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IMAGE PROCESSING DEVICE, IMAGE PROCESSING METHOD, AND PROGRAM

Abstract

To provide a technique advantageous for performing image compression processing of image data while reducing noise of the image data.
An image processing device includes a square root calculation unit that acquires first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data, and a fraction processing unit that acquires second compressed image data by performing fraction processing of the plurality of pixel square roots.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to an image processing device, an image processing method, and a program.

BACKGROUND ART

[0002] An image captured and acquired by an imaging element (image sensor) includes a noise component in addition to an original image of an imaging target.

[0003] A device disclosed in Patent Document 1 performs image processing using a gradation space that is hardly affected by noise caused by an imaging element.

CITATION LIST

Patent Document

[0004] Patent Document 1: WO 2006/006373 A1

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

[0005] With the recent increase in the number of pixels and the size of image sensors, the amount of image data output from the image sensors tends to increase. For example, an image used for medical use such as a biological tissue image is required to have precise reproducibility, and thus the data amount of each image is often large, and a large number of images of the same subject may be captured and acquired.

[0006] In order to store an image having a large data amount in a storage unit as it is, a large-capacity storage unit is required, and a long time is required for data transfer. However, it takes a corresponding cost to prepare a large-capacity storage unit. In addition, data transfer processing over a long period of time increases the time required for image storage processing, and may become a bottleneck of processing of the entire system and cause other processing performed before and after the image storage processing to stagnate.

[0007] Accordingly, by performing image compression processing prior to the image storage processing, the amount of stored data is reduced. Thus, it is possible to suppress an increase in the capacity of the storage unit, shorten the time required for the image storage processing, and promote improvement in processing efficiency of the entire system and reduction in processing time.

[0008] However, by performing image compression processing (particularly lossy compression processing), partial data of an image is lost, and an original image of an imaging target may not be sufficiently reproduced in a compressed and decompressed image. In addition, such image compression processing may increase noise in the compressed and decompressed image, and image quality of the compressed and decompressed image is more likely to deteriorate.

[0009] Note that the lossless compression processing can prevent partial data loss of an image, but inherently has a small compression rate, so that the amount of image data cannot be sufficiently compressed and reduced, and an increase in capacity of the storage unit and an increase in time of the image storage processing cannot be necessarily sufficiently eliminated.

[0010] The present disclosure provides a technique advantageous for performing image compression processing of image data while reducing noise of the image data.

Solutions to Problems

[0011] One aspect of the present disclosure relates to an image processing device including a

square root calculation unit that acquires first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data, and a fraction processing unit that acquires second compressed image data by performing fraction processing of the plurality of pixel square roots.
[0012] The plurality of original pixel values may be derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data.
[0013] The fraction processing unit may acquire the second compressed image data by rounding a numerical value after a decimal point of each of the plurality of pixel square roots on the basis of rounding off.
[0014] The fraction processing unit may obtain an approximation original pixel value that is n{circumflex over ( )}2 (n is a natural number) having a smallest difference with respect to an original pixel value corresponding to each of the pixel square roots for each of the plurality of pixel square roots, and employ n of the approximation original pixel value as a pixel value of the second compressed image data.
[0015] The image processing device may include a word length adjustment unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data.
[0016] The word length adjustment unit may acquire the third compressed image data by reducing the word length of the second compressed image data according to a number of significant digits of a maximum value among the plurality of pixel values included in the second compressed image data.
[0017] The second compressed image data may have a word length equal to or more than 16 bits, and the third compressed image data may have a word length equal to or less than 8 bits.
[0018] The image processing device may include a compression processing unit that acquires fourth compressed image data by performing compression processing on compressed image data based on the second compressed image data.
[0019] The image processing device may include a word length adjustment unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data, in which the compression processing unit may acquire fourth compressed image data by performing compression processing on the third compressed image data.
[0020] The image processing device may include a storage processing unit that causes the compressed image data based on the second compressed image data to be stored in the storage unit.
[0021] The image processing device may include a decoding unit that performs processing of squaring a plurality of pixel values included in the compressed image data based on the second compressed image data.
[0022] The image processing device may include a word length restoration unit that increases a word length of the compressed image data based on the second compressed image data, in which the decoding unit may perform processing of squaring a plurality of pixel values included in the compressed image data based on the second compressed image data after the word length of the compressed image data based on the second compressed image data is increased by the word length restoration unit.
[0023] The image processing device may include a compression processing unit that acquires fourth compressed image data by performing compression processing of the compressed image data based on the second compressed image data, and a decompression processing unit that performs decompression processing on the compressed image data based on the second compressed image data, in which the compressed image data to be decompressed may be based on the fourth compressed image data, and the decompression processing may be processing corresponding to the

