# VIDEO CAMERA

## BACKGROUND

Field of the Inventions

[0001] The present inventions are directed to digital cameras, such as those for capturing still or moving pictures, and more particularly, to digital cameras that compress image data.

Description of the Related Art

[0002] Despite the availability of digital video cameras, the producers of major motion pictures and some television broadcast media continue to rely film cameras. The film used for such provides video editors with very high resolution images that can be edited by conventional means. More recently, however, such film is often scanned, digitized and digitally edited.

## SUMMARY OF THE INVENTIONS

[0003] Although some currently available digital video cameras include high resolution image sensors, and thus output high resolution video, the image processing and compression techniques used on board such cameras are too lossy and thus eliminate too much raw image data to be acceptable in the high end portions of the market noted above. Embodiments disclosed herein include the realization that video quality that is acceptable for the higher end portions of the markets noted above, such as the major motion picture market, can be satisfied by cameras that can capture and store raw or substantially raw video data having a resolution of at least about 2k and at a frame rate of at least about 23 frames per second.

[0004] According to a first aspect, there is provided a video camera comprising: a portable housing; a lens assembly supported by the housing and configured to focus light; a light sensitive device configured to convert the focused light into raw mosaiced image data with a resolution of at least 2 k at a frame rate of at least about twenty-three frames per second; a memory device; and an image processing system configured to compress and store in the memory device the raw mosaiced image data at a compression ratio of at least six to one and remain substantially visually lossless, and at a rate of at least about 23 frames per second.

**[0005]** According to a second aspect, there is provided a method of recording a motion video with a camera, the method comprising: guiding light onto a light sensitive device of a camera; converting the light received by the light sensitive device into raw digital mosaiced image data having a horizontal resolution of at least 2 k at a rate of at least greater than twenty three frames per second; compressing the raw digital mosaiced image data into compressed digital image data such that the data remains substantially visually lossless upon decompression; and recording the compressed digital mosaiced image data at a rate of at least about 23 frames per second onto a storage device of the camera.

**[0006]** According to a third aspect, there is provided a video camera comprising: a lens assembly supported by a housing and configured to focus light; a light sensitive device configured to convert the focused light into a signal of raw mosaiced image data representing the focused light and having a resolution of at least 2 k; a memory device; and means for compressing and recording the raw mosaiced image data in the memory device at a frame rate of at least about 23 frames per second such that the mosaiced image data remains substantially visually lossless upon decompression.

**[0007]** According to a fourth aspect, there is provided a video camera comprising: a portable housing having at least one handle configured to allow a user to manipulate the orientation with respect to at least one degree of movement of the housing during a video recording operation of the camera; a lens assembly comprising at least one lens supported by the housing and configured to focus light at a plane disposed inside the housing; a light sensitive device configured to convert the focused light into raw mosaiced image data with a horizontal resolution of at least 2 k and at a frame rate of at least about twenty three frames per second; a memory device configured to store video image data; an image processing system configured to compress and store in the memory device the raw mosaiced image data at a compression ratio of at least six to one and remain substantially visually lossless, and at a rate of at least about 23 frames per second.

**[0008]** Embodiments disclosed herein include the realization that because the human eye is more sensitive to green wavelengths than any other color, green image data based modification of image data output from an image sensor can be used to enhance compressibility of the data, yet provide a higher quality video image. One such technique can include subtracting the magnitude of green light detected from the magnitudes of red and/or blue light detected prior to compressing the data. This can convert

the red and/or blue image data into a more compressible form. For example, in the known processes for converting gamma corrected RGB data to Y'CbCr, the image is "decorrelated", leaving most of the image data in the Y' (a.k.a. "luma"), and as such, the remaining chroma components are more compressible. However, the known techniques for converting to the Y'CbCr format cannot be applied directly to Bayer pattern data because the individual color data is not spatially correlated and Bayer pattern data includes twice as much green image data as blue or red image data. The processes of green image data subtraction, in accordance with some of the embodiments disclosed herein, can be similar to the Y'CbCr conversion noted above in that most of the image data is left in the green image data, leaving the remaining data in a more compressible form.

**[0009]** Further, the process of green image data subtraction can be reversed, preserving all the original raw data. Thus, the resulting system and method incorporating such a technique can provide lossless or visually lossless and enhanced compressibility of such video image data.

**[0010]** Thus, in accordance with an embodiment, a video camera can comprise a lens assembly supported by the housing and configured to focus light and a light sensitive device configured to convert the focused light into a raw signal of image data representing at least first, second, and third colors of the focused light. An image processing module can be configured to modify image data of at least one of the first and second colors based on the image data of the third color. Additionally, the video camera can include a memory device and a compression device configured to compress the image data of the first, second, and third colors and to store the compressed image data on the memory device.

**[0011]** In accordance with another embodiment, a method of processing an image can be provided. The method can include converting an image and into first image data representing a first color, second image data representing a second color, and third image data representing a third color, modifying at least the first image data and the second image data based on the third image data, compressing the third image data and the modified first and second image data, and storing the compressed data.

**[0012]** In accordance with yet another embodiment, a video camera can comprise a lens assembly supported by the housing and configured to focus light. A light sensitive

device can be configured to convert the focused light into a raw signal of image data representing at least first, second, and third colors of the focused light. The camera can also include means for modifying image data of at least one of the first and second colors based on the image data of the third color, a memory device, and a compression device configured to compress the image data of the first, second, and third colors and to store the compressed image data on the memory device.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]** Figure 1 is a block diagram illustrating a system that can include hardware and/or can be configured to perform methods for processing video image data in accordance with an embodiment.

**[0014]** Figure 2 is an optional embodiment of a housing for the camera schematically illustrated in Figure 1.

**[0015]** Figure 3 is a schematic layout of an image sensor having a Bayer Pattern Filter that can be used with the system illustrated in Figure 1.

**[0016]** Figure 4 is a schematic block diagram of an image processing module that can be used in the system illustrated in Figure 1.

