherein comparing the first pixel value to the second pixel value comprises multiplying the first pixel value by m to provide a multiplied pixel value.

15. The article of manufacture of claim 14, wherein comparing the first pixel value to the second pixel value further comprises:

determining that the multiplied pixel value is greater than or equal to a high threshold pixel value;

determining that the second pixel value is equal to the high threshold pixel value; and

based on the multiplied pixel value being greater than or equal to the high threshold pixel value and the second pixel value being equal to the high threshold pixel value, determining the alignment error value for the first pixel and the second pixel to be zero.

16. The article of manufacture of claim 14, wherein comparing the first pixel value to the second pixel value further comprises:

calculating an absolute value difference of the multiplied pixel value and the second pixel value; and

determining the alignment error value for the first pixel and the second pixel to be the absolute value difference.

17. A computing device comprising:

at least one processor;

data storage; and

program instructions, stored in the data storage, that upon execution by the at least one processor cause the computing device to perform operations including:

obtaining a first set of pixels of a short exposure image and a second set of pixels of a long exposure image, wherein the short exposure image was captured using a short total exposure time (TET) and the long exposure image was captured using a long TET, wherein the long TET is greater than the short TET;

aligning the first set of pixels and the second set of pixels such that pixels in the first set of pixels are pairwise matched with pixels the second set of pixels;

comparing a first pixel value to a second pixel value, wherein the first pixel value is of a first pixel in the first set of pixels, the second pixel value is of a second pixel in the second set of pixels, and the first pixel and second pixel are pairwise matched;

based on the comparison of the first pixel value to the second pixel value, determining an alignment error value for the first pixel and the second pixel; and

determining a global alignment error value, wherein the alignment error value for the first pixel and the second pixel contributes to the global alignment error value;

based on at least the global alignment error value, providing an output image.

18. The computing device of claim 17, wherein the operations further include:

determining that the global alignment error value is less than or equal to threshold tolerance;

based on the global alignment error value being less than or equal to the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has succeeded; and

in response to determining that the alignment of the short exposure image and the long exposure image has succeeded, merging the short exposure image and the long exposure image into a combined image, and providing the combined image as the output image.

19. The computing device of claim 17, wherein the operations further include:

determining that the global alignment error value is greater than a threshold tolerance; and

based on the global alignment error value being greater than the threshold tolerance, determining that the alignment of the short exposure image and the long exposure image has failed.

20. The computing device of claim 19, wherein the operations further include:

obtaining a fallback exposure image, wherein the fallback exposure image was captured using a fallback TET, and wherein the fallback TET is between the short TET and the long TET; and

in response to determining that the alignment of the short exposure image and the long exposure image has failed, providing the fallback exposure image as the output image.