compression processing performed by the compression processing unit.
[0024] The plurality of original pixel values may be derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data, and the decoding unit may acquire a plurality of decompressed pixel values by multiplying a plurality of squared pixel values obtained by squaring a plurality of pixel values included in the compressed image data based on the second compressed image data by the reference pixel value.
[0025] The image data may be biological tissue image data.
[0026] The biological tissue image data may be fluorescent antibody image data.
[0027] Another aspect of the present disclosure relates to an image processing method including a step of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data, and a step of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.
[0028] Another aspect of the present disclosure relates to a program for causing a computer to execute a procedure of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data, and a procedure of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0029] FIG. **1** is a conceptual diagram for describing photoelectric conversion in an imaging element (particularly, a pixel).
[0030] FIG. **2** is a conceptual diagram of pixel values which are 16 bit pixel data.
[0031] FIG. **3** is a conceptual diagram of pixel values which are 16 bit pixel data.
[0032] FIG. **4** is a conceptual diagram of pixel values which are 16 bit pixel data.
[0033] FIG. **5** is a conceptual diagram of pixel values which are 16 bit pixel data.
[0034] FIG. **6** is a conceptual diagram of pixel values which are 16 bit pixel data.
[0035] FIG. **7** is a block diagram illustrating a configuration example of an imaging processing system.
[0036] FIG. **8** is a block diagram illustrating a functional configuration example of the image processing device, and particularly illustrates a functional configuration related to image compression processing.
[0037] FIG. **9** is a block diagram illustrating a functional configuration example of the image processing device, and particularly illustrates a functional configuration related to image decompression processing.
[0038] FIG. **10** is a flowchart illustrating an example of the image compression processing.
[0039] FIG. **11** is a conceptual diagram of pixel data for describing calculation of a square root of pixel data.
[0040] FIG. **12** is a diagram for describing a fraction processing example.
[0041] FIG. **13** is a flowchart illustrating an example of image decompression processing.
[0042] FIG. **14** is a block diagram illustrating a configuration example of a microscope system.
[0043] FIG. **15** is a diagram illustrating an example of an imaging device.
[0044] FIG. **16** is a diagram illustrating an example of a mobile device.
[0045] FIG. **17** is a diagram illustrating an example of a client server system.
MODE FOR CARRYING OUT THE INVENTION
[0046] Typical embodiments of the present disclosure will be described with reference to the

drawings.
[0047] Hereinafter, a case where the image data to be processed is biological tissue image data (for example, fluorescent antibody image data) will be mainly exemplified. However, the image data to which the technology described below can be applied is not limited. The technology described below is also applicable to image data used in any application other than medical care, and is also applicable to, for example, a normal snap photograph.
[0048] In the following description, the image data is also simply referred to as an “image”, and collectively includes a large number of pixel values (pixel data).
[0049] In a biological tissue image, due to its specific application, appropriate retention of original image quality may be required not only in a bright image region but also in a dark image region.
[0050] For example, a researcher or a doctor visually recognizes not only a fine tissue structure of a bright image region but also a fine tissue structure of a dark image region, and observes texture such as roughness that an ordinary person would overlook, thereby determining the presence or absence of cell abnormality such as cancer.
[0051] In a case where a biological tissue image to be observed includes a plurality of frequency components (a plurality of frequency patterns), since a certain frequency component lowers sensitivity of other frequency components, it is difficult for an ordinary people to recognize a fine tissue structure in such a biological tissue image. On the other hand, a researcher or a doctor who is familiar with the fact that sensitivity of each frequency component changes by performing observation while changing the distance and angle of the eye with respect to such an image can appropriately recognize the fine tissue structure in the biological tissue image by distinguishing subtlety of each frequency component.
[0052] In addition, for other purposes, it may be required to perform observation particularly focusing on a dark image region in a biological tissue image including both a bright image region and a dark image region.
[0053] Thus, regarding the biological tissue image, it is required to ensure a wider dynamic range and maintain a fine texture as compared with a normal snap photograph or the like.
[0054] For example, in biological tissue observation by fluorescence microscopy, the type and amount of protein fluorescently expressed in a biological tissue range to be observed greatly vary, and the light emission efficiency and the light emission amount (fluorescence amount) of the fluorescent antibody may greatly vary between observation sites. The fluorescent antibody image obtained in such a case may include both a bright image region and a dark image region.
[0055] However, unlike a normal snap photograph, the fluorescent antibody image is imaged in a state in which the irradiation light amount of excitation light is suppressed in order to suppress deterioration of the tissue due to the excitation light that excites he fluorescent antibody molecules. Thus, the amount of fluorescence signal contained in the fluorescent antibody image is originally small, and the fluorescent antibody image tends to be dark as a whole.
[0056] As described above, in a biological tissue image such as a fluorescent antibody image including a dark image region partially or entirely in this manner, the influence of a noise component such as shot noise becomes relatively large, and the noise component is often included in the biological tissue image at a non-negligible level.
[0057] Thus, it is preferable that image processing for reducing the noise component is performed on the biological tissue image so that the original image of the subject can be appropriately observed in the biological tissue image.
[0058] As such an image processing method, there is a method of acquiring a plurality of fluorescent antibody images by performing imaging a plurality of times, and acquiring a fluorescent antibody image in which a noise component is reduced on the basis of averaging of the plurality of fluorescent antibody images. However, in this method, irradiation of a tissue with excitation light is performed a plurality of times, and deterioration of the tissue due to such irradiation of the excitation light a plurality of times is concerned. Thus, it is often difficult to

