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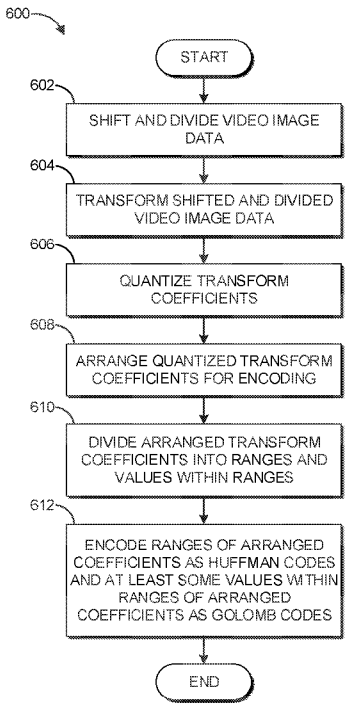


FIG. 6

(57) Abstract: In some embodiments, an electronic device for compressing video image data includes a housing, an image sensor, a memory device, and one or more processors. The image sensor can generate image data from light incident on the image sensor. The one or more processors can transform the image data to obtain transform coefficients, quantize the transform coefficients, encode the quantized transform coefficients, and store the quantized transform coefficients to the memory device. The one or more processors can encode the quantized transform coefficients at least by determining a range of multiple ranges in which one transform coefficient is included, determining a value within the range to which the one transform coefficient corresponds, encoding using a first algorithm the range as a range code, and encoding using a second algorithm the value as a value code.

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VIDEO IMAGE DATA PROCESSING IN ELECTRONIC DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Any and all applications for which a domestic priority claim is identified in the Application Data Sheet of the present application are hereby incorporated by reference under 37 CFR 1.57.

BACKGROUND

[0002] High-end video capture capability continues to advance. Professional cinematographers as well as increasingly large numbers of consumers are demanding high quality video recording capability, not only in traditional digital video cameras, but also in other video camera-equipped electronic devices including cellphones/smart phones, tablets, and the like.

SUMMARY

[0003] Various embodiments described herein relate to image capture devices capable of capture and on-board storage of compressed raw (for example, mosaiced according to a Bayer pattern color filter array or according to another type of color filter array), high resolution (for example, at least 2k, 4k, 6k, 8k, 10k, or ranges of values between any of these resolution levels) video image data. The compressed raw image data can be "raw" in the sense that the video data is not "developed", such that certain image processing image development steps are not performed on the image data prior to compression and storage. Such steps can include one or more of interpolation (for example, de-Bayering or other de-mosaicing), color processing, tonal processing, white balance, and gamma correction. For example, the compressed raw image data can be one or more of mosaiced (for example, not color interpolated, not demosaiced), not color processed, not tonally processed, not white balanced, and not gamma corrected. Rather, such steps can be deferred for after storage, such as for off-board post-processing, thereby preserving creative flexibility instead of than "baking in" particular processing decisions in camera.

[0004] The image processing and compression techniques described herein can be implemented in a variety of form factors. For instance, the techniques described herein for compressing and on-board storage of compressed raw image data can be implemented in a relatively small-form factor device, such as a smart phone having an integrated camera (or multiple cameras including front camera(s) and rear camera(s), or a small form factor camera. For instance, the processing techniques according to certain embodiments are tailored for implementation in a small form factor device having relatively limited power budget, processing capability, and physical real estate for incorporation of electronic components, etc. In another example, the compression techniques described herein can be implemented in relatively larger form factor cameras, including digital cinema cameras.

[0005] According to certain aspects, an image capture device can be configured to capture raw mosaiced image data, compress the raw image data, and store the image data in on-board memory of the image capture device.

[0006] Electronics residing of the image capture device can be configured to, as part of the compression, transform the raw mosaiced image data using a discrete cosine transform (DCT) or another transform (such as a transform that defines a finite sequence of data points in terms of a sum of functions oscillating at different frequencies) to obtain transform coefficients, and compress the transform coefficients. According to some embodiments, the electronics can be configured to perform the compression without using an image frame memory (for example, a dynamic random access memory [DRAM]) that stores a full image frame for processing purposes. For instance, the electronics can compress the transform coefficients using an on-chip first memory (for example, a static random-access memory [SRAM]) that is integrated with an image processing chip (for example, an application specific integrated circuit [ASIC] or field-programmable gate array (FPGA]), and without using any second DRAM or other memory positioned off-chip.

[0007] In certain embodiments, the electronics can nonetheless include a DRAM or other second memory off-chip. However, the off-chip memory in such embodiments may used for purposes other than compression of raw video image data, such as for pixel defect correction, addressing pixel pattern noise, or the like. This is unlike existing image capture devices, such as smart phones, which use an off-chip DRAM to perform image compression.

For instance, some existing image capture devices use an off-chip DRAM to calculate motion vectors for H.264 compression. Certain embodiments described herein use DCT techniques, thereby facilitating memory-efficient compression, without the need to calculate motion vectors or use off-chip memory.

[0008] Performing compression without use of a full image frame memory (for example, an off-chip DRAM) enhances power efficiency (such as, by around 0.5 Watts (W) in some implementations), which is particularly useful in a small-form factor device such as a smart phone. According to certain aspects, the electronics of the image capture device consume less than 15 W or less than about 20 W during operation.

[0009] Features disclosed herein can, in certain embodiments, provide approaches for decoding as much of a frame as possible in real time and may enable decompression at a rate faster than 24 frames per second (fps). Moreover, the approaches can, in some implementations, make extensive use of a Graphical Processing Unit (GPU) of an electronic device and permit significant parallelization of operations while enabling a high image quality to be maintained.

[0010] According to some aspects, the image capture device includes a clock configured to control a timing at which the raw mosaiced image data is processed (for instance, compressed) by electronic circuitry, and the electronic circuitry is configured to correctly process the raw mosaiced image data despite the clock stopping for a period of time. This may be at least because the raw mosaiced image data can be processed by the electronic circuitry using memory that may not require refreshing.

[0011] According to certain aspects, the image capture device is configured to transform raw mosaiced image data to obtain transform coefficients. The device quantizes the transform coefficients to obtain quantized coefficients, and encodes at least some of the quantized coefficients by performing one or more of the following: dividing each quantized coefficient into a plurality of ranges and values within the plurality of ranges; determining a Huffman code for each quantized coefficient according to an individual range in which each quantized coefficient is included; and determining a Golomb code for each quantized coefficient according to an individual value within the individual range in which each quantized coefficient is included.

[0012] In some embodiments, an electronic device is disclosed. The electronic device includes a housing, an image sensor, a memory device, and one or more processors. The image sensor can generate image data from light incident on the image sensor. The one or more processors can: transform the image data to obtain transform coefficients, quantize the transform coefficients to obtain quantized transform coefficients including a first quantized transform coefficient and a second quantized transform coefficient different from the first quantized transform coefficient, encode the quantized transform coefficients to obtain encoded coefficients, and store the encoded coefficients to the memory device. The quantized transform coefficients can be encoded at least by: determining a first range of a plurality of ranges in which the first quantized transform coefficient is included, determining a second range of the plurality of ranges in which the second quantized transform coefficient is included, determining a first value within the first range to which the first quantized transform coefficient corresponds, determining a second value within the second range to which the second quantized transform coefficient corresponds, encoding, using a first algorithm, the first range as a first range code and the second range as a second range code, and encoding, using a second algorithm different from the first algorithm, the first value as a first value code and the second value as a second value code. The encoded coefficients can include the first range code, the second range code, the first value code, and the second value code.

[0013] The electronic device of the preceding paragraph can include one or more of the following features: The first algorithm is a Huffman code, or the second algorithm is a Golomb code. The one or more processors can vary the first algorithm during processing of the image data. The one or more processors can vary the first algorithm from processing a first frame of the image data to processing a second frame of the image data. The second algorithm can remain constant during processing of the image data by the one or more processors. The quantized transform coefficients can include a third quantized transform coefficient different from the first quantized transform coefficient and the second quantized transform coefficient, and the one or more processors can encode the quantized transform coefficients by at least: determining a third range of a plurality of ranges in which the third quantized transform coefficient is included, not determining a third value within the third

range to which the third quantized transform coefficient corresponds, and encoding, using the first algorithm, the third range as a third range code, the encoded coefficients comprising the third range code. The one or more processors can transform the image data using a discrete cosine transform. The discrete cosine transform can be a 16x16 discrete cosine transform. The one or more processors can encode the quantized transform coefficients at least by encoding DC coefficients of the quantized transform coefficients differently from AC coefficients of the quantized transform coefficients. The one or more processors can store a parameter for the first algorithm in a frame header for the encoded coefficients. The one or more processors can quantize the transform coefficients by at least using a first quantization table for green pixels of the image data and a second quantization table for red pixels and blue pixels of the image data, the first quantization table being different from the second quantization table. The image data can be moasiced image data. The image data can be raw moasiced image data. The housing can be a mobile phone housing, and the mobile phone housing can support the image sensor, the memory device, and the one or more processors. The housing can enclose the image sensor, the memory device, and the one or more processors, and the housing can removably attach to a mobile phone. The electronic device can further include a display configured to present holographic images generated by the one or more processors from the image data.

[0014] In some embodiments, a method of coding image data using an electronic device is disclosed. The method can include: generating, by an image sensor, image data from light incident on an image sensor; transforming, by one or more processors, the image data to obtain transform coefficients; quantizing, by the one or more processors, the transform coefficients to obtain quantized transform coefficients including a first quantized transform coefficient and a second quantized transform coefficient different from the first quantized transform coefficient; determining, by the one or more processors, a first range of a plurality of ranges that includes the first quantized transform coefficient and a second range of the plurality of ranges that includes the second quantized transform coefficient; determining, by the one or more processors, a first value within the first range that corresponds to the first quantized transform coefficient and a second value within the second range that corresponds to the second quantized transform coefficient; encoding, by the one or

more processors, the first range as a first range code and the second range as a second range code; encoding, by the one or more processors, the first value as a first value code and the second value as a second value code; and storing the first range code, the second range code, the first value code, and the second value code to the memory device.

[0015] The method of the preceding paragraph can include one or more of the following features: The encoding the first and second ranges and the encoding the first and second values can be performed using lossless compression. The encoding the first and second ranges and the encoding the first and second values can be performed using variable length coding. The method can further include: retrieving the first range code, the second range code, the first value code, and the second value code from the memory device; and decoding, by the one or more processors, the first range code, the second range code, the first value code, and the second value code to obtain the first range, the second range, the first value, and the second value. The first range and the second range can be encoded as the first range code and the second range code using a Huffman code, or the first value and the second value can be encoded as the first value code and the second value code using a Golomb code. The transforming the image data can be performed using a 16x16 discrete cosine transform.

[0016] While certain embodiments are described with respect to specific resolutions (for example, at least 2k or at least 4k) or frame rates (for example, at least 23 frames per second), such embodiments are not limited to those frame rates or resolution levels. For instance, depending on the embodiment (for example, depending on sensor size) the techniques for on-board storage of compressed raw image data described herein can be capable of achieving resolution levels of at least 2k, 3k, 4k, 4.5k, 5k, 6k, 8k, 10k, 12k, 15k, 20k, or greater resolution levels, or resolution levels between and inclusive of any of the foregoing resolution levels (for example, between and inclusive of 4k and 12k). Similarly, depending on the embodiment, the techniques for on-board storage of compressed raw image data described herein can be capable of capturing or storing image data at frame rates of at least 23, 24, 25, 120, 150, or 240 or greater fps, or of frame rates between and inclusive of any of the foregoing resolution levels (for example, between and inclusive of 23 fps and 120 fps).

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figure 1A illustrates a top, front, and left-side perspective view of an example phone.

[0018] Figure 1B illustrates a bottom, rear, and right-side perspective view of the phone of Figure 1A.

[0019] Figure 1C illustrates a side view of the phone of Figure 1A positioned for attachment to an example camera module.

[0020] Figure 1D illustrates a perspective view of the phone of Figure 1A and the camera module of Figure 1C when attached.

[0021] Figure 2 illustrates a perspective view of an example video camera.

[0022] Figures 3A and 3B illustrate components of an example image capture device, such as the phone of Figure 1A, the camera module of Figure 1C, or the video camera of Figure 2.

[0023] Figure 4 illustrates an example process for processing image data that is performable by an image capture device, such as the image capture device of Figure 3A.

[0024] Figure 5 is a plot illustrating an example pre-emphasis function.

[0025] Figure 6 illustrates an example process for compressing video image data that is performable by an image capture device, such as the image capture device of Figure 3A.

[0026] Figure 7 illustrates the image capture device of Figure 3A in communication with an example phone, such as the phone of Figure 1A.

[0027] Figure 8 illustrates example components of the phone of Figure 1A or the camera module of Figure 1C.

[0028] Figure 9A illustrates a perspective view of the phone of Figure 1A positioned for attachment to an expander module and the camera module of Figure 1C.

[0029] Figure 9B illustrates a perspective view of the phone of Figure 1A, the expander module of Figure 9A, and the camera module of Figure 1C when attached.

DETAILED DESCRIPTION

I. Introduction

[0030] This disclosure describes, among other features, approaches for compressing video image data, such as raw Bayer data. The approaches desirably can, in certain embodiments, enable compression of the video image data using several lines of on-chip memory and without using a frame memory like DRAM. The compressed size of the video image data can be set and targeted for individual frames and adapted from frame-to-frame. Moreover, the approaches can provide a hardware-friendly implementation that enables a reduction in size and power consumption for devices which compress video image data. As a result, certain features of this disclosure can be particularly desirable for relatively smaller or low-power handheld devices, such as smart phones, where it may be desirable to save high quality video while limiting power consumption and system size. In some embodiments, such techniques can be used to compress fully-processed YUV data rather than raw.

[0031] Although the electronic devices described herein may be primarily described in the context of a smart phone, the disclosures are applicable to any of a variety of electronic devices with or without cellphone functionality, including digital still and motion cameras, personal navigation devices, mobile internet devices, handheld game consoles, or devices having any or a combination of the functions or other functions.

II. Electronic Device System Overview

[0032] Figure 1A illustrates a top, front, and left-side perspective view of a phone 10 that may implement one or more of the compression techniques or other features described herein. The phone 10 can be a smart phone. The front of the phone 10 includes a display 11, cameras 12 (for instance, four cameras as illustrated), a first speaker grill 13A, and second speaker grills 13B, as well as one or more microphones (not shown). The left side of the phone 10 includes a first input 14.

[0033] Figure 1B illustrates a bottom, rear, and right-side perspective view of the phone 10. The bottom of the phone includes a power input port 15. The left side of the phone 10 includes second inputs 16. The back of the phone 10 includes second cameras 17

(for instance, two cameras as illustrated), a flash 18, a laser focus 19, and a module connector 20.

[0034] The display 11 can display a variety of applications, functions, and information and may also incorporate touch screen control features.

[0035] Each of the first cameras 12 and the second cameras 17 includes a capability for capturing video image data frames with various or adjustable resolutions and aspect ratios as described herein. The first cameras 12 can each generally face the same direction as one another, and the second cameras 17 can generally face the same direction as one another.

[0036] The first input 14 and the second inputs 16 can be buttons and receive user inputs from a user of the phone 10. The first input 14 can, for example, function as a power button for the phone 10 and enable the user to control whether the phone 10 is turned on or off. Moreover, the first input 14 may serve as a user identification sensor, such as a finger print sensor, that enables the phone 10 to determine whether the user is authorized to access the phone 10 or one or more features of or files stored on the phone 10 or a device coupled to the phone 10. The first input 14 can function as a device lock/unlock button, a button to initiate taking of a picture, a button to initiate taking of a video, or select button for the phone 10. The second inputs 16 can function as a volume up button and a volume down button for the phone 10. The functionality of the first input 14 and the second inputs 16 can be configured and varied by the user. Moreover, the side of the phone 10 can include scalloped or serrated edges as illustrated in Figure 1A and as described in U.S. Patent No. 9,917,935; the entire disclosure of which is incorporated herein by reference. Notably, the scallop in which the first input 14 is positioned may not include serrations while the other scallops may include serrations, which can assist a user with distinguishing the two edges of the phone 10 from one another, as well as the first input 14 from the second inputs 16.

[0037] The phone 10 may receive no user inputs to the front of the phone 10 except via the display 11, in some embodiments. The front of the phone 10 thus may include no buttons, and any buttons may be located on one or more sides of the phone 10. Advantageously, such a configuration can, in certain embodiments, improve the ergonomics

of the phone 10 (such as by enabling a user to not have to reach down to a front button) and increase an amount of space available for the display 11 on the phone 10.