**[0017]** Figure 5 is a schematic layout of the green image data from the green sensor cells of the image sensor of Figure 3.

**[0018]** Figure 6 is a schematic layout of the remaining green image data of Figure 5 after an optional process of deleting some of the original green image data.

**[0019]** Figure 7 is a schematic layout of the red, blue, and green image data of Figure 5 organized for processing in the image processing module of Figure 1.

**[0020]** Figure 8 is a flowchart illustrating an image data transformation technique that can be used with the system illustrated in Figure 1.

**[0021]** Figure 8A is a flowchart illustrating a modification of the image data transformation technique of Figure 8 that can also be used with the system illustrated in Figure 1.

**[0022]** Figure 9 is a schematic layout of blue image data resulting from an image transformation process of Figure 8.

[0023] Figure 10 is a schematic layout of red image data resulting from an image transformation process of Figure 8.

[0024] Figure 11 illustrates an exemplary optional transform that can be applied to the image data for gamma correction.

[0025] Figure 12 is a flowchart of a control routine that can be used with the system of Figure 1 to decompress and demosaic image data.

[0026] Figure 12A is a flowchart illustrating a modification of the control routine of Figure 12 that can also be used with the system illustrated in Figure 1.

[0027] Figure 13 is a schematic layout of green image data having been decompressed and demosaiced according to the flowchart of Figure 12.

[0028] Figure 14 is a schematic layout of half of the original green image data from Figure 13, having been decompressed and demosaiced according to the flowchart of Figure 12.

[0029] Figure 15 is a schematic layout of blue image data having been decompressed according to the flowchart of Figure 12.

[0030] Figure 16 is a schematic layout of blue image data of Figure 15 having been demosaiced according to the flowchart of Figure 12.

## DETAILED DESCRIPTION OF EMBODIMENTS

[0031] Figure 1 is a schematic diagram of a camera having image sensing, processing, and compression modules, described in the context of a video camera for moving pictures. The embodiments disclosed herein are described in the context of a video camera having a single sensor device with a Bayer pattern filter because these embodiments have particular utility in this context. However, the embodiments and inventions herein can also be applied to cameras having other types of image sensors (e.g., CMY Bayer as well as other non-Bayer patterns), other numbers of image sensors, operating on different image format types, and being configured for still and/or moving pictures. Thus, it is to be understood that the embodiments disclosed herein are exemplary but nonlimiting embodiments, and thus, the inventions disclosed herein are not limited to the disclosed exemplary embodiments.

[0032] With continued reference to Figure 1, a camera 10 can include a body or housing 12 configured to support a system 14 configured to detect, process, and optionally

store and/or replay video image data. For example, the system 14 can include optics hardware 16, an image sensor 18, an image processing module 20, a compression module 22, and a storage device 24. Optionally, the camera 10 can also include a monitor module 26, a playback module 28, and a display 30.

**[0033]** Figure 2 illustrates a nonlimiting exemplary embodiment of the camera 10. As shown in Figure 2, the optics hardware 16 can be supported by the housing 12 in a manner that leaves it exposed at its outer surface. In some embodiments, the system 14 is supported within the housing 12. For example, the image sensor 18, image processing module 20, and the compression module 22 can be housed within the housing 12. The storage device 24 can be mounted in the housing 12. Additionally, in some embodiments, the storage device 24 can be mounted to an exterior of the housing 12 and connected to the remaining portions of the system 14 through any type of known connector or cable. Additionally, the storage device 24 can be connected to the housing 12 with a flexible cable, thus allowing the storage device 24 to be moved somewhat independently from the housing 12. For example, with such a flexible cable connection, the storage device 24 can be worn on a belt of a user, allowing the total weight of the housing 12 to be reduced. Further, in some embodiments, the housing can include one or more storage devices 24 inside and mounted to its exterior. Additionally, the housing 12 can also support the monitor module 26, and playback module 28. Additionally, in some embodiments, the display 30 can be configured to be mounted to an exterior of the housing 12.

**[0034]** The optics hardware 16 can be in the form of a lens system having at least one lens configured to focus an incoming image onto the image sensor 18. The optics hardware 16, optionally, can be in the form of a multi-lens system providing variable zoom, aperture, and focus. Additionally, the optics hardware 16 can be in the form of a lens socket supported by the housing 12 and configured to receive a plurality of different types of lens systems for example, but without limitation, the optics hardware 16 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, and/or any other lens. As noted above, the optics hardware 16 can be

configured such that despite which lens is attached thereto, images can be focused upon a light-sensitive surface of the image sensor 18.

**[0035]** The image sensor 18 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. In some embodiments, the image sensor 18 can include a CMOS device having about 12 million photocells. However, other size sensors can also be used. In some configurations, 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" horizontal resolution 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 sensor 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 18 can be configured to provide variable resolution by selectively outputting only a predetermined portion of the sensor 18. For example, the sensor 18 and/or the image processing module can be configured to allow a user to identify the resolution of the image data output.

**[0036]** The camera 10 can also be configured to downsample and subsequently process the output of the sensor 18 to yield video output at 2K, 1080p, 720p, or any other resolution. For example, the image data from the sensor 18 can be "windowed", thereby reducing the size of the output image and allowing for higher readout speeds. However, other size sensors can also be used. Additionally, the camera 10 can be configured to upsample the output of the sensor 18 to yield video output at higher resolutions.

**[0037]** With reference to Figure 1 and 3, in some embodiments, the sensor 18 can include a Bayer pattern filter. As such, the sensor 18, by way of its chipset (not shown) outputs data representing magnitudes of red, green, or blue light detected by individual photocells of the image sensor 18. Figure 3 schematically illustrates the Bayer pattern output of the sensor 18. In some embodiments, for example, as shown in Figure 3, the Bayer pattern filter has twice as many green elements as the number of red elements and the number of blue

elements. The chipset of the image sensor 18 can be used to read the charge on each element of the image sensor and thus output a stream of values in the well-known RGB format output.