employ this method.
[0059] In the case of acquiring a biological tissue image, the entire slide including a biological tissue to be observed is imaged using light of various wavelengths (for example, 100 or more wavelengths), and such imaging may be performed for each of a plurality of slides.
[0060] That is, in a case where a biological tissue image is acquired, there is a case where only an image in a single field of view of a microscope is captured and stored, but there is also a case where an image of the entire slide is acquired and stored by performing imaging while scanning the entire slide. In addition, in a case of acquiring a fluorescence microscope image, imaging may be performed using excitation light of various wavelengths.
[0061] The data amount of the biological tissue image obtained by such imaging is enormous.
[0062] Storage of such enormous image data causes an increase in cost of a storage (storage unit). In addition, as the data amount of the image to be saved increases, the time required for data transfer to the storage increases. The increase in the time for data transfer may become a bottleneck that hinders improvement in performance of the entire system.
[0063] For example, in a case where an image of "30,000 px×30,000 px (16 bits)" is stored at a wavelength of 335 channel CH, an image data amount is approximately 603 GB per slide. In a case where the image data is saved in a hard disk drive (HDD) at a transfer speed of 255 MB/s, for example, it takes about 39.41 minutes from the start to the end of saving the image data.
[0064] In this case, the time required to transfer and store the image greatly exceeds the time required to capture and acquire the image, which is a factor that greatly delays the processing speed of the entire system.
[0065] In a case where a SATA SSD (transfer speed: 750 MB/s) or an M.2 SSD (transfer speed: 2800 MB/s) having a transfer speed higher than that of the HDD is used as the storage, the time from the start to the end of the saving of the image data is about 13.40 minutes and 3.59 minutes, respectively. By using the storage with a high transfer speed in this manner, the time required to store the image data is shortened, and the system performance is greatly improved.
[0066] However, a storage having such excellent data transfer speed performance is quite expensive, and may be difficult to employ in terms of cost.
[0067] In order to suppress the increase in storage cost and prolongation of the data transfer time as described above, it is effective to reduce the data amount of the biological tissue image to be stored by image compression processing prior to storing in the storage.
[0068] However, when general-purpose image compression processing is applied to a biological tissue image, a dynamic range (for example, texture in a dark image region) is sacrificed.
[0069] For example, in JPEG using DCT compression, it is possible to acquire compressed image data with a high compression rate by setting the quantization level of the DCT compression to a level sufficiently higher than shot noise in consideration of the brightness of the entire image. However, since such compression processing is processing for reducing the amount of image data by sacrificing the dynamic range, texture in a dark image region is lost.
[0070] In a normal snap photograph, the influence of density of a dark image region adjacent to a bright image region on the texture of the entire image is small, and thus, even if the texture in the dark image region is lost by the compression processing, there is almost no practical disadvantage in observation in many cases.
[0071] On the other hand, general-purpose compression processing such as DCT compression sacrificing a dynamic range is not suitable for a biological tissue image for which precise texture maintenance is required even in a dark image region.
[0072] In addition, since a biological tissue image is required to have precise image reproducibility, the biological tissue image tends to have a large bit depth, and for example, it is not uncommon that the biological tissue image has a word length equal to or more than 16 bits.
[0073] On the other hand, many general-purpose image compression libraries (image encoders) are applicable to images having a word length equal to or less than 8 bits, but the general-purpose

image compression libraries applicable to images having a word length equal to or more than 16 bits are very limited.
[0074] Thus, there is no general-purpose image compression library capable of compressing a high-bit image with high compression efficiency while ensuring a wide dynamic range and suppressing an increase in noise.
[0075] Note that there is an image that originally has an enormous data size other than the biological tissue image, and there is a technical problem similar to the above-described biological tissue image regarding handling of such an image that has an enormous data size.
[0076] Hereinafter, an image processing technique advantageous for reducing noise components such as shot noise while compressing image data will be exemplarily described.
[0077] FIG. **1** is a conceptual diagram for describing photoelectric conversion in an imaging element (in particular, a pixel **81**). FIG. **2** is a conceptual diagram of a pixel value d**1** which is 16 bit pixel data.
[0078] As illustrated in FIG. **1**, the pixel **81** of the imaging element outputs electrons **82** corresponding to received photons **80**, and the electrons **82** output from the pixel **81** are accumulated in an electron storage unit **83**.
[0079] Then, by performing digital conversion (A/D conversion) of the voltage (the number of electrons **82**) accumulated in the electron storage unit **83**, a pixel value d**1** (pixel data) of digital data (16 bit digital data (binary data) in the example illustrated in FIG. **2**) is output.
[0080] The pixel data (image data) output from the imaging element in this manner includes shot noise as a main noise component.
[0081] The shot noise is a kind of circuit noise inevitably generated according to photoelectric conversion performed in each pixel **81**, and is based on an inherent error associated with measurement of particles such as photons and electrons.
[0082] The magnitude of the shot noise is proportional to the square root of intensity of observation light or an average value of current, and as the observation light intensity and the current value are smaller, the proportion of the absolute value of the shot noise in the pixel value d**1** output from each pixel **81** tends to increase.
[0083] Thus, it is possible to reduce the ratio of shot noise in captured image data by increasing the illumination light amount (for example, an output of an excitation light source that excites fluorescent molecules) at the time of imaging.
[0084] However, in practice, considering the damage that can be caused to the biological sample and the fluorescent antibody reagent by the light at the time of image capturing, it is often impossible to perform long-time exposure and multiple times exposure on the biological tissue to be captured.
[0085] The shot noise increases information entropy (that is, unpredictability), causes a decrease in efficiency of image compression in both lossless compression processing and lossy compression processing, and does not provide useful information to the observer.
[0086] On the other hand, it is inherently impossible to make the shot noise smaller than the square root of the signal light amount (that is, the number of electrons generated in the semiconductor of the image sensor) due to quantum mechanical constraints. That is, the shot noise is a noise component generated on the basis of the physical essence, and the shot noise cannot be made smaller than the square root of the signal light amount except in a very special situation.
[0087] Since the shot noise is equal to or proportional to the square root of an expected value of light intensity detected at each pixel, the noise level of the shot noise may vary from pixel to pixel. Thus, it is not possible to uniformly reduce the shot noise by uniformly setting the noise level of the shot noise over the entire image (that is, all pixels).
[0088] FIGS. **3** to **6** are conceptual diagrams of a pixel value d**1** which is 16 bit pixel data. FIGS. **3** to **6** illustrate pixel values d**1** having different numbers of significant digits.
[0089] The standard deviation of the shot noise is equal to or proportional to the square root