[0038] The module connector 20 can interchangeably couple with a module and receive power or data from or transmit power or data to the module or one or more other devices coupled to the module. The module can include a camera, a display, a video game controller, a speaker, a battery, an input/output expander, a light, a lens, a projector, and combinations of the same and the like. The module moreover may be stacked to one or more other module to form a series of connected modules coupled to the phone 10, such as described in U.S. Patent Application Publication No. 2017/0171371; the entire disclosure of which is incorporated herein by reference.

[0039] The module connector 20 can include multiple contacts (for instance, 44 contacts in three rows or 13 contacts in one row, among other possibilities) that engage with contacts on a corresponding connector of a module to electronically communicate data. The multiple contacts can engage with a spring loaded connector or contacts of the module. In some implementations, the phone 10 can magnetically attach to or support the module, and the phone 10 and the module can each include magnets that cause the phone 10 to be attracted and securely couple. The phone 10 and the module can further be coupled in part via a friction fit, interlocking structures, fasteners, mechanical snap surface structures, mechanical latch surface structures, mechanical interference fit surface structures, or the like between one or more portions of the phone 10 and one or more portions of the module.

[0040] Additional information about coupling of and communicating data between a device and one or more modules can be found in U.S. Patent App. Pub. Nos. 2017/0171371 and 2016/0044148 and U.S. Patent No. 9,568,808; the disclosures of which are herein incorporated by reference in their entirety.

[0041] The dimensions of the phone 10 can vary depending on the particular embodiment. For example, the phone 10 can be approximately 100 mm high by 50 mm wide by 15 mm thick. In another example, the phone 10 can be about 150 mm in height, 70 mm wide and 10 mm thick. In yet another example, the phone 10 can be about 130 mm high, by 70 mm wide by 10 mm thick. In yet a further example, the phone 10 can be approximately

120 mm high by 60 mm wide by 10 mm thick. The display 11, for instance, can be a 4", 4.5", 5", 5.5", 5.7", 6", 6.5", 7", or 7.5" display.

[0042] Figure 1C illustrates a side view of the phone 10 positioned for attachment to a camera module 30, and Figure 1D illustrates a perspective view of the phone 10 and the camera module 30 when attached. The camera module 30, alone or in combination with the phone 10, can implement one or more of the compression techniques or other features described herein. The camera module 30 can include a housing that supports magnets 34A and 34B and an input 36. The magnets 34A and 34C can facilitate coupling of the housing to the phone 10. The input 36 can be used to receive user inputs to the camera module 30 to control activities of the camera module 30 like changing of a mode or initiating capture of video. Although not illustrated in Figures 1C and 1D, the camera module 30 can also include magnets on an opposite side of the housing of the camera module 30 from the side shown in Figure 1C to couple the opposite side to the housing of the phone 10.

[0043] The camera module 30 can further couple to an optical module 38 that may be interchangeable with one or more other optical modules. The optical module 38 can, for example, include one or more optical elements such as lenses, shutters, prisms, mirrors, irises, or the like to form an image of an object at a targeted location. Embodiments of camera modules and optical modules and approaches for coupling the camera modules and optical modules are further described in U.S. Patent Application Publication No. 2017/0171371; the entire disclosure of which is incorporated herein by reference.

[0044] The optical module 38 can include a removable lens 39 and a lens mount 41, where the lens 39 may be inserted into an opening (not shown) of the lens mount 41, and then rotated to secure the lens in place. In one embodiment, the lens mount 41 can include a button or other type of control, allowing for removal of the lens 39. For instance, the user can push or otherwise interact with an interface element which allows the user to rotate the lens 39 in the opposite direction and remove the lens 39 from the opening of the lens mount 41. In some embodiments, the lens mount 41 itself is removable and re-attachable via holes 45A, 45B, 45C, 45D, for example, by inserting a mounting screw through each hole. The lens mount 41 or the lens 39 can, for example, be one of those described in U.S. Patent No. 9,568,808, which is hereby incorporated by reference in its entirety.

[0045] The camera module 30 can include a module connector 31, similar to or the same as the module connector 20, that can interchangeably couple with an additional module (for example, engage with contacts on a corresponding connector of the additional module) and receive power or data from or transmit power or data to the module or one or more other devices coupled to the module. The additional module can include a camera, a display, a video game controller, a speaker, a battery, an input/output expander, a light, a lens, a projector, or combinations of the same and the like. In one example, the additional module connected to the module connector 31 can be an input/output expander and include one or more additional inputs that enable a user to control operations of the camera module 30. The additional module moreover may have a form factor that permits coupling of a corresponding connector of the additional module to the module connector 31 without the additional module impeding placement or use of the lens mount 41 or obstructing a view through the lens 39 from an image sensor in the camera module 30 (for example, the additional module may not cover the entire surface of the camera module 30 that includes the module connector 31). In some implementations, the additional module can magnetically attach to or be supported by the camera module, and the additional module and the camera module 30 can each include magnets that cause the two to be attracted and securely couple. Additionally or alternatively, coupling can be achieved at least via a friction fit, interlocking structures, fasteners, mechanical snap surface structures, mechanical latch surface structures, mechanical interference fit surface structures, or the like.

[0046] Figure 2 illustrates a perspective view of a video camera 40. The video camera 40 can include a brain module 42, a lens mount module interface 44, and a lens 46. The video camera 40 can implement one or more of the compression techniques or other features described herein. Embodiments of the video camera 40 and its components are described in greater detail in in U.S. Patent Application Publication Nos. 2016/0295096 and 2017/0171371; the entire disclosures of which are incorporated herein by reference.

[0047] Figure 3A illustrates an image capture device 50 that can implement one or more of the compression techniques or other features described herein. The image capture device 50, in some embodiments, can be or incorporated as part of the phone 10, the camera module 30, or the video camera 40. The image capture device 50 can include a housing

configured to support optics 51, an image sensor 52 (or multiple image sensors), an image processing system 53, a compression system 54, and a memory device 55. In some implementations, the image capture device 50 can further include a multimedia system 56. The image sensor 52, the image processing system 53, the compression system 54, and the multimedia system 56 may be contained within the housing during operation of the image capture device 50. The memory device 55 can be also contained or mounted within the housing, mounted external to the housing, or connected by wired or wireless communication external to the image capture device 50.

[0048] The optics 51 can be in the form of a lens system having at least one lens configured to focus an incoming image onto the image sensor 52. In some embodiments, the optics 51 can be in the form of a multi-lens system providing variable zoom, aperture, and focus. The optics 51 can be in the form of a lens socket supported by the housing and receive multiple different types of lens systems for example, but without limitation, the optics 51 can include a socket configured to receive various sizes of lens systems including a 50-100 millimeter (F2.8) zoom lens, an 18-50 millimeter (F2.8) zoom lens, a 300 millimeter (F2.8) lens, 15 millimeter (F2.8) lens, 25 millimeter (F1.9) lens, 35 millimeter (F1.9) lens, 50 millimeter (F1.9) lens, 85 millimeter (F1.9) lens, or any other lens. As noted above, the optics 51 can be configured such that images can be focused upon a light-sensitive surface of the image sensor 52 despite which lens is attached thereto. Additional information regarding such a lens system can be found in U.S. Patent No. 9,568,808, the entire disclosure of which is herein incorporated by reference.

[0049] The image sensor 52 can be any type of video sensing device, including, for example, but without limitation, CCD, CMOS, vertically-stacked CMOS devices such as the Foveon® sensor, or a multi-sensor array using a prism to divide light between the sensors. The image sensor 52 can further include a color filter array such as a Bayer pattern filter that outputs data representing magnitudes of red, green, or blue light detected by individual photocells of the image sensor 52. In some embodiments, the image sensor 52 can include a CMOS device having about 12 million photocells. However, other size sensors can also be used. In some configurations, video camera 10 can be configured to output video at "2k" (e.g., 2048 x 1152 pixels), "4k" (e.g., 4,096 x 2,540 pixels), "4.5k," "5k," "6k," "8k", or

"16k" or greater resolutions. As used herein, in the terms expressed in the format of "xk" (such as "2k" and "4k" noted above), the "x" quantity refers to the approximate horizontal resolution. As such, "4k" resolution corresponds to about 4000 or more horizontal pixels and "2k" corresponds to about 2000 or more pixels. Using currently commercially available hardware, the image sensor 52 can be as small as about 0.5 inches (8 mm), but it can be about 1.0 inches, or larger. Additionally, the image sensor 52 can provide variable resolution by selectively outputting only a predetermined portion of the image sensor 52. For example, the image sensor 52 or the image processing system 53 can be configured to allow a user to identify, configure, select, or define the resolution of the video data output. Additional information regarding sensors and outputs from sensors can be found in U.S. Patent No. 8,174,560, the entire disclosure of which is herein incorporated by reference.

[0050] The image processing system 53 can format the data stream from the image sensor 52. The image processing system 53, for instance, can separate the green, red, and blue image data into three or four separate data compilations. For example, the image processing system 53 can be configured to separate the red data into one red channel or data structure, the blue data into one blue channel or data structure, and the green data into one green channel or data structure. The image processing system 53 may also separate the green into two separate green data structures in order to preserve the disparity between the diagonally adjacent green pixels in a 2x2 Bayer pattern. The image processing system 53 can process the picture element values to combine, subtract, multiply, divide, or otherwise modify the picture elements to generate a digital representation of the image data.

[0051] The image processing system 53 can further include a subsampling system configured to output reduced or unreduced resolution image data to multimedia system 56. For example, such a subsampling system can be configured to output image data to support 6K, 4K, 2K, 1080p, 720p, or any other resolution. Additionally, the image processing system 53 can include other modules or perform other processes, such as gamma correction processes, noise filtering processes, and the like. Examples of functionality provided by the image processing system 53 are described in U.S. Patent Application Pub. No. 2014/0226036, which is incorporated herein by reference in its entirety.

[0052] The compression system 54 can compress the image data from the image processing system 53 using a compression technique, such as the compression approach described with respect to Figure 7, or another technique. The compression system 54 can be in the form of a separate chip or chips (for example, FPGA, ASIC, etc.). The compression system 54 can be implemented with software and another processor or can be implemented with a combination of processors, software, or dedicated chips. For example, the compression system 54 can include one or more compression chips that perform a compression technique in accordance with DCT-based codecs.

[0053] The compression system 54 can compress the image data from the image processing system 53 using DCT-based codecs with rate control. In some embodiments, the compression system 54 performs a compression technique that modifies or updates compression parameters during compression of video data. The modified or updated compression parameters can be configured to achieve targeted or desired file sizes, video quality, video bit rates, or any combination of these. In some embodiments, the compression system 54 can be configured to allow a user or other system to adjust compression parameters to modify the quality or size of the compressed video output by the compression system 54. For example, the image capture device 50 can include a user interface (not shown) that allows a user to input commands that cause the compression system 54 to change compression parameters.

[0054] The compression system 54 can compress the image data from the image processing system 53 in real time. The compression system 54 can perform compression using a single-pass to compress video frames. This can be used to eliminate the use of an intermediate frame memory used in some compression systems to perform multiple compression passes or to compress a current video frame based on the content from one or more previous video frames stored in an intermediate frame memory. This can reduce the cost or complexity of a video camera with on-board video compression. The compression system 54 can compress image data from the image processing system 53 in real time when the frame rate of the image data is at least 23 frames per second (fps), at least about 24 fps (e.g., 23.976 fps), at least about 25 fps, at least about 30 fps (e.g., 29.97 fps), at least about 48 fps, at least about 50 fps, at least about 60 fps (e.g., 59.94 fps), at least about 120 fps, at least

about 240 fps, or less than or equal to about 240 fps. The compressed video can then be sent to the memory device 55.

[0055] The memory device 55 can be in the form of any type of digital storage, such as, for example, but without limitation, hard disks, flash memory, or any other type of memory. In some embodiments, the size of the memory device 55 can be sufficiently large to store image data from the compression system 54 corresponding to at least about 30 minutes of video at 12 megapixel resolution, 12-bit color resolution, and at 60 fps. However, the memory device 55 can have any size.

[0056] In embodiments that include the multimedia system 56, the multimedia system 56 can allow a user to view video images captured by the image sensor 52 during operation or video images received from the compression system 54 or the memory device 55. In some implementations, the image processing system 53 can include a subsampling system configured to output reduced resolution image data to the monitor system 56. For example, such a subsampling system can be configured to output video image data to support "2k," 1080p, 720p, or any other resolution. Filters used for de-mosaicing can also be adapted to perform down-sampling filtering, such that down-sampling and filtering can be performed at the same time. The multimedia system 56 can perform any type of decompression or de-mosaicing process to the data from the image processing system 53. For example, the multimedia system 56 can decompress data that has been compressed as described herein. Thereafter, the multimedia system 56 can output a de-mosaiced or decompressed image data to a display of the multimedia system 56 or another display.

[0057] Figure 3B illustrates additional components of the image capture device 50 according to some embodiments. Figure 3B, in particular, depicts more implementation details of an embodiment of the image capture device 50 than Figure 3A. As illustrated, the image capture device 50 is further in communication with frame memory 63. The frame memory 63 can be DRAM, such as the RAM 113 of Figure 4.

[0058] The image capture device 50 further includes an image processing unit 60. As shown, the image processing unit 60 can include the image processing system 53, the compression system 54, and on-chip memory 62. The on-chip memory can, for example, be SRAM. Some or all of the components of the image processing unit 60 can be dedicated to

use for processing and storage of image data (for example, compressed raw video image data) captured by the image capture device 50, and may not be used for other purposes, such as for implementing telephone functionality associated with the image capture device 50.

[0059] The image processing unit 60 can include one or more integrated circuits, chips or chipsets which, depending on the implementation, can include an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a combination thereof, or the like. According to certain embodiments, the on-chip memory 62 can be located within the same device (for example, ASIC, FPGA, or other chip[s]) as other components of the image processing unit 60, such as the image processing system 23 and compression system 54. For instance, the image processing unit 60 can include an ASIC or FPGA which implements the image processing system 53, the compression system 54, and the on-chip memory 62. The on-chip memory 62 can therefore be referred to as an "on-chip" memory according to certain embodiments, whereas the frame memory 63 can be referred to as an "off-chip" memory.

[0060] As shown, the frame memory 63 can be implemented separate from the image processing unit 60 and can be a DRAM. For instance, in one embodiment, the frame memory 63 and image processing unit 60 are respectively an ASIC and FPGA implemented in separate packages and mounted on a common printed circuit board. The frame memory 63 can be used to concurrently store an entire image frame (for example, all or substantially all of the pixel data of one image frame) for processing purposes. For instance, the frame memory 63 can be used by the image processing system 53 for storing entire image frames during certain image processing steps, such as pixel defect correction or pixel pattern noise correction as a couple of examples. While the frame memory 63 may be used for some such steps, according to certain embodiments, the image capture device 50 implements an image processing pipeline in which compressed raw video image data is processed without utilizing the frame memory 63 for the purposes of compression. For instance, the compression system 54 in some embodiments implements a DCT-based compression scheme, which can be any of those described herein, such as with respect to Figure 6. Such a DCT-based compression scheme can be relatively lightweight in memory requirements, such that the compression

system 61 can perform the compression utilizing the on-chip memory 62 and not the frame memory 63 or any other frame memory during compression.

[0061] Avoiding use of frame memory during compression can significantly reduce power consumption, and contrasts with certain other compression techniques which involve the use of a frame memory for motion vector calculations. For instance, according to certain DCT-based compression techniques described herein, the compression system 54 operates on a discrete section of a video image frame (for example, a section smaller than a full image frame) at any given time, discards the discrete section of the video image frame immediately after processing. For instance, in one embodiment, the compression system 54 operates on data for 32 horizontal lines of pixels at a time, and only utilizes an amount of storage in the on-chip memory 62 corresponding to 64 lines of pixel data for compression purposes (to hold image data for 32 lines of pixel data currently being compressed and to hold image data for the next 32 lines to be compressed). Depending on the embodiment, power consumption can be reduced such that, according to various embodiments the image capture device 50 consumes less than about 15 or 20 W during operation, and in some embodiments consumes between about 10 W to 20 W, between about 10 W to 25 W, or between about 5 W to 25 W. For instance, according to some embodiments the imaging componentry of the image processing device 50 (for example, the camera-related componentry of the image processing device 50) consumes less than about 10 W or 15 W (for example, between about 4 W to 10 W or between about 6 W 10 W), whereas the remaining non-imaging componentry (for example, phone componentry, display componentry, etc.) consumes less than about 10W (for example, between about 3 W to 10 W or between about 5 W 10 W).