**[0038]** With continued reference to Figure 4, the image processing module 20 optionally can be configured to format the data stream from the image sensor 18 in any known manner. In some embodiments, the image processing module 20 can be configured to separate the green, red, and blue image data into three or four separate data compilations. For example, the image processing module 20 can be configured to separate the red data into one data element, the blue data into one blue data element, and the green data into one green data element. For example, with reference to Figure 4, the image processing module 20 can include a red data processing module 32, a blue data image processing module 34, and a first green image data processing module 36.

**[0039]** As noted above, however, the Bayer pattern data illustrated in Figure 3, has twice as many green pixels as the other two colors. Figure 5 illustrates a data component with the blue and red data removed, leaving only the original green image data.

**[0040]** In some embodiments, the camera 10 can be configured to delete or omit some of the green image data. For example, in some embodiments, the image processing module 20 can be configured to delete 1/2 of the green image data so that the total amount of green image data is the same as the amounts of blue and red image data. For example, Figure 6 illustrates the remaining data after the image processing module 20 deletes ½ of the green image data. In the illustrated embodiment of Figure 6, the rows n-3, n-1, n+1, and n+3 have been deleted. This is merely one example of the pattern of green image data that can be deleted. Other patterns and other amounts of green image data can also be deleted.

**[0041]** In some alternatives, the camera 10 can be configured to delete ½ of the green image data after the red and blue image data has been transformed based on the green image data. This optional technique is described below following the description of the subtraction of green image data values from the other color image data.

**[0042]** Optionally, the image processing module 20 can be configured to selectively delete green image data. For example, the image processing module 20 can include a deletion analysis module (not shown) configured to selectively determine which green image data to delete. For example, such a deletion module can be configured to

determine if deleting a pattern of rows from the green image data would result in aliasing artifacts, such as Moiré lines, or other visually perceptible artifacts. The deletion module can be further configured to choose a pattern of green image data to delete that would present less risk of creating such artifacts. For example, the deletion module can be configured to choose a green image data deletion pattern of alternating vertical columns if it determines that the image captured by the image sensor 18 includes an image feature characterized by a plurality of parallel horizontal lines. This deletion pattern can reduce or eliminate artifacts, such as Moiré lines, that might have resulted from a deletion pattern of alternating lines of image data parallel to the horizontal lines detected in the image.

**[0043]** However, this merely one exemplary, non-limiting example of the types of image features and deletion patterns that can be used by the deletion module. The deletion module can also be configured to detect other image features and to use other image data deletion patterns, such as for example, but without limitation, deletion of alternating rows, alternating diagonal lines, or other patterns. Additionally, the deletion module can be configured to delete portions of the other image data, such as the red and blue image data, or other image data depending on the type of sensor used.

**[0044]** Additionally, the camera 10 can be configured to insert a data field into the image data indicating what image data has been deleted. For example, but without limitation, the camera 10 can be configured to insert a data field into the beginning of any video clip stored into the storage device 24, indicating what data has been deleted in each of the "frames" of the video clip. In some embodiments, the camera can be configured to insert a data field into each frame captured by the sensor 18, indicating what image data has been deleted. For example, in some embodiments, where the image processing module 20 is configured to delete ½ of the green image data in one deletion pattern, the data field can be as small as a single bit data field, indicating whether or not image data has been deleted. Since the image processing module 20 is configured to delete data in only one pattern, a single bit is sufficient to indicate what data has been deleted.

**[0045]** In some embodiments, as noted above, the image processing module 20 can be configured to selectively delete image data in more than one pattern. Thus, the image data deletion field can be larger, including a sufficient number of values to provide an

indication of which of the plurality of different image data deletion patterns was used. This data field can be used by downstream components and or processes to determine to which spatial positions the remaining image data corresponds.

**[0046]** In some embodiments, the image processing module can be configured to retain all of the raw green image data, e.g., the data shown in Figure 5. In such embodiments, the image processing module can include one or more green image data processing modules.

**[0047]** As noted above, in known Bayer pattern filters, there are twice as many green elements as the number of red elements and the number of blue elements. In other words, the red elements comprise 25% of the total Bayer pattern array, the blue elements corresponded 25% of the Bayer pattern array and the green elements comprise 50% of the elements of the Bayer pattern array. Thus, in some embodiments, where all of the green image data is retained, the image processing module 20 can include a second green data image processing module 38. As such, the first green data image processing module 36 can process half of the green elements and the second green image data processing module 38 can process the remaining green elements. However, the present inventions can be used in conjunction with other types of patterns, such as for example, but without limitation, CMY and RGBW.

**[0048]** Figure 7 includes schematic illustrations of the red, blue and two green data components processed by modules 32, 34, 36, and 38 (Figure 4). This can provide further advantages because the size and configuration of each of these modules can be about the same since they are handling about the same amount of data. Additionally, the image processing module 20 can be selectively switched between modes in which is processes all of the green image data (by using both modules 36 and 38) and modes where ½ of the green image data is deleted (in which it utilizes only one of modules 36 and 38). However, other configurations can also be used.

**[0049]** Additionally, in some embodiments, the image processing module 20 can include other modules and/or can be configured to perform other processes, such as, for example, but without limitation, gamma correction processes, noise filtering processes, etc.

**[0050]** Additionally, in some embodiments, the image processing module 20 can be configured to subtract a value of a green element from a value of a blue element and/or red

element. As such, in some embodiments, when certain colors are detected by the image sensor 18, the corresponding red or blue element can be reduced to zero. For example, in many photographs, there can be large areas of black, white, or gray, or a color shifted from gray toward the red or blue colors. Thus, if the corresponding pixels of the image sensor 18 have sensed an area of gray, the magnitude of the green, red, and blue, would be about equal. Thus, if the green value is subtracted from the red and blue values, the red and blue values will drop to zero or near zero. Thus, in a subsequent compression process, there will be more zeros generated in pixels that sense a black, white, or gray area and thus the resulting data will be more compressible. Additionally, the subtraction of green from one or both of the other colors can make the resulting image data more compressible for other reasons.