(=d**1**{circumflex over ( )}(1/2)) of the pixel value d**1** (that is, a pixel signal value (detected light amount value)).
[0090] The number of digits of the shot noise is expressed by "Log [d**1**{circumflex over ( )}(1/2)]=1/2×Log [d**1**]".
[0091] As is clear from this expression, the shot noise occupies approximately the lower half digit of the significant digit of the pixel value d**1**. That is, the digits of the lower half of the significant digits of the pixel value d**1** represented in binary notation are noise dominant digits (that is, a shot noise floor) dominated by the shot noise (see FIGS. **3** to **6**), and barely include intrinsic information regarding the subject image.
[0092] The image compression technology described below is based on this knowledge, and focuses on the fact that the numerical value of the lower order digit in which the shot noise is dominant among the significant digits of each pixel value d**1** (light intensity signal of each pixel) does not have much meaning as the data representing the subject image.
[0093] That is, primary image compression is performed by reducing the number of digits of the image data to be stored according to the number of digits of the shot noise floor. Thus, the data amount of the image data can be compressed to about half, and the shot noise that is not an intrinsic component of the image data can be reduced to lower the information entropy.
[0094] As a result, the amount of image data actually stored in the storage unit is significantly reduced, and a storage cost can be significantly reduced and a data transfer time can be significantly shortened (furthermore, a storage processing time can be significantly shortened).
[0095] In addition, by the image compression processing, the shot noise floor is removed from the image data, and only a portion corresponding to the shot noise component is reduced, so that deterioration in image quality is quite small. Furthermore, in a case where additional image compression processing is performed on the image data in which the shot noise is reduced by the image compression processing, improvement in efficiency of such additional image compression processing can also be expected.
[0096] Hereinafter, a specific device configuration example and a specific processing configuration example will be described.
[0097] FIG. **7** is a block diagram illustrating a configuration example of the imaging processing system **10**.
[0098] An imaging processing system **10** illustrated in FIG. **7** includes an imaging element **11**, an image processing device **12**, a storage unit **13**, a display device **14**, and an imaging processing control unit **15**. The imaging processing system **10** may be configured by a single device or may be configured by combining a plurality of devices.
[0099] The imaging element **11**, the image processing device **12**, the storage unit **13**, and the display device **14** are driven under the control of the imaging processing control unit **15**.
[0100] The imaging element **11** receives imaging light from a subject and outputs image data do including a subject image.
[0101] The imaging element **11** can have any configuration, and is typically constituted by a CCD image sensor or a CMOS image sensor.
[0102] The image data do acquired by the imaging element **11** is not limited, and may be biological tissue image data (for example, fluorescent antibody image data) or image data obtained by imaging any other object.
[0103] The image data do output from the imaging element **11** is input to the image processing device **12**, and undergoes various types of image processing in the image processing device **12**.
[0104] The image processing performed by the image processing device **12** is not limited, but the image processing device **12** of the present embodiment performs at least image compression processing and image decompression processing.
[0105] That is, the image processing device **12** generates compressed image data d**50** by performing the image compression processing on the image data do, and outputs the compressed

image data d**50** to the storage unit **13**. The storage unit **13** stores the compressed image data d**50** output from the image processing device **12**.
[0106] In addition, the image processing device **12** generates decompressed image data d**100** by performing image decompression processing on the compressed image data d**50** read from the storage unit **13**, and outputs the decompressed image data d**100** to the display device **14**. The display device **14** displays the decompressed image data d**100** output from the image processing device **12**.
[0107] The decompressed image data d**100** output from the image processing device **12** may be transmitted to any other device in addition to the display device **14** or instead of the display device **14**.
[0108] In the example illustrated in FIG. **7**, the image compression processing and the image decompression processing are performed by the common image processing device **12**, but the image compression processing and the image decompression processing may be performed by separate image processing devices **12**.
[0109] FIG. **8** is a block diagram illustrating a functional configuration example of the image processing device **12**, and particularly illustrates a functional configuration related to the image compression processing.
[0110] The image processing device **12** illustrated in FIG. **8** includes a square root calculation unit **21**, a fraction processing unit **22**, a word length adjustment unit **23**, a compression processing unit **24**, and a storage processing unit **25**.
[0111] The square root calculation unit **21** acquires first compressed image data d**11** by calculating a plurality of pixel square roots that are respective square roots of a plurality of original pixel values based on a plurality of pixel values d**1** included in the image data do input from the imaging element **11**.
[0112] Here, the plurality of original pixel values is derived by dividing each of the plurality of pixel values d**1** included in the image data do by a reference pixel value that is an output value corresponding to one electron in the photoelectric conversion processing of the imaging element **11** that has acquired the image data do.
[0113] Alternatively, the plurality of original pixel values may be the plurality of pixel values d**1** itself included in the image data do. In this case, the square root calculation unit **21** acquires the first compressed image data d**11** by dividing the calculated square root of each pixel value d**1** by the square root of the reference pixel value.
[0114] The reference pixel value used here is represented by the absolute value of “output value k [LSB] per electron (LSB: Least Significant Bit)” in each pixel **81** (see FIG. **1**) of the imaging element **11**. That is, **1** [LSB] of the output value (pixel value) of each pixel **81** of the imaging element **11** does not necessarily correspond to “one electron”, and a value amplified on the basis of a certain coefficient k is often output from each pixel **81**. Thus, each pixel **81** of the imaging element **11** outputs a pixel value d**1** based on the relationship of “1 electron=k [LSB]”.
[0115] Therefore, as described above, by performing the square root calculation after dividing each pixel value d**1** by the reference pixel value k or by performing division by using the square root of the reference pixel value k after calculating the square root of each pixel value d**1**, the pixel value d**1** is adjusted so that 1 [LSB] corresponds to “one electron”. As a result, the shot noise and quantization noise can be made approximately equal, and the number of significant digits of the pixel intensity information can be reduced while substantial missing of information is suppressed.
[0116] The fraction processing unit **22** performs fraction processing on a plurality of pixel square roots included in the first compressed image data d**11** to acquire integer-converted second compressed image data d**12**. For example, the fraction processing unit **22** can acquire the second compressed image data d**12** by rounding off the numerical value after the decimal point (that is, the fractional part) of each of the plurality of pixel square roots on the basis of rounding off.
[0117] However, the fraction processing unit **22** can also perform the fraction processing in a