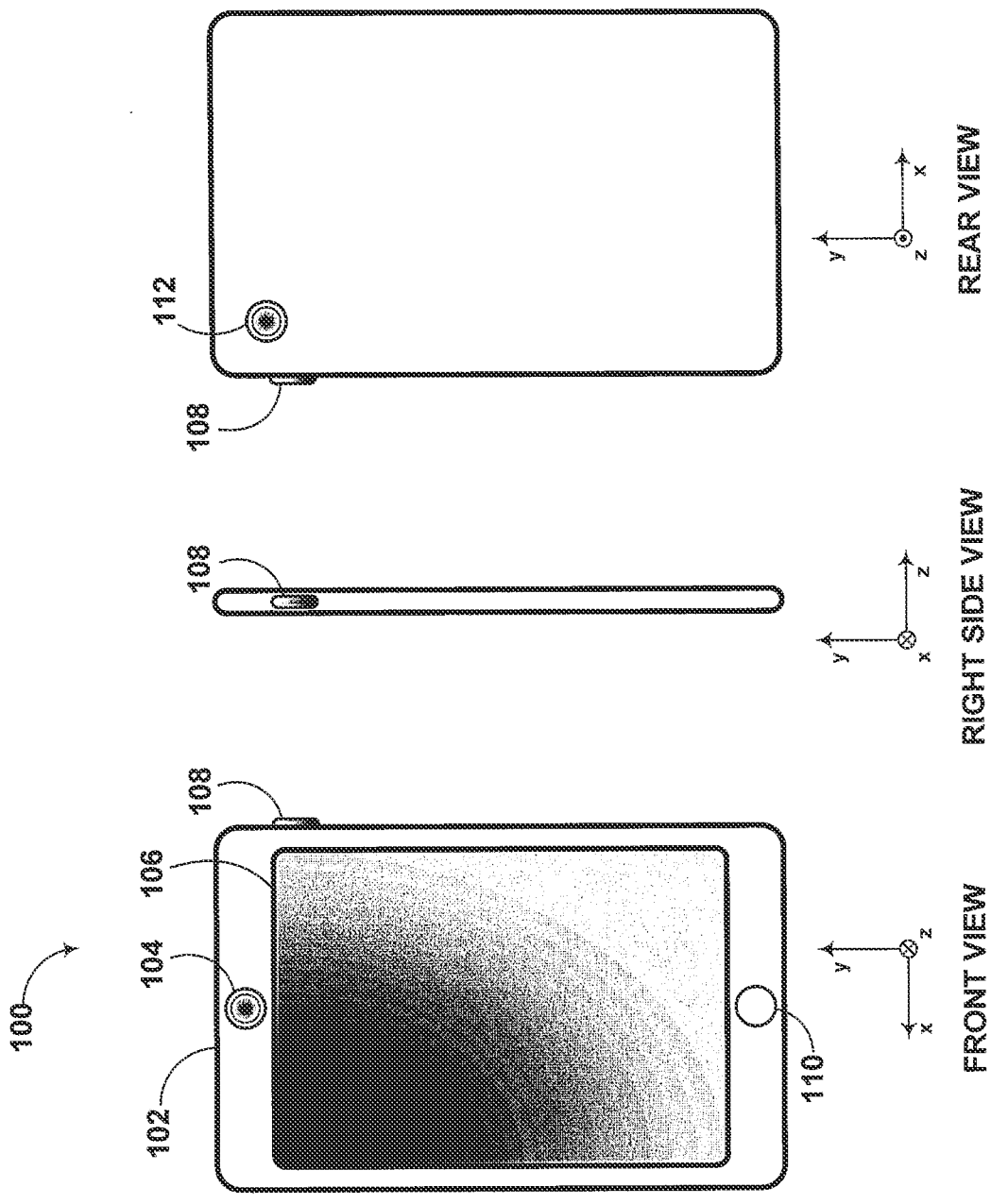

100
102
104
106
108
110
112
FRONT VIEW
RIGHT SIDE VIEW
REAR VIEW
x
y
z

FIG. 1

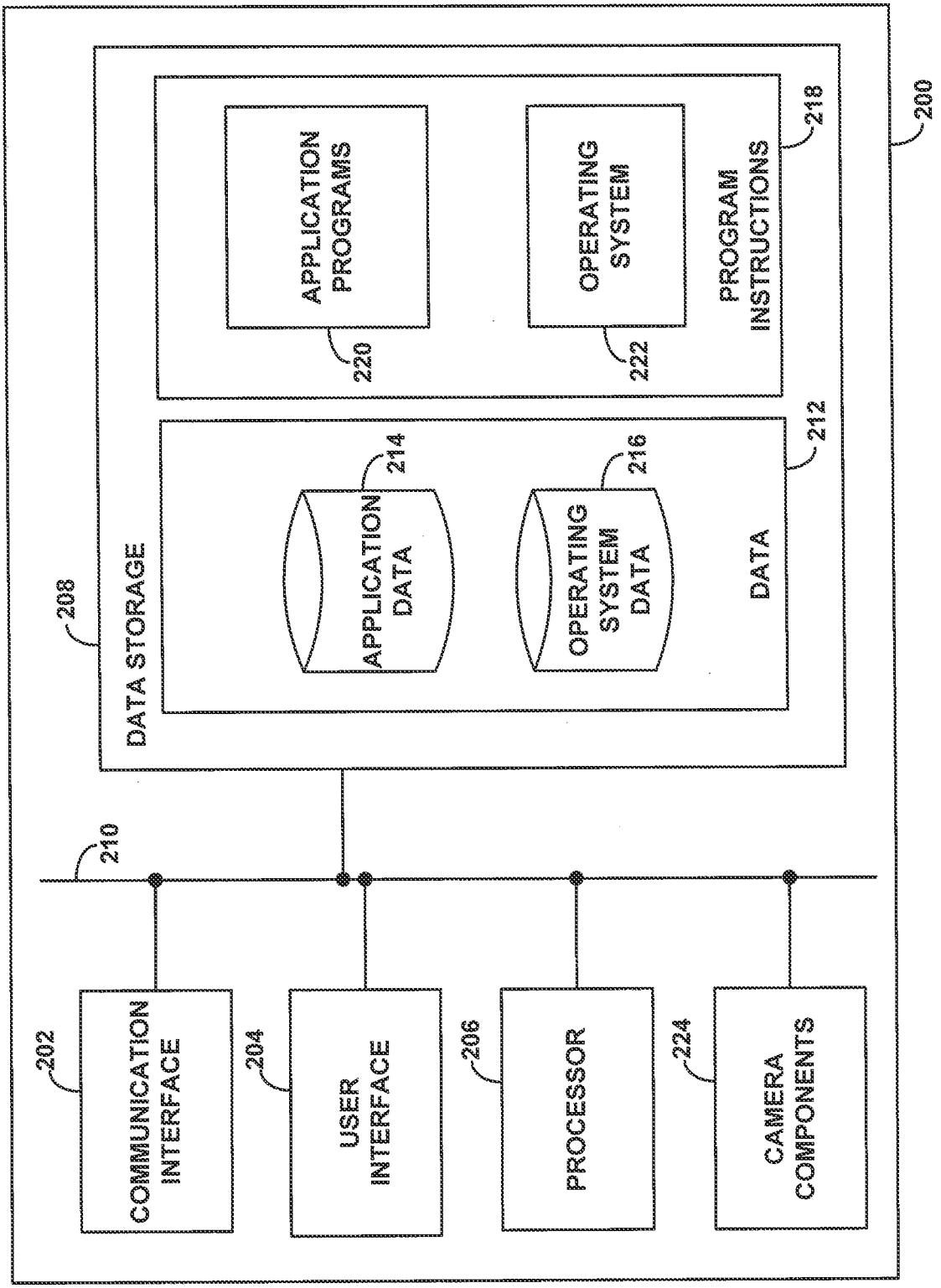

200
208
DATA STORAGE
APPLICATION PROGRAMS
220
OPERATING SYSTEM
222
PROGRAM INSTRUCTIONS
218
DATA
212
APPLICATION DATA
214
OPERATING SYSTEM DATA
216
210
202
COMMUNICATION INTERFACE
204
USER INTERFACE
206
PROCESSOR
224
CAMERA COMPONENTS