**[0051]** Such a technique can help achieve a higher effective compression ratio and yet remain visually lossless due to its relationship to the entropy of the original image data. For example, the entropy of an image is related to the amount of randomness in the image. The subtraction of image data of one color, for example, from image data of the other colors can reduce the randomness, and thus reduce the entropy of the image data of those colors, thereby allowing the data to be compressed at higher compression ratios with less loss. Typically, an image is not a collection of random color values. Rather, there is often a certain degree of correlation between surrounding picture elements. Thus, such a subtraction technique can use the correlation of picture elements to achieve better compression. The amount of compression will depend, at least in part, on the entropy of the original information in the image.

**[0052]** In some embodiments, the magnitudes subtracted from a red or blue pixel can be the magnitude of the value output from a green pixel adjacent to the subject red or blue pixel. Further, in some embodiments, the green magnitude subtracted from the red or blue elements can be derived from an average of the surrounding green elements. Such techniques are described in greater detail below. However, other techniques can also be used.

**[0053]** Optionally, the image processing module 20 can also be configured to selectively subtract green image data from the other colors. For example, the image processing module 20 can be configured to determine if subtracting green image data from a portion of the image data of either of the other colors would provide better compressibility or

not. In this mode, the image processing module 20 can be configured to insert flags into the image data indicating what portions of the image data has been modified (by e.g., green image data subtraction) and which portions have not been so modified. With such flags, a downstream demosaicing/reconstruction component can selectively add green image values back into the image data of the other colors, based on the status of such data flags.

**[0054]** Optionally, image processing module 20 can also include a further data reduction module (not shown) configured to round values of the red and blue data. For example, if, after the subtraction of green magnitudes, the red or blue data is near zero (e.g., within one or two on an 8-bit scale ranging from 0-255 or higher magnitudes for a higher resolution system). For example, the sensor 18 can be a 12-bit sensor outputting red, blue, and green data on a scale of 0-4095. Any rounding or filtering of the data performed the rounding module can be adjusted to achieve the desired effect. For example, rounding can be performed to a lesser extent if it is desired to have lossless output and to a greater extent if some loss or lossy output is acceptable. Some rounding can be performed and still result in a visually lossless output. For example, on a 8-bit scale, red or blue data having absolute value of up to 2 or 3 can be rounded to 0 and still provide a visually lossless output. Additionally, on a 12-bit scale, red or blue data having an absolute value of up to 10 to 20 can be rounded to 0 and still provide visually lossless output.

**[0055]** Additionally, the magnitudes of values that can be rounded to zero, or rounded to other values, and still provide a visually lossless output depends on the configuration of the system, including the optics hardware 16, the image sensor 18, the resolution of the image sensor, the color resolution (bit) of the image sensor 18, the types of filtering, anti-aliasing techniques or other techniques performed by the image processing module 20, the compression techniques performed by the compression module 22, and/or other parameters or characteristics of the camera 10.

**[0056]** As noted above, in some embodiments, the camera 10 can be configured to delete ½ of the green image data after the red and blue image data has been transformed based on the green image data. For example, but without limitation, the processor module 20 can be configured to delete ½ of the green image data after the average of the magnitudes of the surrounding green data values have been subtracted from the red and blue data values.

This reduction in the green data can reduce throughput requirements on the associated hardware. Additionally, the remaining green image data can be used to reconstruct the red and blue image data, described in greater detail below with reference to Figures 14 and 16.

**[0057]** As noted above, the camera 10 can also include a compression module 22. The compression module 22 can be in the form of a separate chip or it can be implemented with software and another processor. For example, the compression module 22 can be in the form of a commercially available compression chip that performs a compression technique in accordance with the JPEG 2000 standard, or other compression techniques.

**[0058]** The compression module can be configured to perform any type of compression process on the data from the image processing module 20. In some embodiments, the compression module 22 performs a compression technique that takes advantage of the techniques performed by the image processing module 20. For example, as noted above, the image processing module 20 can be configured to reduce the magnitude of the values of the red and blue data by subtracting the magnitudes of green image data, thereby resulting in a greater number of zero values, as well as other effects. Additionally, the image processing module 20 can perform a manipulation of raw data that uses the entropy of the image data. Thus, the compression technique performed by the compression module 22 can be of a type that benefits from the presence of larger strings of zeros to reduce the size of the compressed data output therefrom.

**[0059]** Further, the compression module 22 can be configured to compress the image data from the image processing module 20 to result in a visually lossless output. For example, firstly, the compression module can be configured to apply any known compression technique, such as, but without limitation, JPEG 2000, MotionJPEG, any DCT based codec, any codec designed for compressing RGB image data, H.264, MPEG4, Huffman, or other techniques.

**[0060]** Depending on the type of compression technique used, the various parameters of the compression technique can be set to provide a visually lossless output. For example, many of the compression techniques noted above can be adjusted to different compression rates, wherein when decompressed, the resulting image is better quality for lower compression rates and lower quality for higher compression rates. Thus, the

compression module can be configured to compress the image data in a way that provides a visually lossless output, or can be configured to allow a user to adjust various parameters to obtain a visually lossless output. For example, the compression module 22 can be configured to compress the image data at a compression ratio of about 6:1, 7:1, 8:1 or greater. In some embodiments, the compression module 22 can be configured to compress the image data to a ratio of 12:1 or higher.

**[0061]** Additionally, the compression module 22 can be configured to allow a user to adjust the compression ratio achieved by the compression module 22. For example, the camera 10 can include a user interface that allows a user to input commands that cause the compression module 22 to change the compression ratio. Thus, in some embodiments, the camera 10 can provide for variable compression.

**[0062]** As used herein, the term "visually lossless" is intended to include output that, when compared side by side with original (never compressed) image data on the same display device, one of ordinary skill in the art would not be able to determine which image is the original with a reasonable degree of accuracy, based only on a visual inspection of the images.