manner other than rounding off (see FIG. **12** described later).
[0118] The word length adjustment unit **23** acquires third compressed image data d**13** by reducing the word length of the second compressed image data d**12** according to the magnitudes of the plurality of pixel values included in the second compressed image data d**12**.
[0119] For example, the word length adjustment unit **23** can acquire the third compressed image data d**13** by reducing the word length of the second compressed image data d**12** according to the number of significant digits of the maximum value among the plurality of pixel values included in the second compressed image data d**12**. Thus, it is also possible to derive the third compressed image data d**13** having a word length equal to or less than 8 bits from the second compressed image data d**12** having a word length equal to or more than 16 bits.
[0120] The compression processing unit **24** performs the compression processing on the third compressed image data d**13** to acquire fourth compressed image data d**14**. The compression processing unit **24** can perform the compression processing in any manner, and may perform the compression processing using the general-purpose image compression library.
[0121] The storage processing unit **25** causes the compressed image data d**50** based on the fourth compressed image data d**14** to be stored in the storage unit **13**. The compressed image data d**50** may be the fourth compressed image data d**14** itself, or may be image data derived by the storage processing unit **25** performing further processing on the fourth compressed image data d**14**.
[0122] Note that the third compressed image data d**13** and the fourth compressed image data d**14**, which are processing target data in the compression processing unit **24** and the storage processing unit **25** described above, both correspond to “compressed image data based on the second compressed image data d**12**”.
[0123] FIG. **9** is a block diagram illustrating a functional configuration example of the image processing device **12**, and particularly illustrates a functional configuration related to image decompression processing.
[0124] In a case where the image compression processing and the image decompression processing are performed by the common image processing device **12**, the image processing device **12** has a functional configuration related to the image decompression processing illustrated in FIG. **9** in addition to the functional configuration related to the image compression processing illustrated in FIG. **8**. In a case where the image compression processing and the image decompression processing are performed by the separate image processing devices **12**, one image processing device **12** has a functional configuration related to the image compression processing illustrated in FIG. **8**, and the other image processing device **12** has a functional configuration related to the image decompression processing illustrated in FIG. **9**.
[0125] The image processing device **12** illustrated in FIG. **9** includes a decompression processing unit **31**, a word length restoration unit **32**, a decoding unit **33**, and an output processing unit **34**.
[0126] The decompression processing unit **31** performs decompression processing on the compressed image data d**50** (that is, the fourth compressed image data d**14**) read from the storage unit **13** to acquire first decompressed image data d**21**. The decompression processing performed by the decompression processing unit **31** in this manner is processing corresponding to the compression processing performed by the above-described compression processing unit **24** (see FIG. **8**).
[0127] The word length restoration unit **32** increases the word length of the first decompressed image data d**21** to acquire second decompressed image data d**22**. That is, the word length restoration unit **32** acquires the second decompressed image data d**21** by increasing the word length of the first decompressed image data d**22** by the same word length as the word length reduced by the word length adjustment unit **23** (see FIG. **8**) in the above-described image compression processing.
[0128] The decompression processing performed by the word length restoration unit **32** in this manner is processing corresponding to the compression processing performed by the word length

adjustment unit **23** described above. The word length of the second decompressed image data d**22** output from the word length restoration unit **32** is the same word length as the word length of the image data do before the above-described compression processing (FIG. **8**) is performed.

[0129] The decoding unit **33** performs processing of squaring a plurality of pixel values included in the second decompressed image data d**22**. That is, the decoding unit **33** performs processing of squaring a plurality of pixel values included in the second decompressed image data d**22** after the word length of the first decompressed image data d**21** is increased and the second decompressed image data d**22** is acquired by the word length restoration unit **32**.

[0130] Then, the decoding unit **33** obtains a plurality of decompressed pixel values by multiplying a plurality of squared pixel values obtained by squaring a plurality of pixel values included in the second decompressed image data d**22** by the reference pixel value. Alternatively, the decoding unit **33** may acquire a plurality of decompressed pixel values by multiplying a plurality of pixel values included in the second decompressed image data d**22** by a square root of the reference pixel value and then squaring the multiplied pixel values. The reference pixel value used in the decoding unit **33** in this manner is also used when the above-described square root calculation unit **21** (see FIG. **9**) acquires a plurality of original pixel values from the pixel value d**1** included in the image data do.

[0131] The decompression processing performed by the decoding unit **33** as described above is processing corresponding to square root calculation processing performed by the square root calculation unit **21** described above.

[0132] The decoding unit **33** outputs third decompressed image data d**23** including a plurality of decompressed pixel values to the output processing unit **34**. The output processing unit **34** outputs the third decompressed image data d**23** to the display device **14** as the decompressed image data d**100**. The display device **14** displays the decompressed image data d**100** (the third decompressed image data d**23** in the present embodiment) input from the output processing unit **34**.

[0133] All of the fourth compressed image data d**14**, the first decompressed image data d**21**, and the second decompressed image data d**22**, which are processing target data in the decompression processing unit **31**, the word length restoration unit **32**, and the decoding unit **33** described above, correspond to compressed image data based on the second compressed image data d**12**.

[0134] Next, an example of an image processing method (that is, image compression processing and image decompression processing) performed by the above-described image processing device **12** will be described.

[Image Compression Processing]

[0135] FIG. **10** is a flowchart illustrating an example of the image compression processing.