[0062] The compression techniques described herein can allow for enhanced decoding/decompression speeds. For instance, the DCT-based raw compression techniques can allow for enhanced decompression because DCT algorithms allow for use of highly parallelized mathematical operations during decompression, making efficient use of graphics processing units. Depending on the embodiment, the raw compression techniques described herein can allow for decompression of video image frames in less than or equal to about 1/23,

1/24, 1/25, or 1/120 seconds, which can allow for real-time decompression, depending on the frame rate.

III. Image Data Processing

[0063] Figure 4 is a flowchart 400 illustrating an example process for processing video image data that is performable by an image capture device, such as the phone 10, the camera module 30, the video camera 40, or the image capture device 50. The flowchart 400 can represent a control routine stored in a memory device, such as the memory device 55, the ROM 112, RAM 113, or memory 175. Additionally, a processor, such as the controller 110, can be configured to execute the control routine. For convenience, the flowchart 400 is described in the context of the image capture device 50 but may instead be implemented by other systems described herein or other appropriate computing systems not shown. The flowchart 400 advantageously, in certain embodiments, depicts an example approach by which a relatively small or low-power handheld device like a cellphone can process video image data.

[0064] At block 402, the image sensor 52 can generate video image data responsive to light incident on the image sensor 52. For example, the image sensor 52 can generate the video image data as raw mosaiced image data at least at about 23 frames per second and with a resolution of at least 2K. Moreover, the output from the one or more image sensors 202 can in some implementations each be at least 16-bit wide with 15-bit outputs and 1 bit set for black sun effect. The image sensor 52 can, in some instances, be used to generate 3D video image data for processing and eventual presentation as 3D video images.

[0065] At block 404, the image processing system 53 can pre-emphasize the video image data generated by the image sensor 52. The generated video image data can be pre-emphasized by performing a lossy transform to raw pixels of the generated video image data. The pre-emphasis can desirably, in certain embodiments, reduce an amount of video image data to be processed at block 406 while nonetheless preserving video image data quality.

[0066] The image processing system 53 can, for example, perform a piecewise linear function to that transforms the raw pixels from 15-bit or 16-bit data to 12-bit data. The slope of the piecewise linear function can follow a harmonic progression 1, 1/2, 1/3, …., 1/15, 1/16 and change every 256 counts. The shape of the piecewise linear function can be tailored to the image sensor 52 from sensor characterization data and thus vary from sensor to sensor or sensor manufacturer to sensor manufacturer. The input range of the piecewise linear function may, in some instances, go above a maximum value permitted to account for a black offset that may be applied.

[0067] Figure 5 is a plot 500 that graphically illustrates one example piecewise linear function for transforming raw pixels from 15-bit data to 12-bit data. Table 1 below provides example points along the plot 500.

15-bit input	12-bit output
0	0
256	256
768	512
1536	768
2560	1024
3840	1280
5376	1536
7168	1792
9216	2048
11520	2304
14080	2560
16896	2816
19968	3072
23296	3328
26880	3584
30720	3840
34800	4095

Table 1

[0068] The pre-emphasis can be performed by the image processing system 53 given the understanding that not all video image data values in a bit range (such as a 15-bit range including 0–32767) carry the same information. Incoming light at each pixel can be governed by a Poisson process that results in a different photon shot noise (PSN) at each light level. The Poisson random distribution can have a unique characteristic where a variance of a distribution is equal to a mean of the distribution. Thereby, the standard deviation is equal

to the square root of the mean. From this understanding, the uncertainty (such as indicated by the standard deviation) associated with each measured digital number output (DN), corresponding to incoming light for a particular pixel, can be proportional to $\sqrt{DN}$. To pre-emphasize, one or more digital values in an input domain can be lumped to a single digital value in an output domain. If Q adjacent DN values are lumped together (for instance, quantized) into one, the resulting noise can be proportional to $\sqrt{Q^3}$. The quantization noise can be minimized by choosing Q such that $\sqrt{DN}$ α $\sqrt{Q^3}$ (for example, $Q\alpha^3\sqrt{DN}$). The complexity of this function can be reduced by constructing a piecewise linear function from the function. Using this technique, additional noise added by the pre-emphasis can be reduced, such as to a small percentage (like 1% of the photon shot noise in an example worst case scenario).

[0069] A conversion function may be used to convert pre-emphasized values after decoding. For example, the following function, which is expressed in pseudocode, can be used to convert 12-bit data back to 15-bit data after decoding.

```
int index = imageData[i][j] >> 8;
int offset = imageData[i][j] & 0xff;
int value = (index+1) * offset + ((index+1) * index * 128) + ((index + 1) >> 1);
```

[0070] In some instances, using a conversion function (sometimes referred to as a pre-emphasis function) that has a relatively simple inverse can helpful for decoding compressed image in hardware using parallel processing. For example, when an example conversion function has a relatively simple inverse, a Graphical Processing Unit (GPU) may be used to relatively quickly convert 12-bit data back to its original 15-bit data form after decompression.

[0071] Additional information regarding pre-emphasis techniques can be found in U.S. Patent No. 8,174,560, the entire disclosure of which is herein incorporated by reference.

[0072] At block 406, the compression system 54 can compress the video image data pre-emphasized by the image processing system 53. For example, the compression system 54 can compress the pre-emphasized video image data as described with respect to Figure 6 or using another compression algorithm. The compression system 54 can, in some

implementations, perform one or more of the following: (i) compress the video image data without using a frame memory that stores a full image frame, (ii) compress the video image data using one memory device and without using any memory positioned off-chip relative to the one memory device, (iii) compress the video image data using a static memory that may not be periodically refreshed rather than a dynamic memory that must be periodically refreshed, and (iv) operate according to the timing of a clock and correctly compress the video image data despite the clock stopping for a period of time such as a 5, 10, 20, or 30 seconds or 1, 2, 3, 5, or 10 minutes. The compression system 54 moreover can be used to compress video image data that is presentable as 3D video images.

[0073] Figure 6 is a flowchart 600 illustrating an example process for compressing video image data that is performable by an image capture device, such as the phone 10, the camera module 30, the video camera 40, or the image capture device 50. The flowchart 600 can represent a control routine stored in a memory device, such as the memory device 55, the ROM 112, RAM 113, or memory 175. Additionally, a processor, such as the controller 110, can be configured to execute the control routine. For convenience, the flowchart 600 is described in the context of the image capture device 50 but may instead be implemented by other systems described herein or other appropriate computing systems not shown. The flowchart 600 advantageously, in certain embodiments, depicts an example approach by which a relatively small or low-power handheld device like a cellphone can compress video image data.

[0074] At block 602, the compression system 54 can shift and divide video image data. Values of the video image data can be shifted by an amount equal to a central value for the video image data that depends on a number of bits of the data (for instance, the central value can be $0.5 \cdot 2^n$ for n-bit data, which means 2048 in the case of 12-bit data). The shifting can shift the values around a value of 0 for further processing. The values can also be divided into slices and macroblocks. In one implementation, a maximum size of the slice is 256x32 pixels, and maximum size slices are packed from left to right. If some pixels are still left on the end of each line, a slice of size 256x32 pixels, 128x32 pixels, 64x32 pixels, 32x32 pixels, or another size can be made by packing pixels of value 0 at the end. In instances where the pixels follow a Bayer pattern, each slice can have 128x16 Green1, Green2, Red,

and Blue pixels, and the pixels can be further divided into 8 macroblocks (16x16 pixels) of Green1, Green2, Red, and Blue pixels.

[0075] At block 604, the compression system 54 can transform the shifted and divided video image data, such as using a discrete cosine transform (DCT) or another transform. In one example, the compression system 54 can transform each macroblock of the shifted and divided video image data using a 16x16 DCT. The 16x16 DCT notably can provide, in some instances, higher compression efficiency than an 8x8 DCT. The two dimensional 16x16 DCT can moreover be separable into 32 one dimensional 1x16 DCT calculations. This separability advantageously can, in certain embodiments, facilitate the use of memory having a capacity less than a frame memory (for example, multiple lines of on-chip memory 62) when performing compression. The output from the transformation can be transform coefficients for the video image data.

[0076] At block 606, the compression system 54 can quantize the transform coefficients. The quantization can include two components. The first component can be a quantization table value from one or more quantization tables. For example, one quantization table can be used for Green1 and Green2 channels, and another quantization table can be used for blue and red channels. The one or more quantization tables can be defined in a frame header. The second component can be a quantization scale factor. The quantization scale factor can be the same for each value within a slice, vary from a minimum value (for example, 1) to a maximum value (for example, 255), be defined in a slice header, and used for achieving a target slice size. The quantization scale factor can be determined based at least on a target frame size or a technique such as is described in U.S. Patent No. 9,800,875, which is herein incorporated by reference in its entirety. The quantization scale factor may be set constant in some instances to generate a compressed video of certain quality irrespective of the compressed image size. In one implementation, the quantized values for the transform coefficients can be determined using Equation 1 below.

Equation 1: $$\text{Quantized Value} = \frac{\text{Transformed Coefficient Value}}{\text{Quantization Table Value} * \text{Quantization Scale Factor}}$$

[0077] At block 608, the compression system 54 can arrange the quantized transform coefficients slice-by-slice for encoding and so that green, red, and blue components

may be encoded separately within a slice. The DC coefficients of the macroblocks of one slice can be arranged left to right. The AC coefficients of the macroblocks of the one slice can arranged so that (i) all particular location AC coefficients in a 16x16 DCT table from different macroblocks in the slice are arranged one after the other and (ii) the different AC coefficients are arranged by the zig-zag scan order illustrated by Table 2 below where the index in Table 2 indicates a position in the sequence for the quantized transform coefficients.

0	1	5	6	14	15	27	28	44	45	65	66	90	91	119	120
2	4	7	13	16	26	29	43	46	64	67	89	92	118	121	150
3	8	12	17	25	30	42	47	63	68	88	93	117	122	149	151
9	11	18	24	31	41	48	62	69	87	94	116	123	148	152	177
10	19	23	32	40	49	61	70	86	95	115	124	147	153	176	178
20	22	33	39	50	60	71	85	96	114	125	146	154	175	179	200
21	34	38	51	59	72	84	97	113	126	145	155	174	180	199	201
35	37	52	58	73	83	98	112	127	144	156	173	181	198	202	219
36	53	57	74	82	99	111	128	143	157	172	182	197	203	218	220
54	56	75	81	100	110	129	142	158	171	183	196	204	217	221	234
55	76	80	101	109	130	141	159	170	184	195	205	216	222	233	235
77	79	102	108	131	140	160	169	185	194	206	215	223	232	236	245
78	103	107	132	139	161	168	186	193	207	214	224	231	237	244	246
104	106	133	138	162	167	187	192	208	213	225	230	238	243	247	252
105	134	137	163	166	188	191	209	212	226	229	239	242	248	251	253
135	136	164	165	189	190	210	211	227	228	240	241	249	250	254	255

Table 2

[0078] At block 610, the compression system 54 can divide the arranged transform coefficients into ranges and values within ranges. The ranges for the DC coefficients can be ranges of possible values of the DC coefficients, and the ranges for the AC coefficients can be ranges of possible values of the AC coefficients and counts of groupings of 0 values.

[0079] At block 612, the compression system 54 can encode the ranges of the arranged coefficients as Huffman codes and at least some of the values within the ranges of the arranged coefficients as Golomb codes. If a range has no more than one unique value, the one unique value may be encoded with a Huffman code and not a Golomb code. If a range has more than one unique value, values can be encoded by a combination of a Huffman code for the range and a Golomb code for the unique value within the range. The ranges and the Golomb codes for the ranges may be fixed or predefined, such as set at manufacture. The

Huffman codes for the ranges, however, can vary from frame to frame with one or more Huffman tables being defined in a frame header. An encoder can use the adaptability of Huffman coding and may compute one or more Huffman tables at the end of each frame to be used for a next frame to optimize compression efficiency for particular video image data. In one implementation, a maximum number of bits in a Huffman code can be 12.

[0080] The value of a DC coefficient of a particular component in a slice may be encoded as a difference from the previous value of the DC coefficient. This difference can be termed a difference coefficient. An initial value for the DC coefficient for the particular component in the slice can be set to 0. To encode the values of individual DC coefficients, the compression system 54, for example, can (i) calculate the absolute value of the difference coefficient for the individual DC coefficient, (ii) append the Huffman code corresponding to the range of the individual DC coefficient to the bit stream, (iii) append the Golomb code corresponding to the value within the range of the individual DC coefficient to the bit stream, and (iv) append a sign bit (for example, 0 for positive and 1 for negative) to the bitstream if difference coefficient is nonzero.

[0081] Table 3 below provides an example DC encoding table. The Huffman code portion of the table can be used as a default table at the beginning of compression when compression statistics may be unknown.

Example DC Huffman Table			Golomb Code
|DC Value|	Huffman Code	Huffman Bits	
0 - 15	0	1	Golomb-Rice(|DC Value|, 2)
16 - 31	11	2	Golomb-Rice(|DC Value|-16 , 2)
32 - 63	010	3	Golomb-Rice(|DC Value|-32 , 3)
64 - 127	011	3	Golomb-Rice(|DC Value|-64 , 4)
128 - 255	100	3	Golomb-Rice(|DC Value|-128 , 5)
256 - 511	1010	4	Golomb-Rice(|DC Value|-256 , 6)
512 - inf	1011	4	ExpGolomb(|DC Value|-512 , 7)

Table 3

[0082] For example, as can be seen from Table 3, if the difference coefficient may be 20, the Huffman code can be 11, the Huffman bits can be 2, the Golomb code can be Golomb-Rice(4, 2), and the sign bit can be 0. As another example, if the difference coefficient may be -75, the Huffman code can be 011, the Huffman bits can be 3, the Golomb code can be Golomb-Rice(11, 4), and the sign bit can be 1. As yet another example, if the

difference coefficient may be 300, the Huffman code can be 1010, the Huffman bits can be 4, the Golomb code can be Golomb-Rice(44, 6), and the sign bit can be 0.

[0083] The values of AC coefficients can be represented by runs of zeros followed by a non-zero value. Different Huffman codes can denote the values of AC coefficients that are preceded by runs of zeros and those that are not preceded by runs of zeros. To encode the values of non-zero individual AC coefficients, the compression system 54, for example, can (i) calculate EACV = |AC valuel - 1 for the individual AC coefficient, (ii) determine whether the individual AC coefficient is preceded by one or more zeros, (iii) append the Huffman code corresponding to the EACV for the individual DC coefficient to the bit stream, (iv) append the Golomb code corresponding to the EACV to the bit stream if EACV exceeds 3, and (v) append a sign bit (for example, 0 for positive and 1 for negative) to the bitstream. Moreover, to encode the values of individual AC coefficients that have values of zero, the compression system 54, for example, can (i) calculate EACR = AC runs of zeros - 1, (ii) append the Huffman code corresponding to the EACR to the bit stream, and (iii) append the Golomb code corresponding to the EACR to the bit stream if EACR exceeds 3.

[0084] Table 4 below provides an example AC encoding table. The Huffman code portion of the table can be used as a default table at the beginning of compression when compression statistics may be unknown.

Example AC Huffman Table									Golomb Code
AC Value after zero AC Run			AC Value after non-zero AC Run			AC Run Length			
|AC Value| -1	Huffman Code	Huffman Bits	|AC Value| -1	Huffman Code	Huffman Bits	AC Run -1	Huffman Code	Huffman Bits	
0	01	2	0	10	2	0	1	1	
1	110	3	1	1111	4	1	001	3	
2	0010	4	2	000011	6	2	0100	4	
3	00000	5	3	0011000	7	3	0101	4	
4-7	0001	4	4-7	001101	6	4-7	011	3	Golomb-Rice(|AC Value|-4 , 0)
8-15	1110	4	8-15	0011001	7	8-15	0001	4	Golomb-Rice(|AC Value|-8 , 1)
16-31	00111	5	16-31	000010110	9	16-31	00001	5	Golomb-Rice(|AC Value|-16 , 2)
32-63	0000100	7	32-63	0000101110	10	32-63	000000	6	Golomb-Rice(|AC Value|-32 , 3)
64 - inf	00001010	8	64 - inf	0000101111	10	64 - inf	000001	6	ExpGolomb(|AC Value|-64 , 4)

Table 4

[0085] To illustrate how Table 4 may be used for encoding, an example of encoding the eleven coefficient sequence of 0, 2, 0, 0, -10, 50, 0, 0, 0, 0, and 0 will be described. As can be seen from Table 4, for the run of one zero, the "AC Run - 1" can be 0, the Huffman code can be 1, the Huffman bits can be 1, and there may be no Golomb code.