**[0063]** With continued reference to Figure 1, the camera 10 can also include a storage device 24. The storage device 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 device. In some embodiments, the size of the storage device 24 can be sufficiently large to store image data from the compression module 22 corresponding to at least about 30 minutes of video at 12 mega pixel resolution, 12-bit color resolution, and at 60 frames per second. However, the storage device 24 can have any size.

**[0064]** In some embodiments, the storage device 24 can be mounted on an exterior of the housing 12. Further, in some embodiments, the storage device 24 can be connected to the other components of the system 14 through standard communication ports, including, for example, but without limitation, IEEE 1394, USB 2.0, IDE, SATA, etc. Further, in some embodiments, the storage device 24 can comprise a plurality of hard drives operating under a RAID protocol. However, any type of storage device can be used.

**[0065]** With continued reference to Figure 1, as noted above, in some embodiments, the system can include a monitor module 26 and a display device 30 configured to allow a user to view video images captured by the image sensor 18 during operation. In some embodiments, the image processing module 20 can include a subsampling system configured to output reduced resolution image data to the monitor module 26. For example, such a subsampling system can be configured to output video image data to support 2K, 1080p, 720p, or any other resolution. In some embodiments, filters used for demosaicing can be adapted to also perform downsampling filtering, such that downsampling and filtering can be performed at the same time. The monitor module 26 can be configured to perform any type of demosaicing process to the data from the image processing module 20. Thereafter, the monitor module 26 can output a demosaiced image data to the display 30.

**[0066]** The display 30 can be any type of monitoring device. For example, but without limitation, the display 30 can be a four-inch LCD panel supported by the housing 12. For example, in some embodiments, the display 30 can be connected to an infinitely adjustable mount configured to allow the display 30 to be adjusted to any position relative to the housing 12 so that a user can view the display 30 at any angle relative to the housing 12. In some embodiments, the display 30 can be connected to the monitor module through any type of video cables such as, for example, an RGB or YCC format video cable.

**[0067]** Optionally, the playback module 28 can be configured to receive data from the storage device 24, decompressed and demosaic the image data and then output the image data to the display 30. In some embodiments, the monitor module 26 and the playback module 28 can be connected to the display through an intermediary display controller (not shown). As such, the display 30 can be connected with a single connector to the display controller. The display controller can be configured to transfer data from either the monitor module 26 or the playback module 28 to the display 30.

**[0068]** Figure 8 includes a flowchart 50 illustrating the processing of image data by the camera 10. In some embodiments, the flowchart 50 can represent a control routine stored in a memory device, such as the storage device 24, or another storage device (not shown) within the camera 10. Additionally, a central processing unit (CPU) (not shown) can

be configured to execute the control routine. The below description of the methods corresponding to the flow chart 50 are described in the context of the processing of a single frame of video image data. Thus, the techniques can be applied to the processing of a single still image. These processes can also be applied to the processing of continuous video, e.g., frame rates of greater than 12, as well as frame rates of 20, 23.976, 24, 30, 60, and 120, or other frame rates between these frame rates or greater.

**[0069]** With continued reference to Figure 8, control routine can begin at operation block 52. In the operation block 52, the camera 10 can obtain sensor data. For example, with reference to Figure 1, the image sensor 18, which can include a Bayer Sensor and chipset, can output image data.

**[0070]** For example, but without limitation, with reference to Figure 3, the image sensor can comprise a CMOS device having a Bayer pattern filter on its light receiving surface. Thus, the focused image from the optics hardware 16 is focused on the Bayer pattern filter on the CMOS device of the image sensor 18. Figure 3 illustrates an example of the Bayer pattern created by the arrangement of Bayer pattern filter on the CMOS device.

**[0071]** In Figure 3, column m is the fourth column from the left edge of the Bayer pattern and row n is the fourth row from the top of the pattern. The remaining columns and rows are labeled relative to column m and row n. However, this layout is merely chosen arbitrarily for purposes of illustration, and does not limit any of the embodiments or inventions disclosed herein.

**[0072]** As noted above, known Bayer pattern filters often include twice as many green elements as blue and red elements. In the pattern of figure 5, blue elements only appear in rows n-3, n-1, n+1, and n+3. Red elements only appear in rows n-2, n, n+2, and n+4. However, green elements appear in all rows and columns, interspersed with the red and blue elements.

**[0073]** Thus, in the operation block 52, the red, blue, and green image data output from the image sensor 18 can be received by the image processing module 20 and organized into separate color data components, such as those illustrated in Figure 7. As shown in Figure 7, and as described above with reference to Figure 4, the image processing module 20 can separate the red, blue, and green image data into four separate components. Figure 7

illustrates two green components (Green 1 and Green 2), a blue component, and a red component. However, this is merely one exemplary way of processing image data from the image sensor 18. Additionally, as noted above, the image processing module 20, optionally, can arbitrarily or selectively delete ½ of the green image data.

**[0074]** After the operation block 52, the flowchart 50 can move on to operation block 54. In the operation block 56, the image data can be further processed. For example, optionally, any one or all of the resulting data (e.g., green 1, green 2, the blue image data from Figure 9, and the red image data from Figure 10) can be further processed.

**[0075]** For example, the image data can be pre-emphasized or processed in other ways. In some embodiments, the image data can be processed to be more (mathematically) non-linear. Some compression algorithms benefit from performing such a linearization on the picture elements prior to compression. However, other techniques can also be used. For example, the image data can be processed with a linear curve, which provides essentially no emphasis.