[0136] First, image data do to be processed is input to the image processing device **12** (see FIG. **8**) (S**1** in FIG. **10**).

[0137] Then, the square root calculation unit **21** (see FIG. **8**) of the image processing device **12** calculates a square root of each pixel value d**1** (a plurality of pixel square roots) of the image data do and acquires the first compressed image data d**11** (S**2** in FIG. **10**).

[0138] In the present embodiment, the biological tissue image is used as the image data do, but the image that can be used as the image data do is not limited. The biological tissue image available as the image data do is not limited, and for example, a bright field microscope image, a dark field microscope image, or a fluorescence microscope image may be input to the image processing device **12** as the image data do.

[0139] In a case where the microscopic image is used as the image data do, the subject included in the image data do is not limited to the target in the visual field, and may be the entire slide by performing imaging while scanning the entire slide once or a plurality of times. Furthermore, in a case where the fluorescence microscope image is used as the image data do, imaging is performed while the wavelength of the excitation light with which the imaging target is irradiated is changed, and a plurality of pieces of image data do having different wavelengths of the excitation light may be acquired and input to the image processing device **12**. In addition, the slide of the imaging target may be automatically replaced, the imaging element **11** may automatically image the slide of the target, and the image data do of each slide may be automatically input from the imaging element **11** to the image processing device **12**.

[0140] In this processing step S**2**, calculating the square root of each original pixel value of the image data do corresponds to making a quantization level (that is, a value corresponding to one bit) for each original pixel value equivalent to shot noise.

[0141] FIG. **11** is a conceptual diagram of pixel data for describing calculation of a square root of pixel data.

[0142] The processing of calculating the square root of the pixel data is processing of halving the number of significant digits of the integer part of the pixel data.

[0143] For example, as illustrated in FIG. **11**, in the square root of the original pixel data having the number of significant digits of 16 bits, the value of the upper half (upper 8 bits) of the original significant digits corresponds to the integer part, and the value of the lower half (lower 8 bits) of the original significant digits corresponds to the fractional part.

[0144] On the other hand, as described above, the shot noise included in each pixel data corresponds to the lower half digits (shot noise floor) of the significant digits of the pixel data (see FIGS. **3** to **6**), and the shot noise floor does not include or hardly includes the data of the original subject image.

[0145] Therefore, in this processing step S**2**, calculating the square root of each original pixel value corresponds to calculating a pixel value in which most of the shot noise is represented by a fractional part and most of the data of the original subject image is represented by an integer part.

[0146] Note that, in general, it is considered that quantization noise tends to increase as the quantization level increases. However, in the present embodiment, since the square root of each original pixel value is calculated in order to acquire the first compressed image data d**11** as described above, the quantization level is equivalent to the shot noise. Thus, in this processing step S**2** of acquiring the first compressed image data d**11**, the influence of the quantization noise on each pixel value is very limited.

[0147] Since the level of shot noise is equal to or proportional to the square root of each pixel value d**1** (signal value of each pixel), for example, in a dark image region in the image data do, the intensity value of the shot noise is absolutely low, and in a bright image region, the intensity value of the shot noise is absolutely high.

[0148] Thus, when quantization is performed at the same level for the entire region of the image data do, only the noise signal component can be reduced in the bright image region, but the subject image component may be reduced together with the noise signal component in the dark image region.

[0149] On the other hand, by calculating the square root of each original pixel value of the image data do as in the present embodiment, the substantial quantization level for each pixel is changed according to the magnitude of the original pixel value (pixel value d**1**). Therefore, in both the bright image region and the dark image region, it is possible to effectively prevent a signal component meaningful as an image from being cut off by quantization.

[0150] Then, the fraction processing unit **22** (see FIG. **8**) of the image processing device **12** performs the fraction processing on each pixel value (that is, each pixel square root) of the first compressed image data d**11**, and the fractional part of each pixel square root is rounded (S**3** in FIG. **10**). The second compressed image data d**12** is acquired by converting each pixel value into an integer in this manner, and each of the plurality of pixel values included in the second compressed image data d**12** becomes an integer value.

[0151] For example, the fraction processing unit **22** may convert each pixel value into an integer by rounding the numerical value at the first decimal place of each pixel square root on the basis of “rounding off”. Alternatively, the fraction processing unit **22** may convert each pixel value into an integer on the basis of any other method.

[0152] Specifically, fraction processing based on rounding off can be performed on the basis of the following Expression (1).

[00001] $A = \text{Integerpart}[\text{Sqrt}[x] + 0.5]$ Expression(1)

[0153] In the above Expression (1), “A” represents a value (that is, an integer value) derived by fraction processing, and “x” represents each pixel value (each pixel square root) of the first compressed image data d**11** that is the original value. “Sqrt [x]” represents a square root calculation operator of x, and “IntegerPart [Q]” represents an operator for extracting an integer part of Q.

[0154] Fraction processing based on rounding off represented by the above Expression (1) has an advantage that calculation is simple, but is not a method for minimizing quantization noise.

[0155] FIG. **12** is a diagram for describing a fraction processing example.

[0156] In FIG. **12**, the horizontal axis represents a pixel value (original pixel value), and the vertical axis represents a pixel square root that is the square root of the pixel value. A solid curve illustrated in FIG. **12** indicates a correspondence between the pixel value and a pixel square root.

[0157] A solid line extending between the curve illustrated in FIG. **12** and the vertical axis and the horizontal axis in FIG. **12** indicates a case where both the corresponding pixel value and the pixel square root are integer values.

[0158] A straight line of a one-dot chain line extending between the curve illustrated in FIG. **12** and each of the vertical axis and the horizontal axis in FIG. **12** corresponds to a boundary in a case where fraction processing of a pixel square root is performed on the basis of rounding off.