Next, for the value of 2 which is preceded by the run of at least one zero, the "|AC Valuel - 1" can be 1, the Huffman code can be 1111, the Huffman bits can be 4, there may be no Golomb code, and the sign bit can be 0. Subsequently, for the run of two zeros, the "AC Run - 1" can be 1, the Huffman code can be 001, the Huffman bits can be 3, and there may be no Golomb code. Then next, for the value of -10 which is preceded by the run of at least one zero, the "|AC Valuel - 1" can be 9, the Huffman code can be 0011001, the Huffman bits can be 7, the Golomb code can be Golomb-Rice(2, 1), and the sign bit can be 1. Then subsequently, for the value of 50 which is not preceded by a run of at least one zero, the "|AC Valuel - 1" can be 49, the Huffman code can be 0000100, the Huffman bits can be 7, the Golomb code can be Golomb-Rice(18, 3), and the sign bit can be 0. Finally, for the remaining run of five zeros, the "AC Run - 1" can be 4, the Huffman code can be 011, the Huffman bits can be 3, and the Golomb code can be Golomb-Rice(1, 0).

[0086] As further part of the process of the flowchart 600, adaptive compression may be performed in certain implementations. For example, a size of a compressed frame can be set close to a target number of bytes, such as using the technique described in U.S. Patent No. 9,800,875, which was previously herein incorporated by reference in its entirety. An entropy index for each slice can moreover be calculated, such as using a technique described in U.S. Patent No. 9,800,875, which was previously herein incorporated by reference in its entirety. The entropy index along with an entropy multiplier can be used to calculate the quantization scale factor. The range of DCT 16x16 may notably be higher than that of DCT 8x8 for the same 12-bit input.

[0087] In some instances, because 32 lines of raw image data may be processed at a time, an image can be divided vertically (or otherwise) into 8 or more sections. After processing individual sections, a size of the compressed image thus far can be available. The size of the compressed image can then be used to update an entropy multiplier. At the end of frame compression, the size of the compressed image can be compared to a target size to further update the entropy multiplier.

[0088] Although some examples herein describe coding ranges or values within ranges using Huffman codes (or algorithms) and Golomb codes (or algorithms), other codes

(or algorithms) can be used. For example, a lossless code, a lossy code, a variable length code, or a prefix code may be used.

[0089] In some embodiments, a first algorithm can be used for coding ranges and a second algorithm can be used for coding values within ranges. The first algorithm can, in some instances, be different from the second algorithm so that ranges and values within ranges may be coded differently. In other instances, the first algorithm can be the same as the second algorithm.

IV. Video Stream Specification

[0090] Video image data, which may be compressed using one or more approaches disclosed herein, can be organized according to a video stream specification. The video stream specification can, in some implementations, include one or more of the following features.

[0091] A frame structure in a compressed file can be divided into header and data portions. The header can be designed to be hardware friendly. In some instances, all values in the header other than the size of a compressed frame may be known before the compression begins. A header version may be used to decode the compressed file, such as for playback on-camera or off-camera, if revisions were made to the file format. The header can, for instance, contain 600 bytes. The header can be followed by slices ordered left to right and top to bottom. Each slice can contain an integer number of bytes. One example header structure is shown below in Table 5.

Frame Header		
Begin Location	**Bytes**	**Description**
0	8	Number of bytes in compressed frame
8	1	Header: Major Version
9	1	Header: Minor Version
10	2	Horizontal Size
12	2	Veritical Size
14	1	Macroblocks per slice
15	1	Chroma Format 0 --> 422 1 --> 444
16	2	Number of slices per Frame
18	2	Reserved - Set to 0
20	256	Luma Quantization Table
276	256	Chroma Quantization Table
532	14	DC Huffman Table
546	18	AC Value zero run Huffman table
564	18	AC Value non-zero run Huffman table
582	18	AC run length Huffman table

Table 5

[0092] Individual entries in a Huffman table can be 2 bytes (16-bits) wide. As illustrated by Table 6 below, the most significant bits (for example, first 4 bits) of a Huffman table structure can represent a size of the Huffman code, and the least significant bits (for example, last 12 bits) of the Huffman table structure can represent the Huffman code itself that may be aligned to the right and left padded with zeros.

Code Size (4 bits)	Huffman Code (12 bits)

Table 6

[0093] Each slice can have a header (for example, 9 bytes) followed by Green1, Green2, Red, and Blue components. Each component can begin on a byte boundary. If a component may have fractional bytes, the component can be padded with zeros to form a complete byte. Table 7 below illustrates an example slice structure.

Slice Header (9 bytes)	Green1 Data (Variable)	Green2 Data (Variable)	Red Data (Variable)	Blue Data (Variable)

Table 7

[0094] Table 8 below shows an example slice header structure. The number of bits of the slice header structure can be specified to avoid confusing padded bits with

Huffman codes of value zero. If the number of bits in a component may not be a multiple of 8, a next component can begin on a byte boundary.

Slice Header		
Begin Location	**Bytes**	**Description**
0	1	Quantization Scale Factor
1	2	Number of bits in G1 Stream
3	2	Number of bits in G2 Stream
5	2	Number of bits in B Stream
7	2	Number of bits in R Stream

Table 8

V. 3D Image Display

[0095] The displays of or connected to the image capture devices described herein (for example, the display 11 of the device 10 of Figure 1A) can, in some implementations, be or include 3D displays. A 3D display may be configured to produce light so that a 3D image (sometimes referred to as "multi-dimensional content") is observed by the user. Stereoscopic displays may, for instance, be used to form images that appear to a user to be 3D when viewed at the proper angle or using specifically designed eye wear. At least some embodiments are directed to a display that is configured to produce an image that appears to be in 3D space, such that a user may be able to view the 3D image from multiple directions without moving the display. The display may not need to be positioned within the user's field of view. In some embodiments, the 3D image may appear to be suspended or float above the display. Thus, a user may be able to "walk around" the 3D image to observe different views of the image as though the content in the image was a physical object.

[0096] Some embodiments of the 3D display may include a diffractive lightfield backlighting system. The diffractive lightfield backlighting system may include a multiview or 3D display and a light source configured for rear illumination of the 3D display. The multiview display may include a plurality of diffractive elements, each including a plurality of diffractive gratings, configured to direct light illuminated thereon into multiple directions. The direction that the light is directed may be based on the diffractive properties of the diffractive elements. In some embodiments, the multiple directions may correspond to a different view of the 3D image. Multiple light rays directed in the same or substantially

similar direction may form and image corresponding to a particular view of the 3D content. Accordingly, multiple views of the 3D content may be displayed in multiple directions based on the plurality of diffractive elements. Some implementations of embodiments herein are described in more detail, for example, in U.S. Pat. No. 9,128,226 entitled "Multibeam Diffraction Grating-Based Backlighting" and U.S. Pat. No. 9,459,461 entitled "Directional Backlighting," the contents of which are each incorporated herein in their entirety. A 3D display may be separately operable from a 2 Dimensional (2D) display. The 3D display may, for instance, be disposed behind or in front of the 2D display. As such, the 3D display or 2D display can each be turned on and off without affecting the use of the other.

[0097] Other embodiments of the 3D display are possible for generating a 3D image. For example, the 3D display may be configured to display a 3D image based on a reconstruction of a holographic interference pattern associated with a hologram. The interference pattern may be reconstructed based on features stored in the fringe pattern, and the display may include pixels driven to duplicate the interference fringe pattern on a screen. The pixels may be illuminated by a light source, which may be transformed (e.g., varied in phase or transmittance) by the interference pattern of the pixels to generate a 3D holographic image. Some implementations may be found in, for example, U.S. Pat. No. 9,304,491, entitled "Transparent Holographic Display with Dynamic Image Control"; U.S. Pat. No. 6,760,135, entitled "Holographic Display," the contents of which are each incorporated herein in their entirety. In another embodiment, the display may include a plurality of holographic pixels that are illuminated modulated using an spatial light modulator, for example, as described in U.S. Pat. No. 7,190,496, entitled "Enhanced Environment Visualization Using Holographic Sterograms," the contents of which is incorporated herein in its entirety.

[0098] Advantageously, the 3D display may, in certain embodiments, not need to utilize lenticular lenses or eye tracking technology. Without subscribing to a particular scientific theory, embodiments herein can provide for higher resolution as compared to displays using lenticular lenses, the 3D display may be separately operable from a standard 2D display, and the 3D display provides for multi-directional content having multiple views.

[0099] Moreover, the image capture devices described herein can, in some implementations, capture 3D images for reproduction by a 3D display. For instance, the first cameras 12, the second cameras 17, images sensors of the camera module 30, or image sensors of the video camera can be used to capture 3D images. In one example, the first cameras 12, the second cameras 17, or the images sensors of the camera module 30 can be used to capture 3D images, and the phone 10 can in turn store the 3D images and playback the 3D images using the display 11. Such a design can facilitate live or simultaneous capture and display of 3D images.

[0100] The 3D content, holographic content, or other content displayed on the 3D display can be compressed according to any of the techniques described herein, such as for example according to the techniques for compressing raw image data described with respect to Figures 3A-6. For instance, the phone 10 may capture compressed raw image data using two or more of the first cameras 12, using the second cameras 17, or one or more of the image sensors of the camera module 30 (or using a different camera module attached to the phone 10). The phone 10 can then record the compressed image data in one or more files on a memory device of the phone 10, or in a memory device in a module attached to the phone 10. The phone 10 can then access the image data, decompress it, and prepare it for playback on the display 11 as 3D, holographic content, or the like, as appropriate. The phone 10 can additionally according to some embodiments play the 3D, holographic, or other content back in real-time without first compressing and storing the content, while the phone 10 is recording.

VI. Additional Embodiments and Terminology

[0101] Figure 7 illustrates the image capture device 50 in communication with a phone 100. The image capture device 50 can, for example, be an embodiment of the camera module 30, and the phone 100 can, for example, be an embodiment of the phone 10. The phone 100 can be modular and couple to one or more modules as described herein. For example, the phone can mechanically or electrically connect to a power source 60, a memory device 62, or an input/output (I/O) device 64, as well as the image capture device 50 or one or more other modules 66. In addition, the phone 100 can electrically communicate with one or

more other modules 61, 63, 65, 67 respectively through the power source 60, the memory device 62, the input/output (I/O) device 64, and the image capture device 50, and the one or more other modules 61, 63, 65, 67 can respectively couple to the power source 60, the memory device 62, the input/output (I/O) device 64, and the image capture device 50. Embodiments and features of modular phones and camera modules are further described in U.S. Patent Application Publication No. 2017/0171371; the entire disclosure of which is incorporated herein by reference.

[0102] Figure 8 illustrates components of the phone 100. The phone 100 may be connected to an external device by using an external connection device, such as a sub-communication module 130, a connector 165, and an earphone connecting jack 167. The "external device" may include a variety of devices, such as earphones, external speakers, Universal Serial Bus (USB) memories, chargers, cradles/docks, Digital Multimedia Broadcasting (DMB) antennas, electronic payment related devices, health care devices (for example, blood sugar testers), game consoles, vehicle navigations, a cellphone, a smart phone, a tablet PC, a desktop PC, a server, and the like, which are removable from the electronic device and connected thereto via a cable.

[0103] The phone 100 includes a touch screen display 190 and a touch screen controller 195. The phone 100 also includes a controller 110, a mobile communication module 120, the sub-communication module 130, a multimedia module 140, a camera module 150, a Global Positioning System (GPS) module 155, an input/output module 160, a sensor module 170, a memory 175, and a power supply 180. The sub-communication module 130 includes at least one of Wireless Local Area Network (WLAN) 131 and a short-range communication module 132, and the multimedia module 140 includes at least one of a broadcast communication module 141, an audio play module 142, and a video play module 143. The input/output module 160 includes at least one of buttons 161, a microphone 162, a speaker 163, a vibration motor 164, the connector 165, and a keypad 166. Additionally, the electronic device 100 can include one or more lights including a first light 153 that faces one direction and a second light 154 that faces another direction.

[0104] The controller 110 may include a Central Processing Unit (CPU) 111, a Read Only Memory (ROM) 112 for storing a control program, such as an Operating System

(OS), to control the phone 100, and a Random Access Memory (RAM) 113 for storing signals or data input from an external source or for being used as a memory space for working results in the phone 100. The CPU 111 may include a single core, dual cores, triple cores, or quad cores. The CPU 111, ROM 112, and RAM 113 may be connected to each other via an internal bus.

[0105] The controller 110 may control the mobile communication module 120, the sub-communication module 130, the multimedia module 140, the camera module 150, the GPS module 155, the input/output module 160, the sensor module 170, the memory 175, the power supply 180, the touch screen display 190, and the touch screen controller 195.

[0106] The mobile communication module 120 connects the electronic device 100 to an external device through mobile communication using at least a one-to-one antenna or a one-to-many antenna under the control of the controller 110. The mobile communication module 120 transmits/receives wireless signals for voice calls, video conference calls, Short Message Service (SMS) messages, or Multimedia Message Service (MMS) messages to/from a cell phone, a smart phone, a tablet PC, or another device, with the phones having phone numbers entered into the phone 100.

[0107] The sub-communication module 130 may include at least one of the WLAN module 131 and the short-range communication module 132. For example, the sub-communication module 130 may include either the WLAN module 131 or the-short range communication module 132, or both.

[0108] The WLAN module 131 may be connected to the Internet in a place where there is a wireless Access Point (AP), under the control of the controller 110. The WLAN module 131 supports the WLAN Institute of Electrical and Electronic Engineers (IEEE)802.11x standard. The short-range communication module 132 may conduct short-range communication between the phone 100 and an image rendering device under the control of the controller 110. The short-range communication may include communications compatible with BLUETOOTH™, a short range wireless communications technology at the 2.4 GHz band, commercially available from the BLUETOOTH SPECIAL INTEREST GROUP, INC., Infrared Data Association (IrDA), WI-FI™ DIRECT, a wireless technology

for data exchange over a computer network, commercially available from the WI-FI ALLIANCE, NFC, and the like.

[0109] The phone 100 may include at least one of the mobile communication module 120, the WLAN module 131, and the short-range communication module 132 based on the performance requirements of the phone 100. For example, the phone 100 may include a combination of the mobile communication module 120, the WLAN module 131, and the short-range communication module 132 based on the performance requirements of the phone 100.

[0110] The multimedia module 140 may include the broadcast communication module 141, the audio play module 142, or the video play module 143. The broadcast communication module 141 may receive broadcast signals (for example, television broadcast signals, radio broadcast signals, or data broadcast signals) and additional broadcast information (for example, an Electric Program Guide (EPG) or an Electric Service Guide (ESG)) transmitted from a broadcasting station through a broadcast communication antenna under the control of the controller 110. The audio play module 142 may play digital audio files (for example, files having extensions, such as mp3, wma, ogg, or way) stored or received under the control of the controller 110. The video play module 143 may play digital video files (for example, files having extensions, such as mpeg, mpg, mp4, avi, move, or mkv) stored or received under the control of the controller 110. The video play module 143 may also play digital audio files.

[0111] The multimedia module 140 may include the audio play module 142 and the video play module 143 except for the broadcast communication module 141. The audio play module 142 or video play module 143 of the multimedia module 140 may be included in the controller 110.

[0112] The camera module 150 may include one or more cameras for capturing still images or video images under the control of the controller 110. Furthermore, the one or more cameras may include an auxiliary light source (for example, a flash) for providing an amount of light for capturing an image. In one example, one or more cameras may be placed on the front of the phone 100, and one or more other cameras may be placed on the back of phone 100. Two or more cameras may be arranged, in some implementations, adjacent to

each other (for example, the distance between the two or more cameras, respectively, may be in the range of 1 cm. to 8 cm.), capturing 3 Dimensional (3D) still images or 3D video images.

[0113] The GPS module 155 receives radio signals from a plurality of GPS satellites in orbit around the Earth and may calculate the position of the phone 100 by using time of arrival from the GPS satellites to the phone 100.

[0114] The input/output module 160 may include at least one of the plurality of buttons 161, the microphone 162, the speaker 163, the vibrating motor 164, the connector 165, and the keypad 166.

[0115] The at least one of the buttons 161 may be arranged on the front, side or back of the housing of the phone 100, and may include at least one of a power/lock button, a volume button, a menu button, a home button, a back button, and a search button.

[0116] The microphone 162 generates electric signals by receiving voice or sound under the control of the controller 110.

[0117] The speaker 163 may output sounds externally corresponding to various signals (for example, radio signals, broadcast signals, digital audio files, digital video files or photography signals) from the mobile communication module 120, sub-communication module 130, multimedia module 140, or camera module 150 under the control of the controller 110. The speaker 163 may output sounds (for example, button-press sounds or ringback tones) that correspond to functions performed by the electronic device 100. There may be one or multiple speakers 163 arranged in at least one position on or in the housing of the phone 100.