FIG. 2

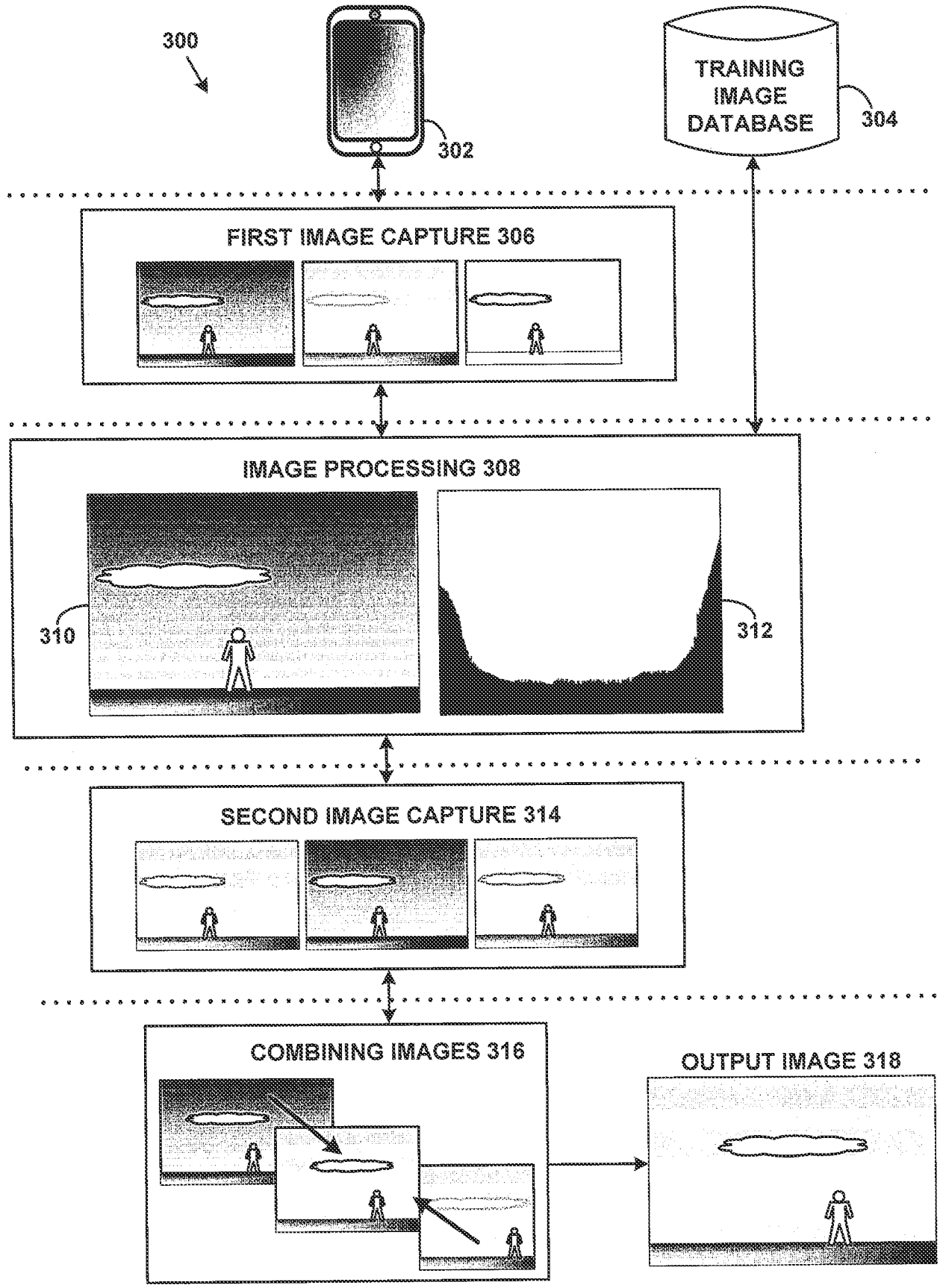

300
302
TRAINING IMAGE DATABASE
304
FIRST IMAGE CAPTURE 306
IMAGE PROCESSING 308
310
312
SECOND IMAGE CAPTURE 314
COMBINING IMAGES 316
OUTPUT IMAGE 318