[0159] A dotted straight line extending between the curve illustrated in FIG. **12** and each of the vertical axis and the horizontal axis in FIG. **12** corresponds to a boundary in a case where fraction processing of a pixel square root is performed on the basis of a rounding reference value that is the square root of a center value between n{circumflex over ( )}2 (n is a natural number).

[0160] A case will be considered where, after square root compression is tentatively applied to a random variable continuously distributed with equal probability in the range from 0 to a measurement maximum value, a variance of an original random variable is minimized. In this case, an expected value of the quantization level can be minimized by performing fraction processing (that is, rounding down processing and rounding up processing) using the square root of a center value (middle value) between “n{circumflex over ( )}2 (n is a natural number)” as a boundary value (incorporation boundary value).

[0161] Here, the “center value between n{circumflex over ( )}2 (n is a natural number)” is represented by, for example, (n.sup.2+(n+1).sup.2)/2. Therefore, the “square root of the center value between n{circumflex over ( )}2 (n is a natural number)” is represented by, for example, {(n.sup.2+(n+1).sup.2)/2}{circumflex over ( )}.sup.(1/2). For example, a pixel square root larger than “n (n is a natural number)” and smaller than “n+1” may be rounded to “n+1” by fraction processing in a case where the square root is equal to or larger than a rounding reference value represented by {(n.sup.2+(n+1).sup.2)/2} {circumflex over ( )}.sup.(1/2). On the other hand, in a case where the pixel square root is smaller than the rounding reference value, the square root of the pixel may be rounded to “n” by fraction processing.

[0162] It can be said that the case of performing the fraction processing of the pixel square root using the square root of the center value between n{circumflex over ( )}2 (n is a natural number) as a rounding reference value is more suitable for the actual situation than the case of applying rounding off to the pixel square root for converting the pixel square root into an integer. That is, for each square root of pixels, an approximation original pixel value that is n{circumflex over ( )}2 (n is a natural number) having the smallest difference with respect to the pixel value (original pixel value) corresponding to each pixel square root may be obtained, and n for the approximation original pixel value may be employed as the pixel value of the second compressed image data d**12**.

[0163] In a case where rounding off is applied to the pixel square root, the integer value after the

fraction processing changes above and below a one-dot chain line (incorporation boundary) extending in a horizontal direction from the vertical axis in FIG. **12**. On the other hand, in a case where the fraction processing in which the square root of the center value between n{circumflex over ( )}2 (n is a natural number) is employed as the rounding reference value is applied to the pixel square root, the integer value after the fraction processing changes above and below the dotted line (incorporated boundary) extending in the horizontal direction from the vertical axis in FIG. **12**. Therefore, the pixel square root located between the one-dot chain line and the dotted line extending in the horizontal direction from the vertical axis in FIG. **12** is converted into an integer value not conforming to the actual situation when rounding off is used for the fraction processing, which leads to an increase in quantization noise.
[0164] On the other hand, as indicated by a dotted line in FIG. **12**, by employing n for the approximation original pixel value that is n{circumflex over ( )}2 (n is a natural number) having the smallest difference with respect to the original pixel value corresponding to each pixel square root as a value after the fraction processing of each pixel square root, an increase in quantization noise can be suppressed.
[0165] The above-described “fraction processing of employing n for the approximation original pixel value that is n{circumflex over ( )}2 (n is a natural number) having the smallest difference with respect to the original pixel value corresponding to each pixel square root as a value after the fraction processing of each pixel square root” can be specifically performed on the basis of the following Expressions (2) and (3). The meaning of each symbol of the following Expressions (2) and (3) is similar to that of the above Expression (1).
[00002] n = IntegerPart[Sqrt[x]] Expression(2)

A = IntegerPart[1 + n - Sqrt[1 / 2 + n + $n^{\cdot \text{Math.}}$ 2] + Sqrt[x]] Expression(3)

[0166] Then, the word length of the second compressed image data d**12** is reduced by the word length adjustment unit **23** (see FIG. **8**) of the image processing device **12**, and the third compressed image data d**13** is acquired (S**4** in FIG. **10**).
[0167] The extent of the data word length reduced by the word length adjustment unit **23** is not limited, but it is preferable that the word length of each pixel value of the second compressed image data d**12** is reduced according to the magnitudes (particularly, the maximum values) of the plurality of pixel values included in the second compressed image data d**12**. That is, the word length adjustment unit **23** can reduce the word length of each pixel value of the second compressed image data d**12** to the number of digits that can indicate all the pixel values included in the second compressed image data d**12** (that is, the number of digits that can indicate the maximum value of the pixel value).
[0168] For example, in a case where the pixel value d**1** indicating the maximum value in the image data do has the number of significant digits of 16 bits, the pixel value has the number of significant digits of 8 bits by the above-described square root calculation and integer conversion. Thus, the word length adjustment unit **23** may reduce the word length of each pixel value of the second compressed image data d**12** and acquire the third compressed image data d**13** in which each pixel value has a word length of 8 bits.
[0169] As described above, the word length adjustment unit **23** can cast (reduce) the word length of the pixel data to half. By thus halving the word length of the pixel data, the data amount can be halved as described above, and the influence of shot noise can be reduced to about 1 [LSB] (see FIG. **11** described above).
[0170] Then, additional compression processing of the third compressed image data d**13** is performed by the compression processing unit **24** (see FIG. **8**) of the image processing device **12**, and the fourth compressed image data d**14** is acquired (S**5** in FIG. **10**).
[0171] Then, the fourth compressed image data d**14** is stored in the storage unit **13** as the compressed image data d**50** by the storage processing unit **25** (see FIG. **8**) of the image processing

device **12** (S**6** in FIG. **10**).