**[0076]** In some embodiments, the operation block 54 can process the image data using curve defined by the function y=x^0.5. In some embodiments, this curve can be used where the image data was, for example but without limitation, floating point data in the normalized 0-1 range. In other embodiments, for example, where the image data is 12-bit data, the image can be processed with the curve y=(x/4095)^0.5. Additionally, the image data can be processed with other curves, such as y=(x+c)^g where $0.01<g<1$ and c is an offset, which can be 0 in some embodiments. Additionally, log curves can also be used. For example, curves in the form y=A*log(B*x+C) where A, B, and C are constants chosen to provide the desired results. Additionally, the above curves and processes can be modified to provide more linear areas in the vicinity of black, similar to those techniques utilized in the well-known Rec709 gamma curve. In applying these processes to the image data, the same processes can be applied to all of the image data, or different processes can be applied to the different colors of image data. However, these are merely exemplary curves that can be used to process the image data, or curves or transforms can also be used. Additionally, these processing techniques can be applied using mathematical functions such as those noted above, or with Look Up Tables (LUTs). Additionally, different processes, techniques, or

transforms can be used for different types of image data, different ISO settings used during recording of the image data, temperature (which can affect noise levels), etc.

**[0077]** After the operation block 54, the flowchart 50 can move to an operation block 56. In the operation block 56, the red and blue picture elements can be transformed. For example, as noted above, green image data can be subtracted from each of the blue and red image data components. In some embodiments, a red or blue image data value can be transformed by subtracting a green image data value of at least one of the green picture elements adjacent to the red or blue picture element. In some embodiments, an average value of the data values of a plurality of adjacent green picture elements can be subtracted from the red or blue image data value. For example, but without limitation, average values of 2, 3, 4, or more green image data values can be calculated and subtracted from red or blue picture elements in the vicinity of the green picture elements.

**[0078]** For example, but without limitation, with reference to Figure 3, the raw output for the red element $R_{m-2,n-2}$ is surrounded by four green picture elements $G_{m-2,n-3}$, $G_{m-1,n-2}$, $G_{m-3,n-2}$, and $G_{m-2,n-1}$. Thus, the red element $R_{m-2,n-2}$ can be transformed by subtracting the average of the values of the surrounding green element as follows:

(1) $$R_{m,n} = R_{m,n} - (G_{m,n-1} + G_{m+1,n} + G_{m,n+1} + G_{m-1,n})/4$$

**[0079]** Similarly, the blue elements can be transformed in a similar manner by subtracting the average of the surrounding green elements as follows:

(2) $$B_{m+1,n+1} = B_{m+1,n+1} - (G_{m+1,n} + G_{m+2,n+1} + G_{m+1,n+2} + G_{m,n+1})/4$$

**[0080]** Figure 9 illustrates a resulting blue data component where the original blue raw data $B_{m-1,n-1}$ is transformed, the new value labeled as $B'_{m-1,n-1}$ (only one value in the component is filled in and the same technique can be used for all the blue elements). Similarly, Figure 10 illustrates the red data component having been transformed in which the transformed red element $R_{m-2,n-2}$ is identified as $R'_{m-2,n-2}$. In this state, the image data can still be considered "raw" data. For example, the mathematical process performed on the data are entirely reversible such that all of the original values can be obtained by reversing those processes.

**[0081]** With continued reference to Figure 8, after the operation block 56, the flowchart 50 can move on to an operation block 58. In the operation block 58, the resulting

data, which is raw or can be substantially raw, can be further compressed to using any known compression algorithm. For example, the compression module 22 (Figure 1) can be configured to perform such a compression algorithm. After compression, the compressed raw data can be stored in the storage device 24 (Figure 1).

**[0082]** Figure 8A illustrates a modification of the flowchart 50, identified by the reference numeral 50'. Some of the steps described above with reference to the flowchart 50 can be similar or the same as some of the corresponding steps of the flowchart 50' and thus are identified with the same reference numerals.

**[0083]** As shown in Figure 8A, the flowchart 50', in some embodiments, can optionally omit operation block 54. In some embodiments, the flowchart 50' can also include an operation block 57 in which a look up table can be applied to the image data. For example, an optional look-up table, represented by the curve of Figure 11, can be used to enhance further compression. In some embodiments, the look-up table of Figure 11 is only used for the green picture elements. In other embodiments, the look-up table can also be used for red and blue picture elements. The same look-up table may be used for the three different colors, or each color may have its own look-up table. Additionally, processes other than that represented by the curve of Figure 11 can also be applied.

**[0084]** By processing the image data in the manner described above with reference to Figures 8 and 8A, it has been discovered that the image data from the image sensor 18 can be compressed by a compression ratio of 6 to 1 or greater and remain visually lossless. Additionally, although the image data has been transformed (e.g., by the subtraction of green image data) all of the raw image data is still available to an end user. For example, by reversing certain of the processes, all or substantially all of the original raw data can be extracted and thus further processed, filtered, and/or demosaiced using any process the user desires.

**[0085]** For example, with reference to Figure 12, the data stored in the storage device 24 can be decompressed and demosaiced. Optionally, the camera 10 can be configured to perform the method illustrated by flowchart 60. For example, but without limitation, the playback module 28 can be configured to perform the method illustrated by

flowchart 60. However, a user can also transfer the data from the storage device 24 into a separate workstation and apply any or all of the steps and/or operations of the flowchart 60.

**[0086]** With continued reference to Figure 12, the flowchart 60 can begin with the operation block 62, in which the data from the storage device 24 is decompressed. For example, the decompression of the data in operation block 62 can be the reverse of the compression algorithm performed in operational block 58 (Figure 8). After the operation block 62, the flowchart 60 can move on to an operation block 64.

**[0087]** In the operation block 64, a process performed in operation block 56 (Figure 8) can be reversed. For example, the inverse of the curve of Figure 11 or the inverse of any of the other functions described above with reference to operation block 56 of Figures 8 and 8A, can be applied to the image data. After the operation block 64, the flowchart 60 can move on to a step 66.

**[0088]** In the operation block 66, the green picture elements can be demosaiced. For example, as noted above, all the values from the data components Green 1 and/or Green 2 (Figure 7) can be stored in the storage device 24. For example, with reference to Figure 5, the green image data from the data components Green 1, Green 2 can be arranged according to the original Bayer pattern applied by the image sensor 18. The green data can then be further demosaiced by any known technique, such as, for example, linear interpolation, bilinear, etc.