FIG. 3

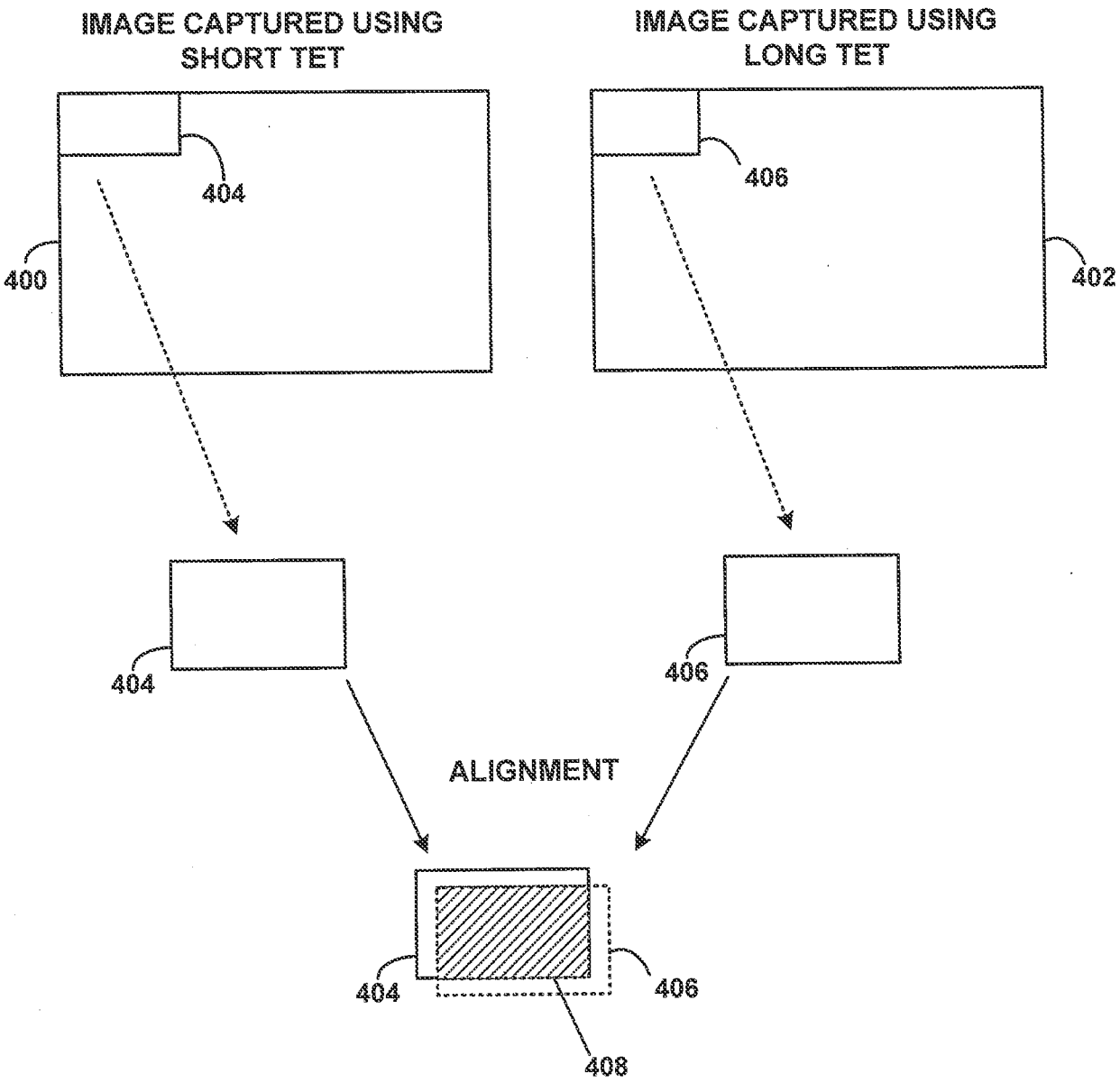

IMAGE CAPTURED USING SHORT TET
IMAGE CAPTURED USING LONG TET
404
406
400
402
404
406
ALIGNMENT
404
406
408

FIG. 4

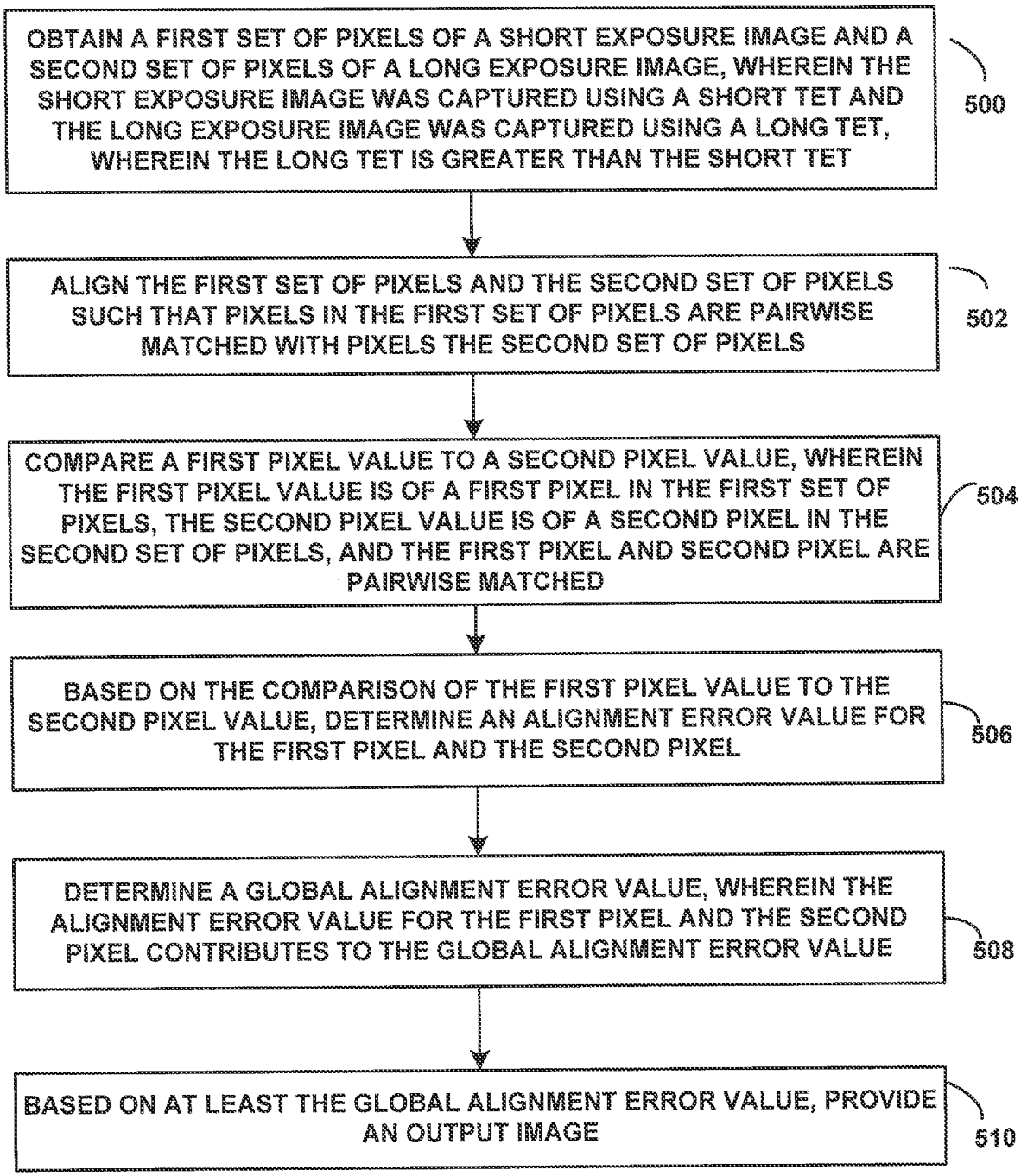

OBTAIN A FIRST SET OF PIXELS OF A SHORT EXPOSURE IMAGE AND A SECOND SET OF PIXELS OF A LONG EXPOSURE IMAGE, WHEREIN THE SHORT EXPOSURE IMAGE WAS CAPTURED USING A SHORT TET AND THE LONG EXPOSURE IMAGE WAS CAPTURED USING A LONG TET, WHEREIN THE LONG TET IS GREATER THAN THE SHORT TET
500
ALIGN THE FIRST SET OF PIXELS AND THE SECOND SET OF PIXELS SUCH THAT PIXELS IN THE FIRST SET OF PIXELS ARE PAIRWISE MATCHED WITH PIXELS THE SECOND SET OF PIXELS
502
COMPARE A FIRST PIXEL VALUE TO A SECOND PIXEL VALUE, WHEREIN THE FIRST PIXEL VALUE IS OF A FIRST PIXEL IN THE FIRST SET OF PIXELS, THE SECOND PIXEL VALUE IS OF A SECOND PIXEL IN THE SECOND SET OF PIXELS, AND THE FIRST PIXEL AND SECOND PIXEL ARE PAIRWISE MATCHED
504
BASED ON THE COMPARISON OF THE FIRST PIXEL VALUE TO THE SECOND PIXEL VALUE, DETERMINE AN ALIGNMENT ERROR VALUE FOR THE FIRST PIXEL AND THE SECOND PIXEL
506
DETERMINE A GLOBAL ALIGNMENT ERROR VALUE, WHEREIN THE ALIGNMENT ERROR VALUE FOR THE FIRST PIXEL AND THE SECOND PIXEL CONTRIBUTES TO THE GLOBAL ALIGNMENT ERROR VALUE
508
BASED ON AT LEAST THE GLOBAL ALIGNMENT ERROR VALUE, PROVIDE AN OUTPUT IMAGE
510