[0118] The vibrating motor 164 may convert an electric signal to a mechanical vibration under the control of the controller 110. For example, the phone 100 in a vibrating mode operates the vibrating motor 164 when receiving a voice call from another device. There may be at least one vibration motor 164 inside the housing of the phone 100. The vibration motor 164 may operate in response to a touch activity or continuous touches of a user over the touch screen display 190.

[0119] The connector 165 may be used as an interface for connecting the phone 100 to the external device or a power source. Under the control of the controller 110, the

phone 100 may transmit data stored in the memory 175 of the electronic device 100 to the external device via a cable connected to the connector 165, or receive data from the external device. Furthermore, the phone 100 may be powered by the power source via a cable connected to the connector 165 or may charge the battery using the power source.

[0120] The keypad 166 may receive key inputs from the user to control the phone 100. The keypad 166 includes a mechanical keypad formed in the phone 100, or a virtual keypad displayed on the touch screen display 190. The mechanical keypad formed in the phone 100 may optionally be omitted from the implementation of the phone 100, depending on the performance requirements or structure of the phone 100.

[0121] An earphone may be inserted into the earphone connecting jack 167 and thus, may be connected to the phone 100.

[0122] A stylus pen 168 may be inserted and removably retained in the phone 100 and may be drawn out and detached from the phone 100.

[0123] A pen-removable recognition switch 169 that operates in response to attachment and detachment of the stylus pen 168 is equipped in an area inside the phone 100 where the stylus pen 168 is removably retained, and sends a signal that corresponds to the attachment or the detachment of the stylus pen 168 to the controller 110. The pen-removable recognition switch 169 may have a direct or indirect contact with the stylus pen 168 when the stylus pen 168 is inserted into the area. The pen-removable recognition switch 169 generates the signal that corresponds to the attachment or detachment of the stylus pen 168 based on the direct or indirect contact and provides the signal to the controller 110.

[0124] The sensor module 170 includes at least one sensor for detecting a status of the phone 100. For example, the sensor module 170 may include a proximity sensor for detecting proximity of a user to the phone 100, an illumination sensor for detecting an amount of ambient light of the electronic device 100, a motion sensor for detecting the motion of the phone 100 (for example, rotation of the phone 100, acceleration or vibration applied to the phone 100), a geomagnetic sensor for detecting a point of the compass using the geomagnetic field, a gravity sensor for detecting a direction of gravity, and an altimeter for detecting an altitude by measuring atmospheric pressure. At least one sensor may detect the status and generate a corresponding signal to transmit to the controller 110. The sensor of

the sensor module 170 may be added or removed depending on the performance requirements of the phone 100.

[0125] The memory 175 may store signals or data input/output according to operations of the mobile communication module 120, the sub-communication module 130, the multimedia module 140, the camera module 150, the GPS module, the input/output module 160, the sensor module 170, the touch screen display 190 under the control of the controller 110. The memory 175 may store the control programs and applications for controlling the phone 100 or the controller 110.

[0126] The term "storage" can refer to the memory 175, and also to the ROM 112, RAM 113 in the controller 110, or a memory card (for example, a Secure Digital (SD) card, a memory stick, and the like) installed in the phone 100. The storage may also include a non-volatile memory, a volatile memory, a Hard Disc Drive (HDD), a Solid State Drive (SSD), and the like.

[0127] The power supply 180 may supply power from at least one battery placed inside the housing of the phone 100 under the control of the controller 110. The at least one battery can thus power the phone 100. The power supply 180 may supply the phone 100 with the power input from the external power source via a cable connected to the connector 165. The power supply 180 may also supply the phone 100 with wireless power from an external power source using a wireless charging technology.

[0128] The touch screen controller 195 receives information (for example, information to be generated for making calls, data transmission, broadcast, or photography) that is processed by the controller 110, converts the information to data to be displayed on the touch screen display 190, and provides the data to the touch screen display 190. The touch screen display 190 displays the data received from the touch screen controller 195. For example, in a call mode, the touch screen display 190 may display a User Interface (UI) or a Graphic User Interface (GUI) with respect to a call. The touch screen display 190 may include at least one of liquid crystal displays, thin film transistor-liquid crystal displays, organic light-emitting diodes, flexible displays, 3D displays (for instance, for presenting 3D images as described herein), multiview displays, electrophoretic displays, or combinations of the same and the like. The touch screen display 190 moreover can be used to present video

images as described herein, such as including 2D video images, 3D video images, and 2D/3D virtual reality (VR), augmented reality (AR), and mixed reality (MR). In some implementations, the phone 100 further includes a holographic module that processes and outputs holographic video images for presentation, such as on the touch screen display 190 or another display of the phone 100.

[0129] The touch screen display 190 may be used as an output device and also as an input device, and for the latter case, may have a touchscreen panel to operate as a touch screen. The touch screen display 190 may send to the touch screen controller 195 an analog signal that corresponds to at least one touch to the UI or GUI. The touch screen display 190 may detect the at least one touch by a user's physical contact (for example, by fingers including a thumb) or by a touchable input device (for example, the stylus pen). The touch screen display 190 may also receive a dragging movement of a touch among at least one touch and transmit an analog signal that corresponds to the dragging movement to the touch screen controller 195. The touch screen display 190 may be implemented to detect at least one touch in, for example, a resistive method, a capacitive method, an infrared method, an acoustic wave method, and the like.

[0130] The term "touches" is not limited to physical touches by a physical contact of the user or contacts with the touchable input device, but may also include touchless proximity (for example, maintaining a detectable distance less than 1 mm. between the touch screen display 190 and the user's body or touchable input device). The detectable distance from the touch screen display 190 may vary depending on the performance requirements of the phone 100 or structure of the phone 100, and more particularly, the touch screen display 190 may output different values (for example, current values) for touch detection and hovering detection to distinguishably detect that a touch event occurred by a contact with the user's body or the touchable input device and a contactless input (for example, a hovering event). Furthermore, the touch screen display 190 may output different values (for example, current values) for hovering detection over distance from where the hovering event occurs.

[0131] The touch screen controller 195 converts the analog signal received from the touch screen display 190 to a digital signal (for example, in XY coordinates on the touch panel or display screen) and transmits the digital signal to the controller 110. The controller

110 may control the touch screen display 190 by using the digital signal received from the touch screen controller 195. For example, in response to the touch event or the hovering event, the controller 110 may enable a shortcut icon displayed on the touch screen display 190 to be selected or to be executed. The touch screen controller 195 may also be incorporated in the controller 110.

[0132] Further, the touch screen controller 195 may determine the distance between where the hovering event occurs and the touch screen display 190 by detecting a value (for example, a current value) output through the touch screen display 190, convert the determined distance to a digital signal (for example, with a Z coordinate), and provide the digital signal to the controller 110.

[0133] One of more of the components or modules of the phone 100 can be removably coupled to a housing of the phone 100. To help illustrate this coupling, the housing of the phone 100 may be understood to be the phone 10, while the one of more of the components or modules can be removably coupled to the phone 10 via the module connector 20 to add or remove functionality for the phone 10. As one example, a portion or all of the camera module 30 can be removably coupled to the phone 10 to provide the phone 10 with the functionality of part or all the camera module 30.

[0134] While certain electronic devices shown and described herein are cellphones, other handheld electronic device embodiments are not cellphones, and do not include telephonic capability. For instance, some embodiments have the same or similar exterior as the electronic devices described herein, but do not include telephonic capability, such as in the case of a tablet computing device or digital camera. Such embodiments may nonetheless include any combination of the non-telephone components and functionality described herein, such as one or more of the following or portions thereof: controller 110, touch screen display 190 and touch screen controller 195, camera module 150, multi-media module 140, sub-communication module 130, first light 153, second light 154, GPS module 155, I/O module 160, and memory 176.

[0135] Figure 9A illustrates a perspective view of the phone 10 positioned for attachment to an expander module 900 and the camera module 30, and Figure 9B illustrates a perspective view of the phone 10, the expander module 900, and the camera module 30 when

attached. The expander module 900 can include a memory device, a battery, or other component for enhancing the capacity of the phone 10. The expander module 900 can include a housing that supports magnets, which can be similar in structure and function to those of the camera module 30 in Figures 1C and 1D. The magnets can facilitate coupling of the housing to the phone 10 on one side and the camera module 30 on the other side. Additionally or alternatively, coupling can be achieved at least via a friction fit, interlocking structures, fasteners, mechanical snap surface structures, mechanical latch surface structures, mechanical interference fit surface structures, or the like.

[0136] The expander module 900 can also include module connectors (for example, two module connectors with one expander module connector 910 for coupling to a corresponding connector (now shown) on the camera module 30 and another expander module connector (not shown) for coupling to the module connector 20), similar to or the same as the module connector 20, that can interchangeably couple with a module and receive power or data from or transmit power or data to the module or one or more other devices coupled to the module.

[0137] Although Green1 and Green2 may be described as processed separately or differently in some instances herein, Green1 and Green2 may or may not be processed separately or differently. For example, Green1 and Green2 pixels can be separated into separate DCT macroblocks or may not be separated into separate DCT macroblocks. As another example, Green1 and Green2 pixels can be separated into separate scans or may not be separated into separate scans. In yet another example, a slice structure can have separate portions for Green1 and Green2 or may not have separate portions for Green1 and Green2. In a further example, Green1 and Green2 can have separate sizes in a slice header structure or may not have separate sizes in the slice header structure.

[0138] The various image capture devices (or certain components of the devices) may be described herein as being "configured to" perform one or more functions. As used herein this means that the device is capable of being placed in at least one mode (for example, user selectable modes) in which the device performs the specified functions. For example, the device may not necessarily perform the specified functions in all of the operational modes. Along these lines, use of the phrase "configured to" does not imply that

the device has to actually be currently placed in the operational mode to be "configured to" perform the function, but only that the device is capable of being (for example, programmed to be) selectively placed into that mode.

[0139] As used herein, a phrase referring to "at least one of" a list of items refers to any combination of those items, including single members. As an example, "at least one of: a, b, or c" is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

[0140] The various illustrative logics, logical blocks, modules, circuits and algorithm steps described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and steps described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

[0141] The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A processor may be a microprocessor, or, any processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of electronic devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular steps and methods may be performed by circuitry that is specific to a given function.

[0142] In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be

implemented as one or more computer programs, for example, one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

[0143] If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. The steps of a method or algorithm disclosed herein may be implemented in a processor-executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. Storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Combinations of the above also may be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

[0144] Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

[0145] Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed

combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0146] Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise,” “comprising,” and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to.” The word “coupled”, as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Likewise, the word “connected”, as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Additionally, the words “herein,” “above,” “below,” and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the above Detailed Description using the singular or plural number may also include the plural or singular number respectively. The word “or” in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[0147] Moreover, conditional language used herein, such as, among others, "can," "could," "might," "can," “for example,” “for example,” “such as” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements or states. Thus, such conditional language is not generally intended to imply that features, elements or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements or states are included or are to be performed in any particular embodiment.

[0148] The above detailed description of embodiments is not intended to be exhaustive or to be limiting to the precise form disclosed above. While specific embodiments and examples are described above for illustrative purposes, various equivalent modifications are possible within the scope of the inventions described herein, as those skilled in the relevant art will recognize. For example, while processes or blocks are

presented in a given order, alternative embodiments may perform routines having steps, or employ systems having blocks, in a different order, and some processes or blocks may be deleted, moved, added, subdivided, combined, or modified. Each of these processes or blocks may be implemented in a variety of different ways. Also, while processes or blocks are at times shown as being performed in series, these processes or blocks may instead be performed in parallel, or may be performed at different times.

[0149] The teachings provided herein can be applied to other systems, not only the systems described above. The elements and acts of the various embodiments described above can be combined to provide further embodiments.

[0150] While certain embodiments of the inventions have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure.

WHAT IS CLAIMED:

1. An electronic device comprising:

a housing;

an image sensor configured to generate image data from light incident on the image sensor;

a memory device; and

one or more processors configured to:

transform the image data to obtain transform coefficients,

quantize the transform coefficients to obtain quantized transform coefficients including a first quantized transform coefficient and a second quantized transform coefficient different from the first quantized transform coefficient,

encode the quantized transform coefficients to obtain encoded coefficients, the quantized transform coefficients being encoded at least by:

determining a first range of a plurality of ranges in which the first quantized transform coefficient is included,

determining a second range of the plurality of ranges in which the second quantized transform coefficient is included,

determining a first value within the first range to which the first quantized transform coefficient corresponds,

determining a second value within the second range to which the second quantized transform coefficient corresponds,

encoding, using a first algorithm, the first range as a first range code and the second range as a second range code, and

encoding, using a second algorithm different from the first algorithm, the first value as a first value code and the second value as a second value code, and

store the encoded coefficients to the memory device, the encoded coefficients comprising the first range code, the second range code, the first value code, and the second value code.

2. The electronic device of claim 1, wherein the first algorithm is a Huffman code, and the second algorithm is a Golomb code.

3. The electronic device of claim 1, wherein the one or more processors is configured to vary the first algorithm during processing of the image data.

4. The electronic device of claim 3, wherein the one or more processors is configured to vary the first algorithm from processing a first frame of the image data to processing a second frame of the image data.

5. The electronic device of claim 3, wherein the second algorithm remains constant during processing of the image data by the one or more processors.

6. The electronic device of claim 1, wherein the quantized transform coefficients include a third quantized transform coefficient different from the first quantized transform coefficient and the second quantized transform coefficient, and the one or more processors is configured to encode the quantized transform coefficients by at least:

determining a third range of a plurality of ranges in which the third quantized transform coefficient is included,

not determining a third value within the third range to which the third quantized transform coefficient corresponds, and

encoding, using the first algorithm, the third range as a third range code, the encoded coefficients comprising the third range code.

7. The electronic device of claim 1, wherein the one or more processors is configured to transform the image data using a discrete cosine transform.

8. The electronic device of claim 7, wherein the discrete cosine transform is a 16x16 discrete cosine transform.

9. The electronic device of claim 1, wherein the one or more processors is configured to encode the quantized transform coefficients at least by encoding DC coefficients of the quantized transform coefficients differently from AC coefficients of the quantized transform coefficients.

10. The electronic device of claim 1, wherein the one or more processors is configured to store a parameter for the first algorithm in a frame header for the encoded coefficients.

11. The electronic device of claim 1, wherein the one or more processors is configured to quantize the transform coefficients by at least using a first quantization table for green pixels of the image data and a second quantization table for red pixels and blue pixels of the image data, the first quantization table being different from the second quantization table.

12. The electronic device of claim 1, wherein the image data is raw moasiced image data.

13. The electronic device of claim 1, wherein the housing is configured to enclose the image sensor, the memory device, and the one or more processors, and the housing is configured to removably attach to a mobile phone.

14. The electronic device of claim 1, further comprising a display configured to present holographic images generated by the one or more processors from the image data.

15. A method of coding image data using an electronic device, the method comprising:

generating, by an image sensor, image data from light incident on an image sensor;

transforming, by one or more processors, the image data to obtain transform coefficients;

quantizing, by the one or more processors, the transform coefficients to obtain quantized transform coefficients including a first quantized transform coefficient and a second quantized transform coefficient different from the first quantized transform coefficient;

determining, by the one or more processors, a first range of a plurality of ranges that includes the first quantized transform coefficient and a second range of the plurality of ranges that includes the second quantized transform coefficient;

determining, by the one or more processors, a first value within the first range that corresponds to the first quantized transform coefficient and a second value within the second range that corresponds to the second quantized transform coefficient;

encoding, by the one or more processors, the first range as a first range code and the second range as a second range code;

encoding, by the one or more processors, the first value as a first value code and the second value as a second value code; and

storing the first range code, the second range code, the first value code, and the second value code to the memory device.

16. The method of claim 15, wherein said encoding the first and second ranges and said encoding the first and second values are performed using lossless compression.

17. The method of claim 15, wherein said encoding the first and second ranges and said encoding the first and second values are performed using variable length coding.

18. The method of claim 15, further comprising:

retrieving the first range code, the second range code, the first value code, and the second value code from the memory device; and

decoding, by the one or more processors, the first range code, the second range code, the first value code, and the second value code to obtain the first range, the second range, the first value, and the second value.

19. The method of claim 18, further comprising using the decoded first range, second range, first value, and second value to generate holographic content for display on a display of the electronic device.

20. The method of claim 15, wherein the first range and the second range are encoded as the first range code and the second range code using a Huffman code, and the first value and the second value are encoded as the first value code and the second value code using a Golomb code.