**[0089]** Figure 13 illustrates an exemplary layout of green image data demosaiced from all of the raw green image data. The green image elements identified with the letter $G_x$ represent original raw (decompressed) image data and the elements identified with "$DG_x$" represent elements that were derived from the original data through the demosaic process. This nomenclature is used with regard to the below descriptions of the demosaicing process for the other colors. Figure 14 illustrates an exemplary image data layout for green image data demosaiced from ½ of the original green image data.

**[0090]** With continued reference to Figure 12, the flowchart 60 can, after the operation block 66, move on to an operation block 68. In the operation block 68, the demosaiced green image data can be further processed. For example, but without limitation, noise reduction techniques can be applied to the green image data. However, any other image

processing technique, such as anti-aliasing techniques, can also be applied to the green image data. After the operation block 68, the flowchart 60 can move on to an operation block 70.

**[0091]** In the operation block 70, the red and blue image data can be demosaiced. For example, firstly, the blue image data of Figure 9 can be rearranged according to the original Bayer pattern (Figure 15). The surrounding elements, as shown in Figure 16, can be demosaiced from the existing blue image data using any known demosaicing technique, including linear interpolation, bilinear, etc. As a result of demosaicing step, there will be blue image data for every pixel as shown in Figure 16. However, this blue image data was demosaiced based on the modified blue image data of Figure 9, i.e., blue image data values from which green image data values were subtracted.

**[0092]** The operation block 70 can also include a demosaicing process of the red image data. For example, the red image data from Figure 10 can be rearranged according to the original Bayer pattern and further demosaiced by any known demosaicing process such as linear interpolation, bilinear, etc.

**[0093]** After the operation block 70, the flowchart can move on to an operation block 72. In the operation block 72, the demosaiced red and blue image data can be reconstructed from the demosaiced green image data.

**[0094]** In some embodiments, each of the red and blue image data elements can be reconstructed by adding in the green value from co-sited green image element (the green image element in the same column "m" and row "n" position). For example, after demosaicing, the blue image data includes a blue element value $DB_{m-2,n-2}$. Because the original Bayer pattern of Figure 3 did not include a blue element at this position, this blue value $DB_{m-2,n-2}$ was derived through the demosaicing process noted above, based on, for example, blue values from any one of the elements $B_{m-3,n-3}$, $B_{m-1,n-3}$, $B_{m-3,n-1}$, and $B_{m-1,n-1}$ or by any other technique or other blue image elements. As noted above, these values were modified in operation block 54 (Figure 8) and thus do not correspond to the original blue image data detected by the image sensor 18. Rather, an average green value had been subtracted from each of these values. Thus, the resulting blue image data $DB_{m-2,n-2}$ also represents blue data from which green image data has been subtracted. Thus, in one

embodiment, the demosaiced green image data for element $DG_{m-2,n-2}$ can be added to the blue image value $DB_{m-2,n-2}$ thereby resulting in a reconstructed blue image data value.

**[0095]** In some embodiments, optionally, the blue and/or red image data can first be reconstructed before demosaicing. For example, the transformed blue image data $B'_{m-1,n-1}$ can be first reconstructed by adding the average value of the surrounding green elements. This would result in obtaining or recalculating the original blue image data $B_{m-1,n-1}$. This process can be performed on all of the blue image data. Subsequently, the blue image data can be further demosaiced by any known demosaicing technique. The red image data can also be processed in the same or similar manners.

**[0096]** Figure 12A illustrates a modification of the flowchart 60, identified by the reference numeral 60'. Some of the steps described above with reference to the flowchart 60 can be similar or the same as some of the corresponding steps of the flowchart 60' and thus are identified with the same reference numerals.

**[0097]** As shown in Figure 12A, the flow chart 60' can include the operation block 68' following operation block 62. In operation block 68', a noise reduction technique can be performed on the image data. For example, but without limitation, noise reduction techniques can be applied to the green image data. However, any other image processing technique, such as anti-aliasing techniques, can also be applied to the green image data. After operation block 68', the flow chart can move on to operation block 70'

**[0098]** In operation block 70', the image data can be demosaiced. In the description set forth above with reference to operation blocks 66 and 70, the green, red, and blue image data can be demosacied in two steps. However, in the present flow chart 60', the demosaicing of all three colors of image data is represented in a single step, although the same demosaicing techniques described above can be used for this demosaicing process. After the operation block 70', the flow chart can move on to operation block 72, in which the red and blue image data can be reconstructed, and operation block 64 in which an inverse look-up table can be applied.

**[0099]** After the image data has been decompressed and processed according to either of the flow charts 70 or 70', or any other suitable process, the image data can be further processed as demosaiced image data.

**[0100]** By demosaicing the green image data before reconstructing the red and blue image data, certain further advantages can be achieved. For example, as noted above, the human eye is more sensitive to green light. Demosiacing and processing the green image data optimize the green image values, to which the human eye is more sensitive. Thus, the subsequent reconstruction of the red and blue image data will be affected by the processing of the green image data.

**[0101]** Additionally, Bayer patterns have twice as many green elements as red and blue elements. Thus, in embodiments where all of the green data is retained, there is twice as much image data for the green elements as compared to either the red or blue image data elements. Thus, the demosaicing techniques, filters, and other image processing techniques result in a better demosaiced, sharpened, or otherwise filtered image. Using these demosaiced values to reconstruct and demosaic the red and blue image data transfers the benefits associated with the higher resolution of the original green data to the process, reconstruction, and demosaicing of the red and blue elements. As such, the resulting image is further enhanced.

**CLAIMS**

1. video camera comprising:

a portable housing;

a lens assembly supported by the housing and configured to focus light;

a light sensitive device configured to convert the focused light into raw mosaiced image data with a resolution of at least 2 k at a frame rate of at least about twenty-three frames per second;

a memory device; and

an image processing system configured to compress and store in the memory device the raw mosaiced image data at a compression ratio of at least six to one and remain substantially visually lossless, and at a rate of at least about 23 frames per second.