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/072564

A. CLASSIFICATION OF SUBJECT MATTER

H04N 5/262(2006.01)i, G06T 5/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N 5/262; H04N 5/355; H04N 5/217; H04N ; G06T 1/00; G06T 5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: exposure, time, long, short, align, error, and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010-0321539 A1 (YASUHIRO ITO) 23 December 2010 See paragraphs [0066]-[0097]; figure 2; and claim 5.	1,2,5-11,14-18
A		3,4,12,13,19,20
A	WO 2004-098167 A2 (MICROSOFT CORPORATION) 11 November 2004 See pages 27, 28; figure 2; and claim 1.	1-20
A	KR 10-2010-0086987 A (OMNIVISION TECHNOLOGIES, INC.) 02 August 2010 See paragraphs [0011]-[0013]; and figure 3.	1-20
A	JP 2005-045804 A (MICROSOFT CORPORATION) 17 February 2005 See abstract; figure 2A; and claim 1.	1-20
A	KR 10-2007-0085867 A (BRIGHT IMAGING LTD.) 27 August 2007 See abstract; figure 1; and claim 1.	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 March 2014 (10.03.2014)	**11 March 2014 (11.03.2014)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
KIM, Seong Woo
Telephone No. +82-42-481-3348

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Information on patent family members

International application No.
PCT/US2013/072564

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