21. The method of claim 15, wherein said transforming the image data is performed using a 16x16 discrete cosine transform.

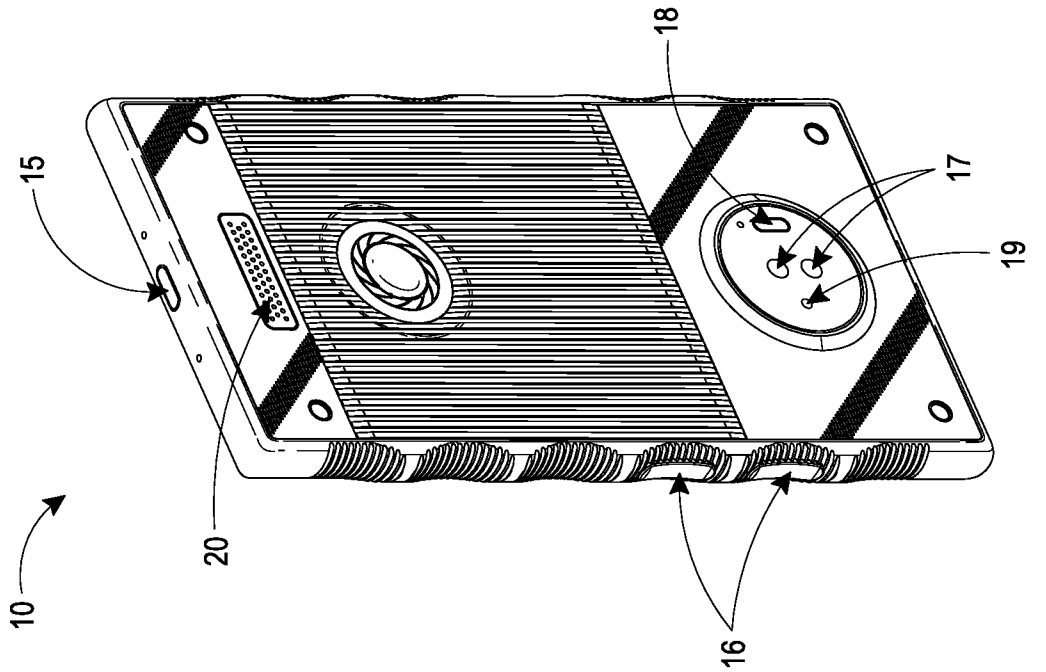


FIG. 1B

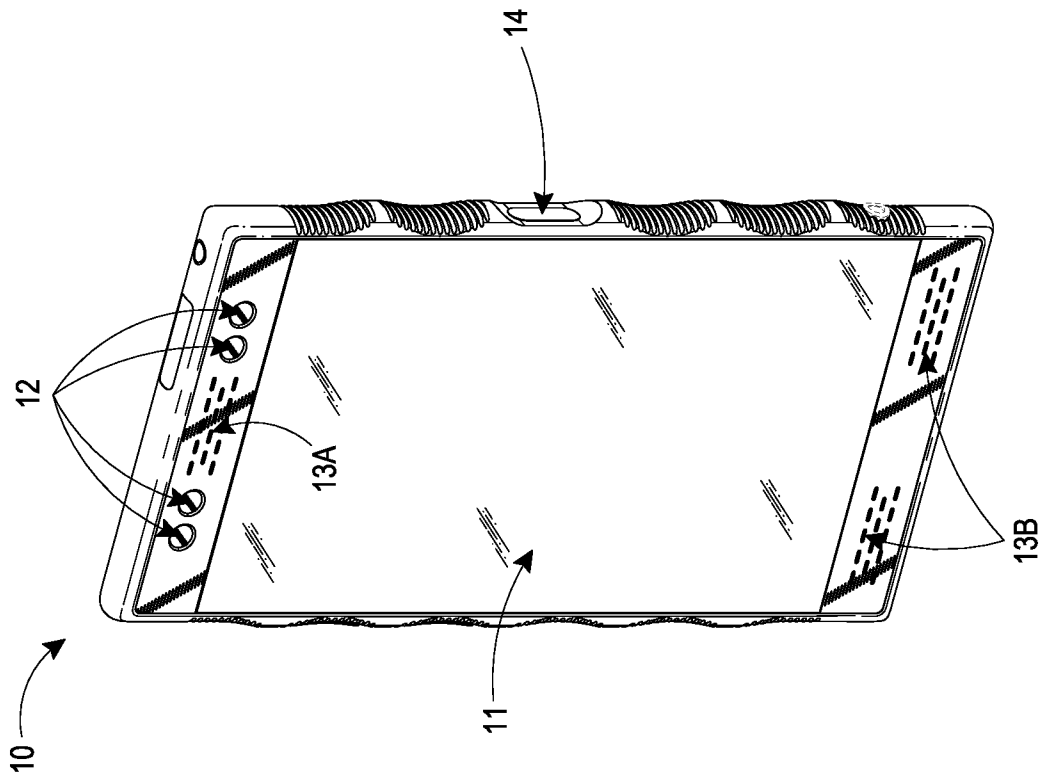


FIG. 1A

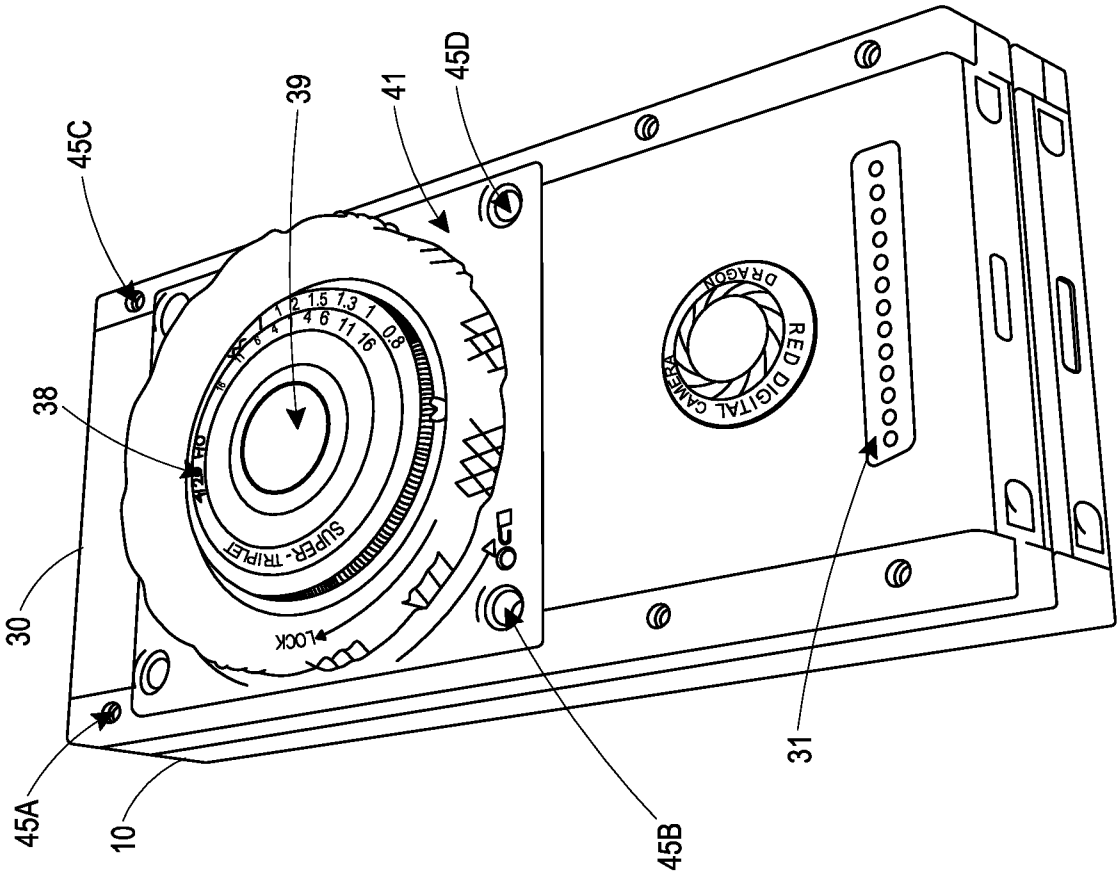

45C
39
41
45D
38
30
45A
10
45B
31
SUPER-TRIPLET
LOCK
RED DIGITAL CAMERA
DRAGON

FIG. 1D

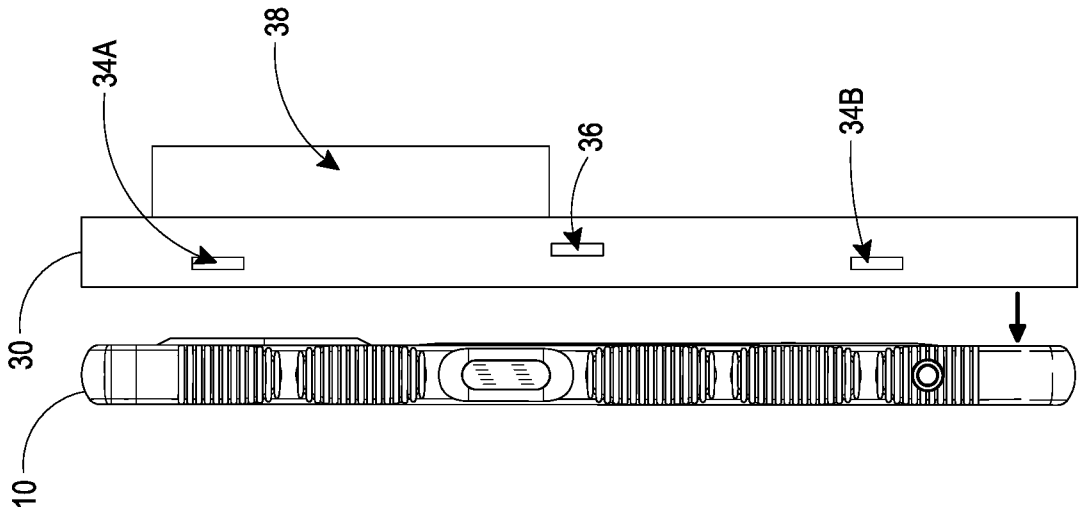

38
34A
36
34B
30
10

FIG. 1C

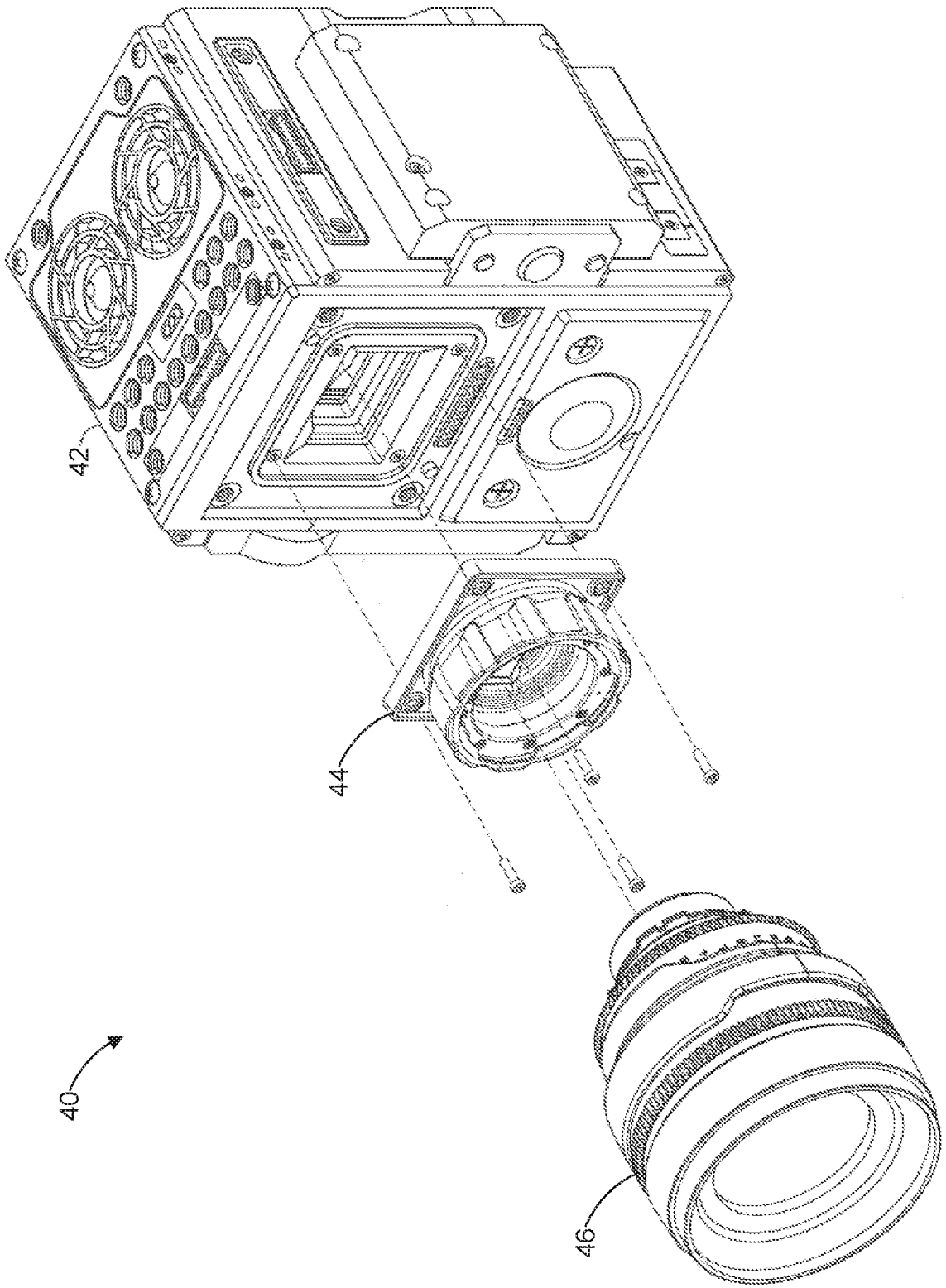


FIG. 2

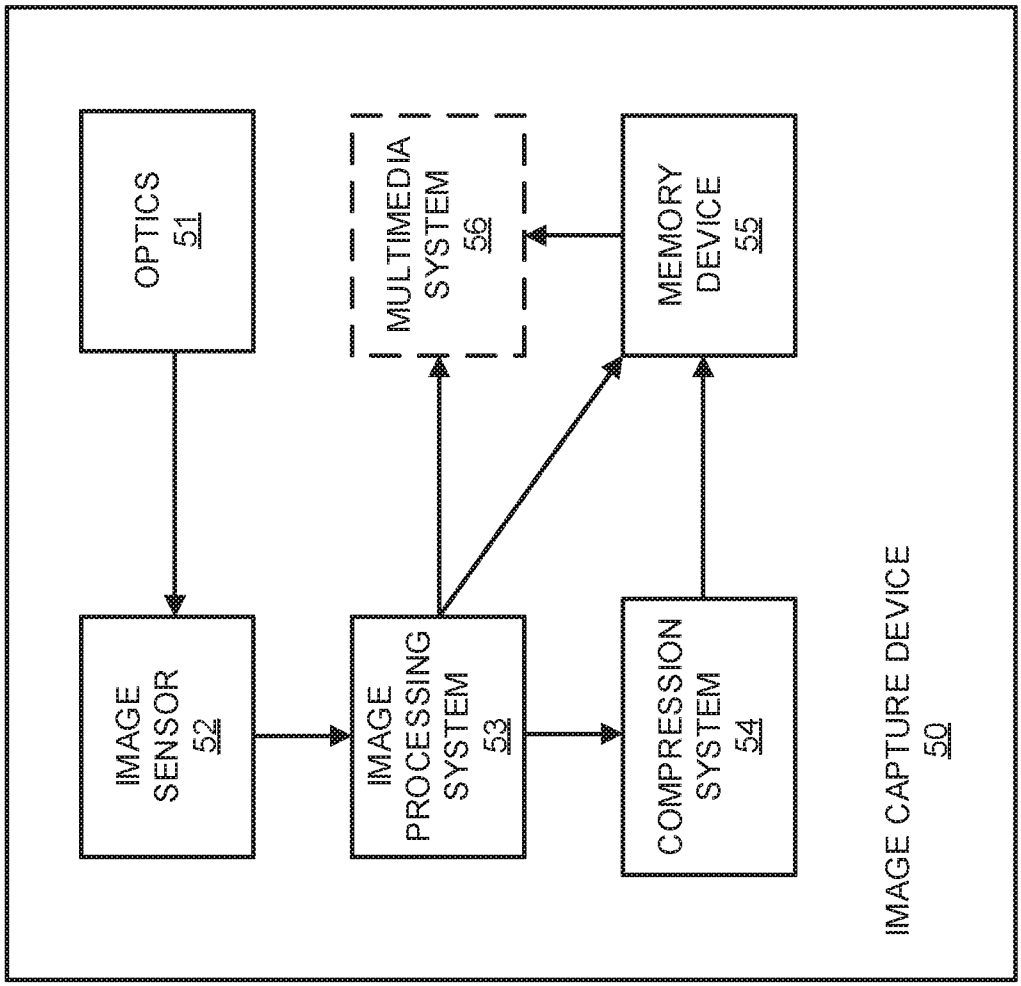

OPTICS
51
MULTIMEDIA
SYSTEM
56
MEMORY
DEVICE
55
IMAGE
SENSOR
52
IMAGE
PROCESSING
SYSTEM
53
COMPRESSION
SYSTEM
54
IMAGE CAPTURE DEVICE
50