2. A video camera according to claim 1, wherein the light sensitive device includes a first group of sensor cells configured to detect a first color, a second group of sensor cells configured to detect a second color, and a third group of sensor cells configured to detect a third color, the third group of sensor cells comprising twice as many sensor cells as the second group of sensor cells.

3. A video camera according to claim 1, wherein the memory device is disposed within the housing.

4. A video camera according to claim 1, wherein the memory device is supported on the outside of the housing.

5. A video camera according to claim 1, wherein the memory device is connected to the housing with a flexible cable.

6. A method of recording a motion video with a camera, the method comprising:

guiding light onto a light sensitive device of a camera;

converting the light received by the light sensitive device into raw digital mosaiced image data having a horizontal resolution of at least 2 k at a rate of at least greater than twenty three frames per second;

compressing the raw digital mosaiced image data into compressed digital image data such that the data remains substantially visually lossless upon decompression; and

recording the compressed digital mosaiced image data at a rate of at least about 23 frames per second onto a storage device of the camera.

7. The method according to claim 6, wherein the step of compressing the raw digital mosaiced image data comprises compressing the raw digital mosaiced image data to an effective compression ratio of at least 6 to 1.

8. The method according to claim 6, wherein the step of compressing the raw digital mosaiced image data comprises compressing the raw digital mosaiced image data with an effective compression ratio of at least about 12:1.

9. The method according to claim 6, wherein the step of recording comprises storing the compressed digital mosaiced image data.

10. The method according to claim 6, wherein the step of recording comprises recording the compressed digital mosaiced image data at a rate of at least about 23.976 frames per second onto the storage device.

11. A video camera comprising:

a lens assembly supported by a housing and configured to focus light;

a light sensitive device configured to convert the focused light into a signal of raw mosaiced image data representing the focused light and having a resolution of at least 2 k;

a memory device; and

means for compressing and recording the raw mosaiced image data in the memory device at a frame rate of at least about 23 frames per second such that the mosaiced image data remains substantially visually lossless upon decompression.

12. A video camera comprising:

a portable housing having at least one handle configured to allow a user to manipulate the orientation with respect to at least one degree of movement of the housing during a video recording operation of the camera;

a lens assembly comprising at least one lens supported by the housing and configured to focus light at a plane disposed inside the housing;

a light sensitive device configured to convert the focused light into raw mosaiced image data with a horizontal resolution of at least 2 k and at a frame rate of at least about twenty three frames per second;

a memory device configured to store video image data;

an image processing system configured to compress and store in the memory device the raw mosaiced image data at a compression ratio of at least six to one and remain substantially visually lossless, and at a rate of at least about 23 frames per second.

13. A video camera according to claim 1 additionally comprising a playback module configured to receive data from the memory device, and decompress and demosaic the compressed raw mosaiced image data stored in the memory device.

14. A video camera according to claim 1 wherein the image processing module comprises a compression chip.

15. A video camera according to claim 14 wherein the compression chip is configured to perform compression using a JPEG 2000 standard.

16. A video camera according to Claim 1, wherein the light sensitive device is configured to convert light into raw mosaiced image data with a resolution of at least 4 k.

17. A video camera according to Claim 1, wherein the image processing system is configured to alter the raw mosaiced image data by subtracting values based on some of the raw mosaiced image data from other values of the raw mosaiced image data and to compress and store the raw mosaiced image data after subtracting.

18. A video camera according to Claim 1, wherein the image processing system is configured to compress and store the raw mosaiced image data which is Bayer patterned mosaiced data.

19. The method according to claim 6 additionally comprising decompressing and demosaicing the compressed raw mosaiced image data stored in the storage device.

20. The method according to claim 6, wherein the step of compressing comprises compressing raw mosaiced image data with a compression chip.

21. The method according to claim 20 wherein step of compressing comprises compressing raw mosaiced image data with a JPEG 2000 standard.

22. The method according to claim 6, wherein the step of converting comprises converting light into raw mosaiced image data with a resolution of at least 4 k.

23. The method according to claim 6, additionally comprising subtracting values based on some of the raw mosaiced image data from other values of the raw mosaiced image data before the steps of compressing and recording the raw mosaiced image data.

24. The method according to claim 6, wherein the step of compressing comprises compressing the raw mosaiced image which is Bayer patterned mosaiced data.

25. A video camera according to claim 11 additionally comprising a playback module configured to receive data from the means for compressing and recording, and to

decompress and demosaic the compressed raw mosaiced image data stored in the memory device.

26. A video camera according to claim 11 wherein the means for compressing and recording comprises a compression chip.

27. A video camera according to claim 26 wherein the compression chip is configured to perform compression using a JPEG 2000 standard.

28. A video camera according to claim 11, wherein the light sensitive device is configured to convert light into raw mosaiced image data with a resolution of at least 4 k.

29. A video camera according to Claim 11, wherein the means for compressing and recording is configured to alter the raw mosaiced image data by subtracting values based on some of the raw mosaiced image data from other values of the raw mosaiced image data and to record and store the raw mosaiced image data after subtracting.

30. A video camera according to Claim 11, wherein the means for compressing and recording is configured to compress and record the raw mosaiced image data which is Bayer patterned mosaiced data.

31. A video camera according to claim 12 additionally comprising a playback module configured to receive data from the memory device, and decompress and demosaic the compressed raw mosaiced image data stored in the memory device.

32. A video camera according to claim 12 wherein the image processing system comprises a compression chip.

33. A video camera according to claim 32 wherein the compression chip is configured to perform compression using the JPEG 2000 standard.

34. A video camera according to claim 12, wherein the light sensitive device is configured to convert light into raw mosaiced image data with a resolution of at least 4 k.

35. A video camera according to Claim 12, wherein the image processing system is configured to alter the raw mosaiced image data by subtracting values based on some of the raw mosaiced image data from other values of the raw mosaiced image data and to compress and store the raw mosaiced image data after subtracting.

36. A video camera according to Claim 12, wherein the image processing system is configured to compress and store the raw mosaiced image data which is Bayer patterned mosaiced data.