FIG. 3A

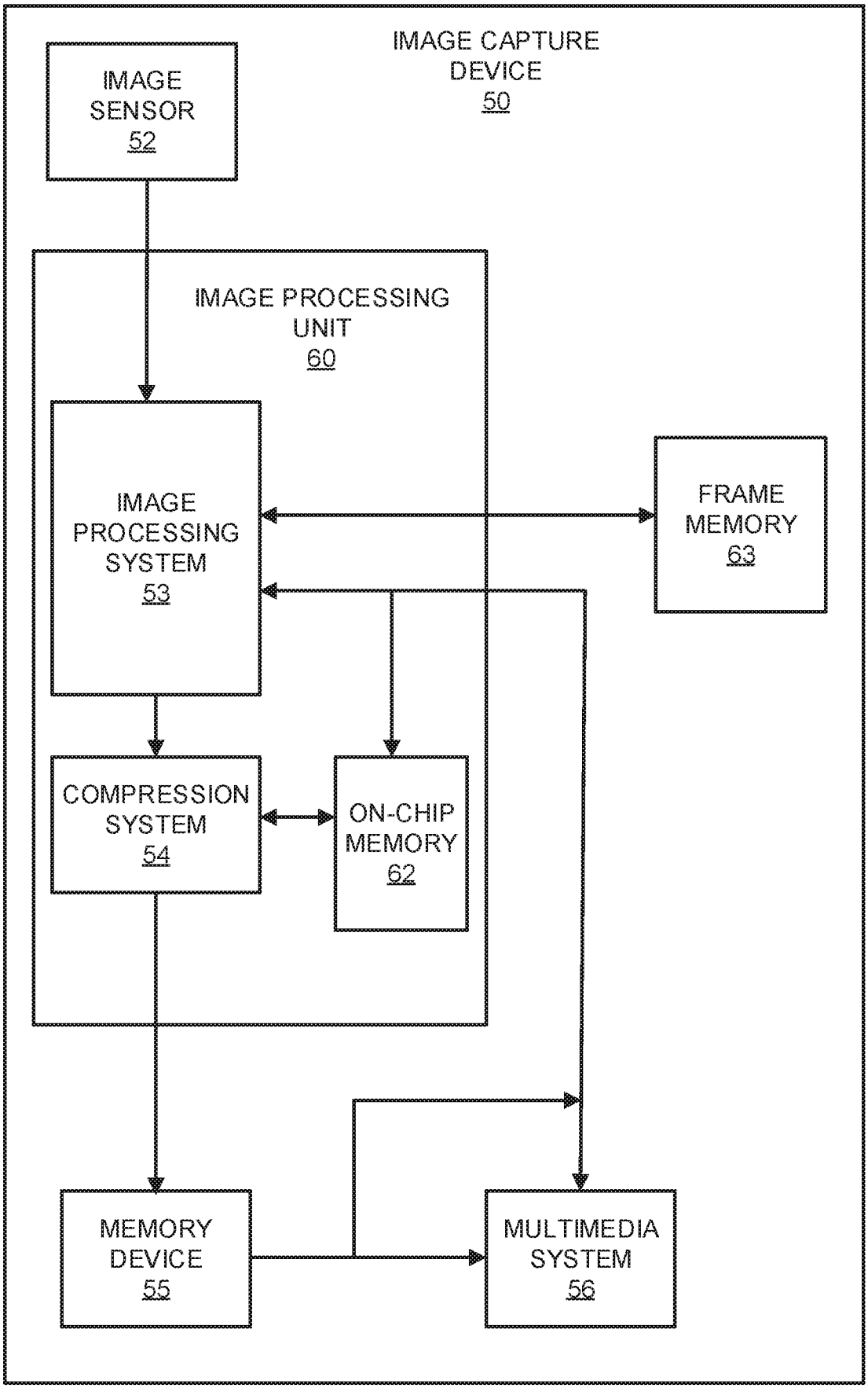

IMAGE CAPTURE DEVICE
50
IMAGE SENSOR
52
IMAGE PROCESSING UNIT
60
IMAGE PROCESSING SYSTEM
53
FRAME MEMORY
63
COMPRESSION SYSTEM
54
ON-CHIP MEMORY
62
MEMORY DEVICE
55
MULTIMEDIA SYSTEM
56

FIG. 3B

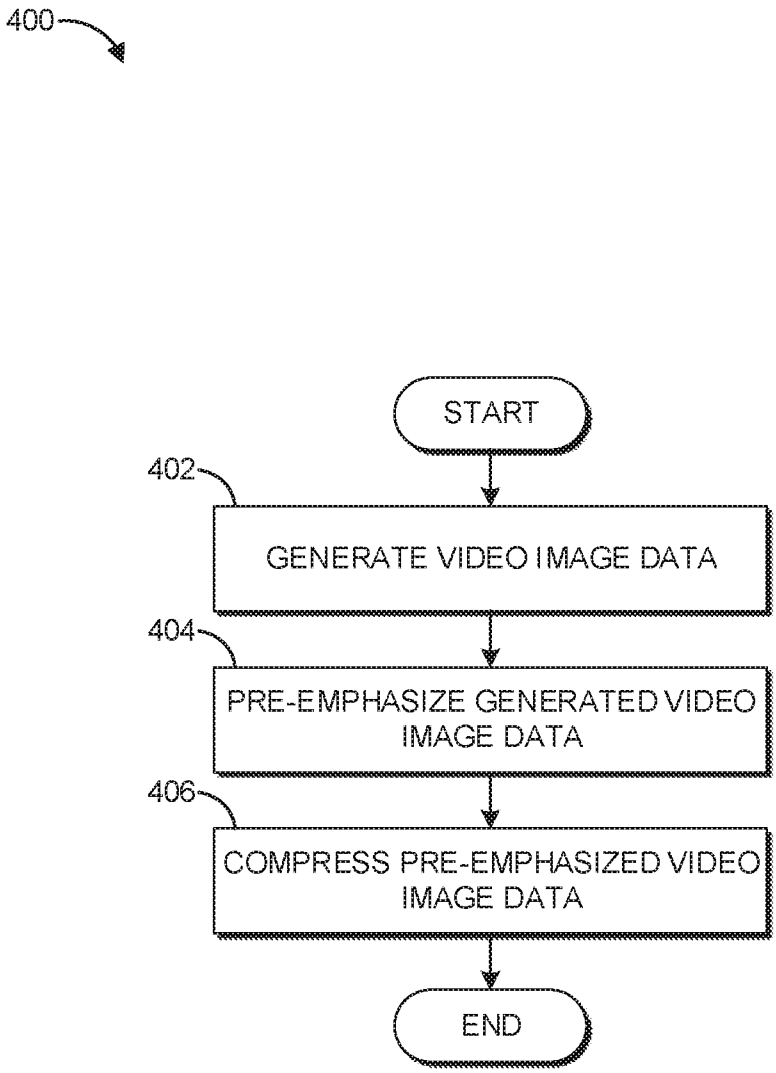

400
START
402
GENERATE VIDEO IMAGE DATA
404
PRE-EMPHASIZE GENERATED VIDEO IMAGE DATA
406
COMPRESS PRE-EMPHASIZED VIDEO IMAGE DATA
END

FIG. 4

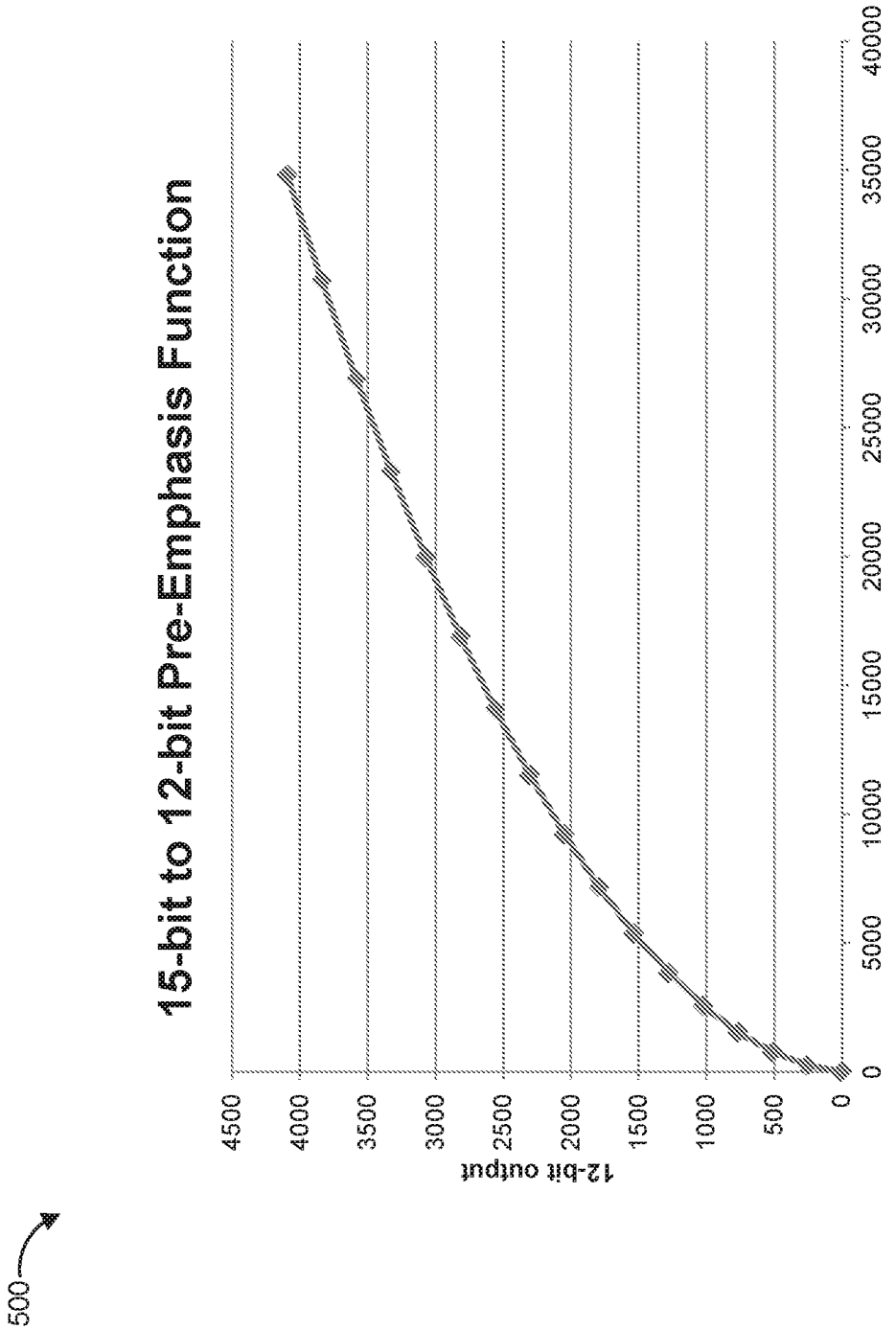

500
15-bit to 12-bit Pre-Emphasis Function
12-bit output
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000
25000
30000
35000
40000
15-bit input

FIG. 5

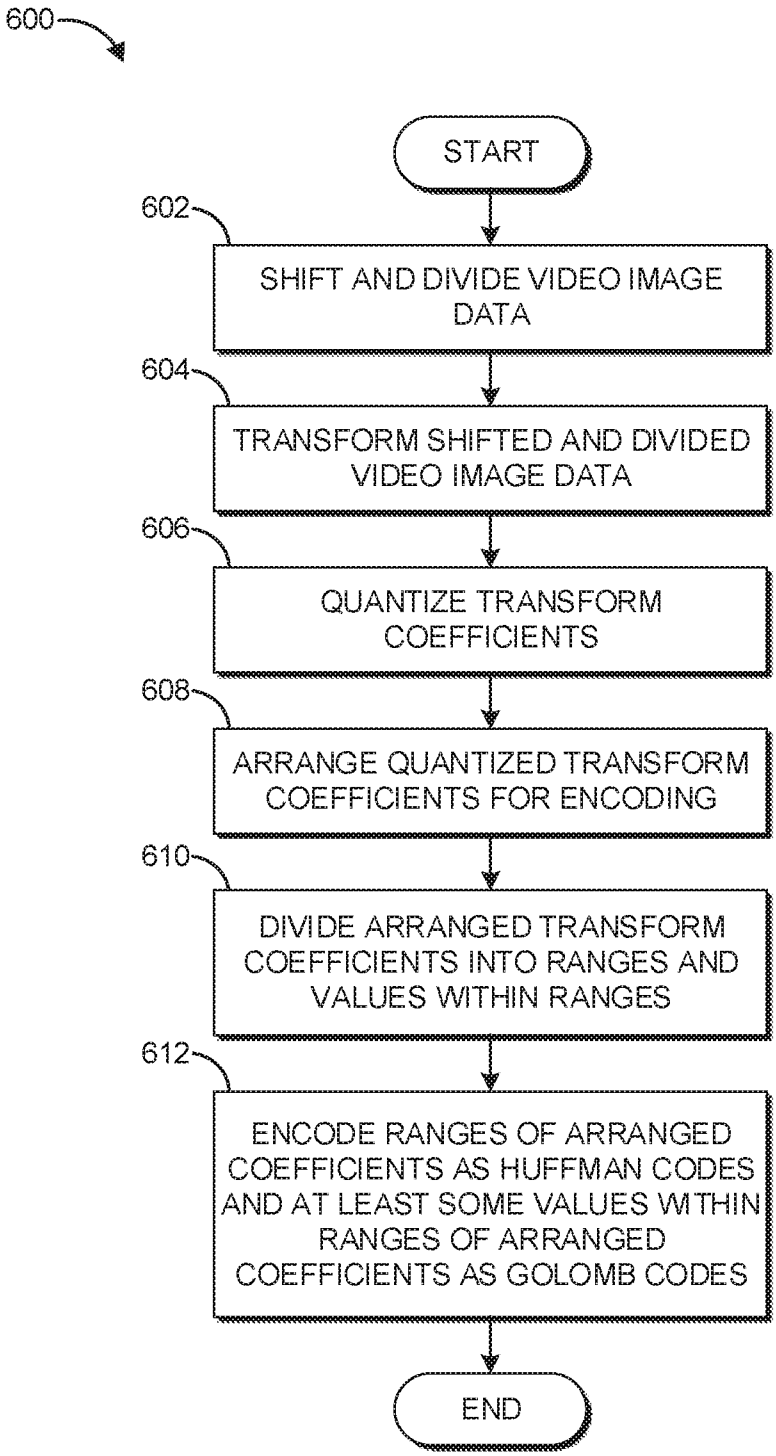

600
START
602
SHIFT AND DIVIDE VIDEO IMAGE DATA
604
TRANSFORM SHIFTED AND DIVIDED VIDEO IMAGE DATA
606
QUANTIZE TRANSFORM COEFFICIENTS
608
ARRANGE QUANTIZED TRANSFORM COEFFICIENTS FOR ENCODING
610
DIVIDE ARRANGED TRANSFORM COEFFICIENTS INTO RANGES AND VALUES WITHIN RANGES
612
ENCODE RANGES OF ARRANGED COEFFICIENTS AS HUFFMAN CODES AND AT LEAST SOME VALUES WITHIN RANGES OF ARRANGED COEFFICIENTS AS GOLOMB CODES
END

FIG. 6

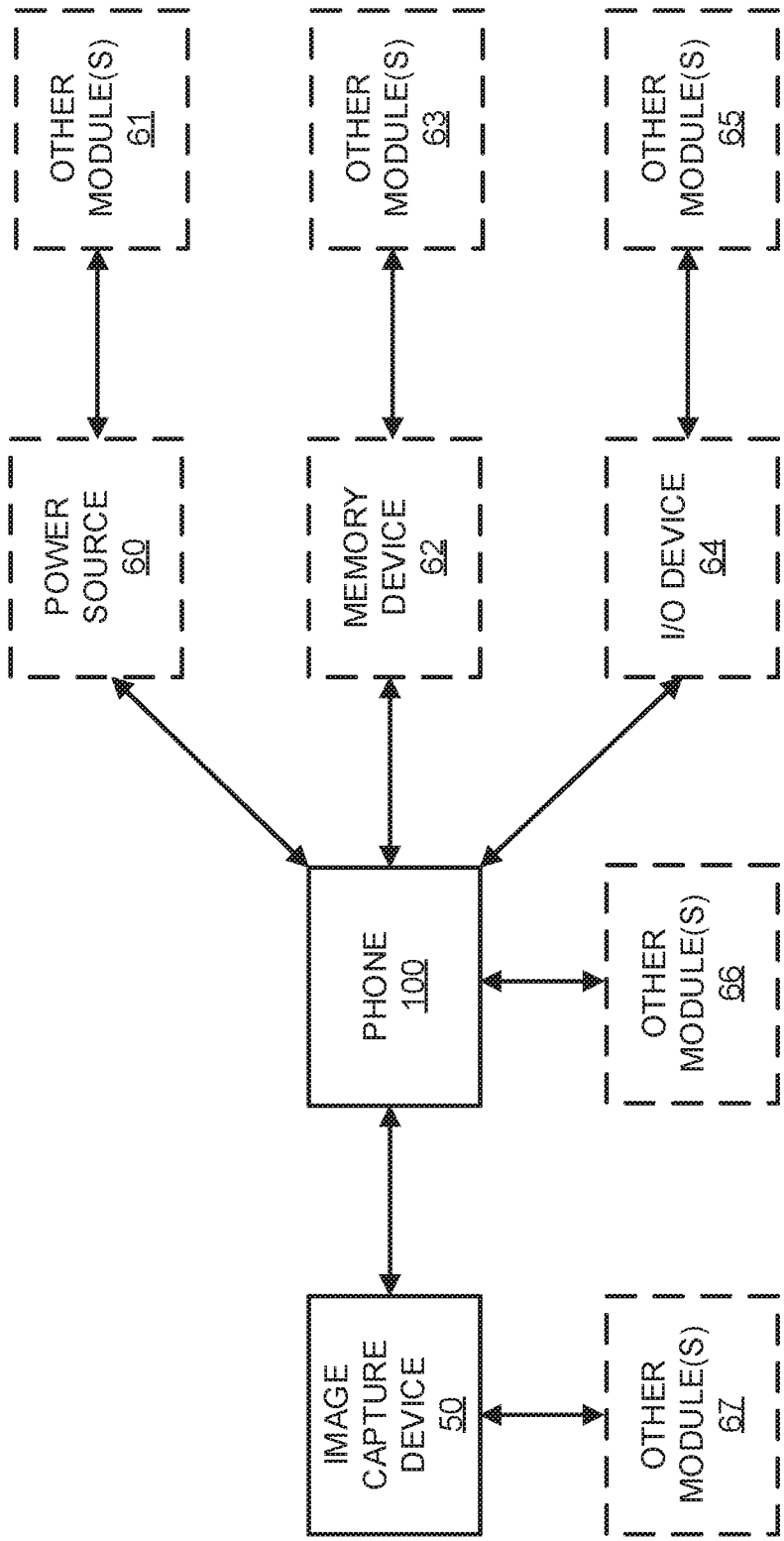

OTHER MODULE(S) 61
OTHER MODULE(S) 63
OTHER MODULE(S) 65
POWER SOURCE 60
MEMORY DEVICE 62
I/O DEVICE 64
PHONE 100
OTHER MODULE(S) 66
IMAGE CAPTURE DEVICE 50
OTHER MODULE(S) 67

FIG. 7

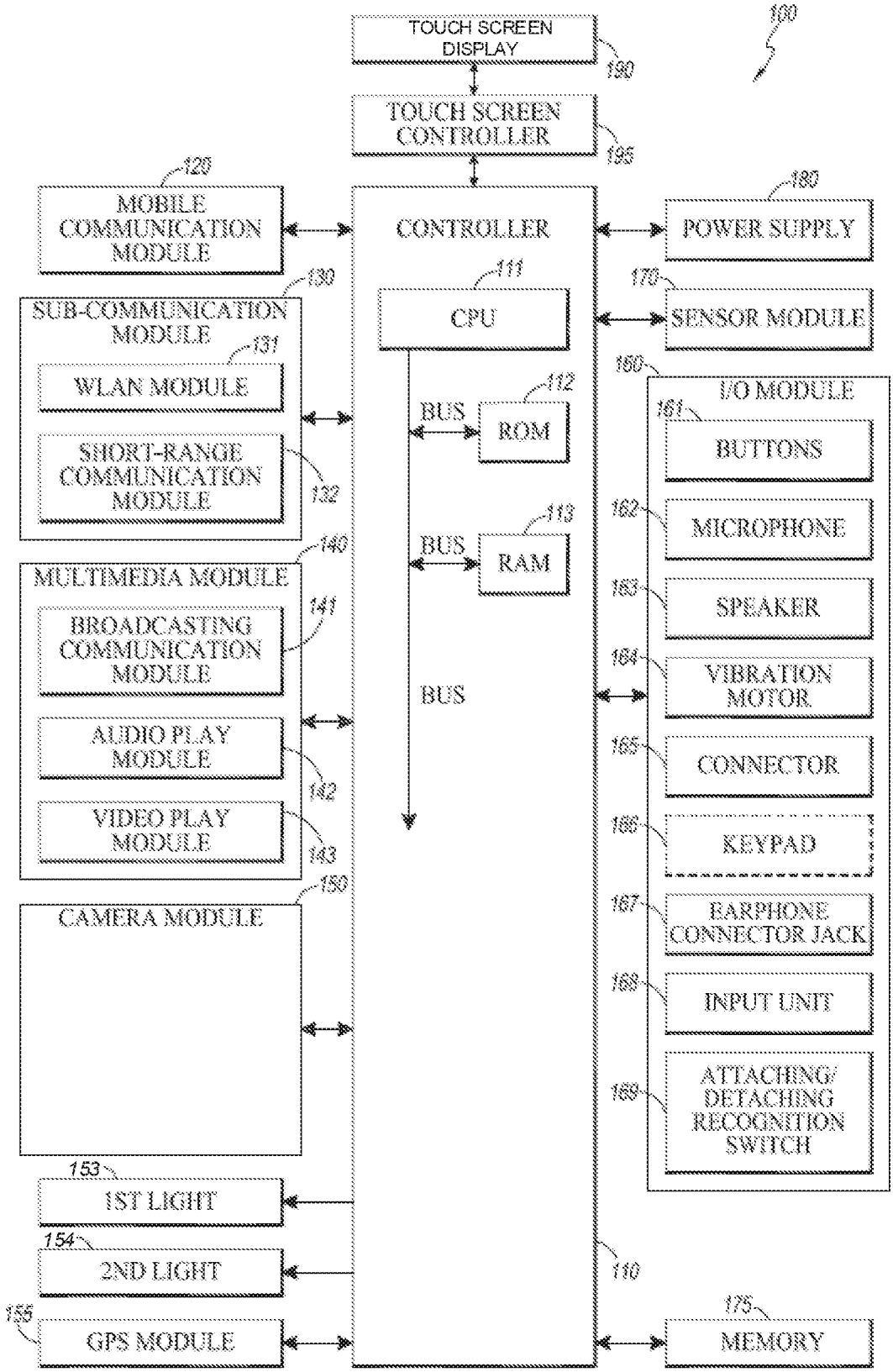

100
TOUCH SCREEN DISPLAY
190
TOUCH SCREEN CONTROLLER
195
120
MOBILE COMMUNICATION MODULE
CONTROLLER
180
POWER SUPPLY
130
SUB-COMMUNICATION MODULE
131
WLAN MODULE
SHORT-RANGE COMMUNICATION MODULE
132
111
CPU
170
SENSOR MODULE
160
I/O MODULE
112
BUS
ROM
161
BUTTONS
113
BUS
RAM
162
MICROPHONE
163
SPEAKER
140
MULTIMEDIA MODULE
141
BROADCASTING COMMUNICATION MODULE
AUDIO PLAY MODULE
142
VIDEO PLAY MODULE
143
BUS
164
VIBRATION MOTOR
165
CONNECTOR
166
KEYPAD
167
EARPHONE CONNECTOR JACK
168
INPUT UNIT
169
ATTACHING/ DETACHING RECOGNITION SWITCH
150
CAMERA MODULE
153
1ST LIGHT
154
2ND LIGHT
155
GPS MODULE
110
175
MEMORY

FIG. 8

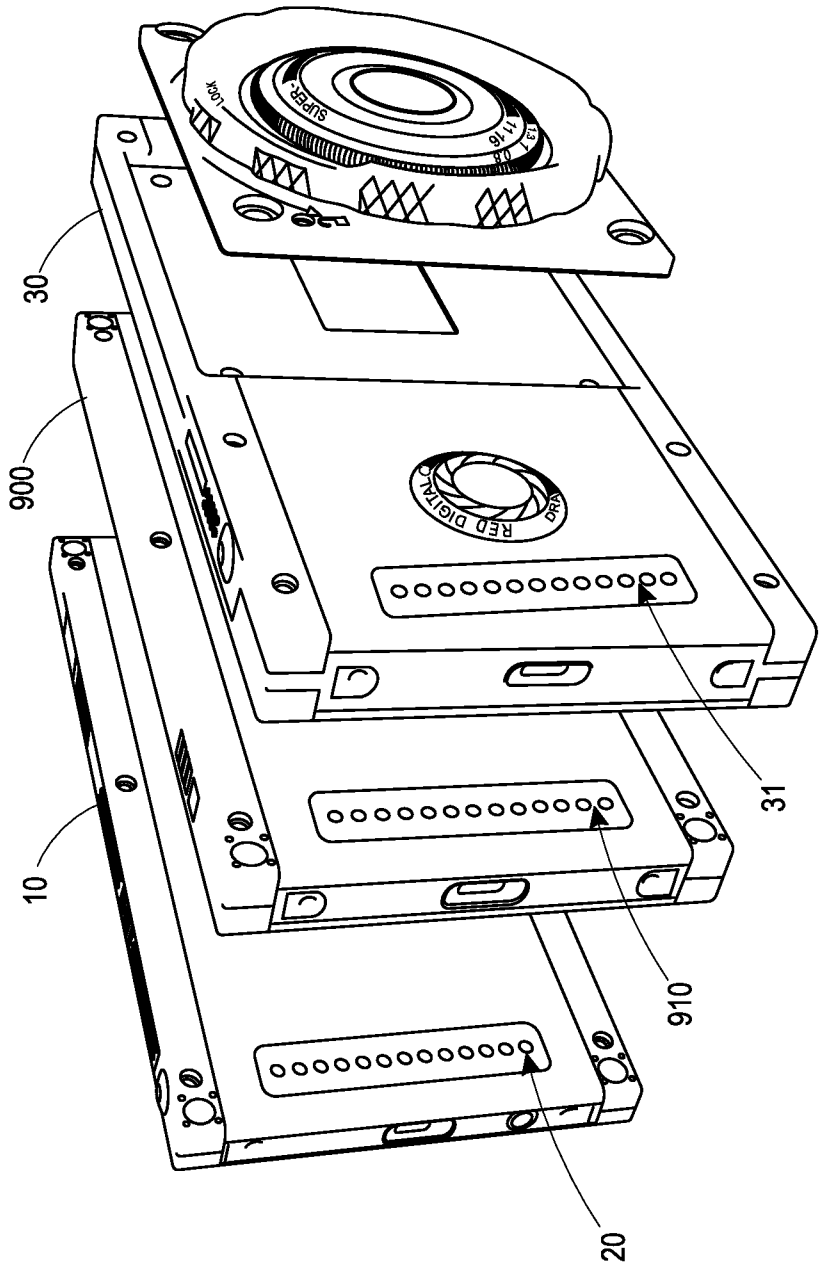


FIG. 9A

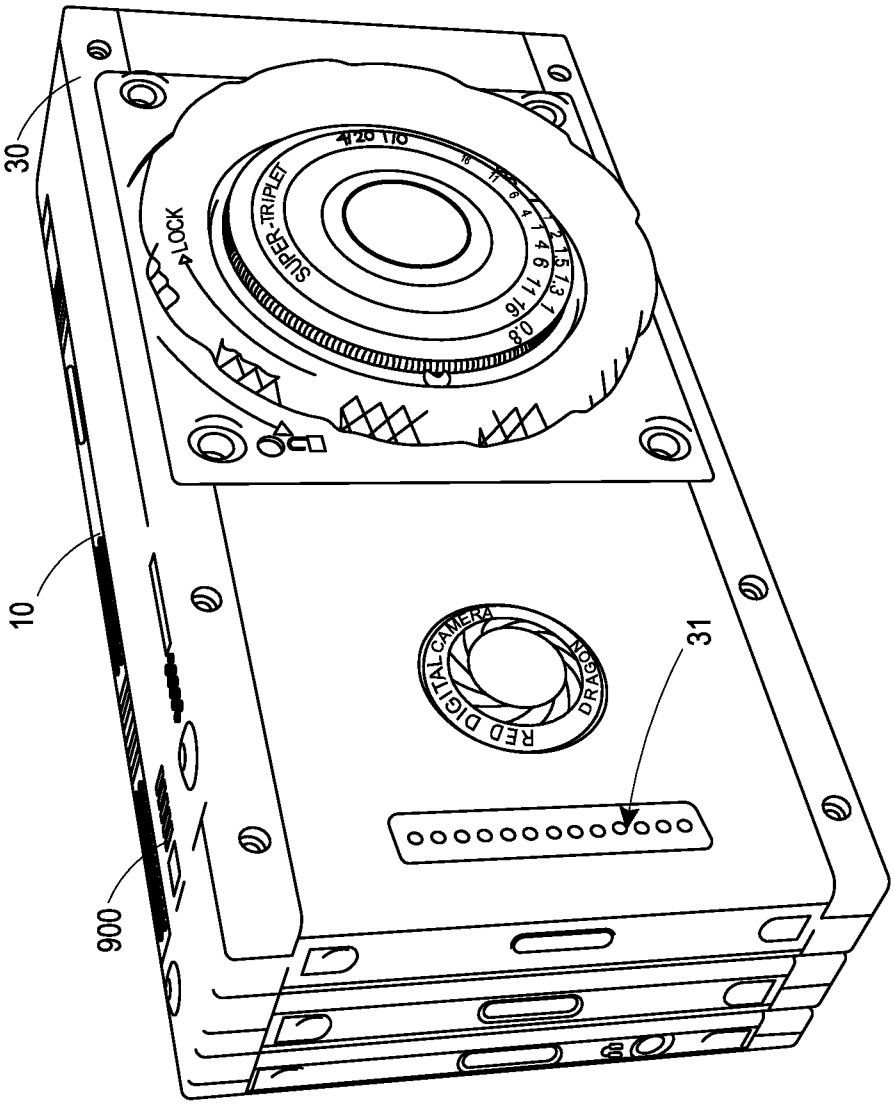


FIG. 9B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/040804

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N19/18 H04N19/13 H04N19/91 H04N19/93
ADD.

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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 512 137 A2 (IMAGINATION TECH LTD [GB]) 17 October 2012 (2012-10-17)	1,5,6, 10, 12-15, 17-19
Y	abstract figure 2 and 4 figures 7-9 paragraph [0002] paragraph [0009] paragraph [0056] paragraph [0065] - paragraph [0070] paragraph [0073] - paragraph [0076]	2-4,7-9, 11,16, 20,21

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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
17 September 2018	24/09/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Wedi, Thomas

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/040804

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Khalid Sayood: "Introduction to Data Compression (Third Edition)", 2006, Elsevier, XP040425808, ISBN: 978-0-12-620862-7 sections 3.2, 3.4, and 3.5 sections 3.8.1 and 1.1.1 sections 13.4.2 and 13.6.1 section 13.6.2 sections 13.6 and 18 -----	2-4,7-9, 11,16, 20,21

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/040804

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2512137 A2	17-10-2012	EP 2183920 A2	12-05-2010
		EP 2512137 A2	17-10-2012
		GB 2451911 A	18-02-2009
		JP 5232863 B2	10-07-2013
		JP 2010537534 A	02-12-2010
		US 2009046937 A1	19-02-2009
		WO 2009024744 A2	26-02-2009