[0172] The additional compression processing performed by the compression processing unit **24** is not limited, and may be lossless compression processing or lossy compression such as JPEG.

[0173] As described above, the additional compression processing is performed on the image data in which the shot noise is reduced and the data amount is compressed by the above-described processing steps S**2** to S**4**, whereby the compression rate of the image data is further increased.

[0174] Note that, in a case where the word length of each pixel data has become half or less by the processing in the above-described processing steps S**2** to S**4**, the image data amount has also become half or less, and thus it can be said that a sufficient image compression rate has already been achieved. Therefore, the image data (compressed image data) acquired as a result of processing steps S**2** to S**4** described above may be stored in the storage unit **13** without performing this processing step S**5**.

[0175] However, the noise component (shot noise) reduced through the above-described processing steps S**2** to S**4** is information having no meaning for the observer, and is an element that increases the information entropy that defines the limit of the image compression rate.

[0176] Thus, in a case where the additional image compression processing is performed on the image data in which the noise component is sufficiently reduced by the above-described processing steps S**2** to S**4**, a better result can be expected in terms of the processing speed and the compression rate in the additional image compression processing.

[0177] As described above, in general, compression processing using DCT compression such as JPEG may result in loss of details of a dark portion of an image. However, by performing the above-described processing steps S**2** to S**4** as pre-stage compression processing prior to the DCT compression, loss of details of the dark portion of the image due to the subsequent DCT compression (additional image compression processing) can be reduced.

[0178] In particular, while the dynamic range of each pixel data is effectively compressed by the square root calculation processing (S**2** in FIG. **10**), reduction in the dynamic range of the image after decompression is suppressed, so that details of the dark portion of the image tend not to be lost even if additional image compression processing is performed.

[0179] Furthermore, the amount of image data subjected to such additional compression processing is half or less of the original amount of image data by the compression processing in the preceding processing steps S**2** to S**4**. Thus, the data transfer time and the compression processing operation amount required for the additional compression processing are reduced, and the overall processing speed of the additional compression processing is increased.

[0180] In addition, the image data amount after the additional compression processing is compressed to half or less (about 1/10 at times) of the original image data amount. Thus, the data transfer time when the compressed image data d**50** (fourth compressed image data d**14**) is stored in the storage unit **13** is significantly shortened, the storage capacity required for the storage unit **13** can be significantly reduced, and the storage cost can be reduced.

[0181] In addition, in the image data (pixel data), in order to ensure a wide dynamic range in the conventional method, it is necessary to secure a word length of a corresponding length. For example, when the word length of the image data (pixel data) is about 16 bits, a general-purpose compression library that can be used for the additional compression processing is limited. On the other hand, since the word length of the image data is sufficiently reduced by the above-described processing steps S**2** to S**4**, the range of selection of the general-purpose compression library that can be used for the additional compression processing is expanded.

[Image Decompression Processing]

[0182] FIG. **13** is a flowchart illustrating an example of image decompression processing.

[0183] The image decompression processing can be executed on the basis of a procedure reverse to the above-described image compression processing.

[0184] That is, first, the compressed image data d**50** (fourth compressed image data d**14** in the present embodiment) is acquired from the storage unit **13** by the image processing device **12** (for example, the decompression processing unit **31**) (S**11** in FIG. **13**).

[0185] Then, decompression processing on the compressed image data d**50** is performed by the decompression processing unit **31**, and the first decompressed image data d**21** is acquired (S**12**). The decompression processing here is processing corresponding to the compression processing (see S**5** in FIG. **10**) by the compression processing unit **24** described above.

[0186] Then, the word length of the first decompressed image data d**21** is increased by the word length restoration unit **32**, and the second decompressed image data d**22** is acquired (S**13**). The word length increasing processing here is processing corresponding to the word length reducing processing (see S**4** in FIG. **10**) by the word length adjustment unit **23** described above.

[0187] Then, by the decoding unit **33**, each of the plurality of pixel values included in the second decompressed image data d**22** is squared to obtain a plurality of squared pixel values, and the plurality of squared pixel values is multiplied by the reference pixel value to obtain a plurality of decompressed pixel values (S**14**). The square processing here is processing corresponding to the square root calculation processing (see S**2** in FIG. **10**) by the square root calculation unit **21** described above.

[0188] Note that, in this processing step S**14**, the decoding unit **33** may alternatively obtain a plurality of decompressed pixel values by squaring a value obtained by multiplying each of a plurality of pixel values included in the second decompressed image data d**22** by a square root of the reference pixel value.

[0189] Then, the output processing unit **34** outputs the third decompressed image data d**23** including the plurality of decompressed pixel values obtained through the series of processing steps S**11** to S**14** to the display device **14** as the decompressed image data d**100** (S**15**). As a result, the decompressed image data d**100** is displayed on the display device **14**.

[0190] Note that, intuitively, there may be a concern that the quantization noise increases by the square root calculation processing (see S**2** in FIG. **10**) performed in the above-described image compression processing as compared with a case where the square root calculation processing is not performed.

[0191] However, in the above-described image compression processing, in principle, shot noise is included in the pixel data at a ratio equivalent to the quantization level, and thus, actually, an increase in quantization noise is quite small.

[0192] The inventor of the present application has compared original pixel data including shot noise (original image data) with decompressed pixel data (decompressed image data) obtained from the original pixel data through the above-described image compression processing and image decompression processing.

[0193] As a result, the inventor of the present application confirmed that no obvious noise increase was observed in the decompressed pixel data, and that the magnitude of noise included in the decompressed pixel data was suppressed to 15% or less of the magnitude of noise included in the original pixel data for almost all pixel value intensities.

[0194] As described above, according to the present embodiment, it is possible to advantageously perform the image compression processing of the image data do while reducing the noise of the image data do.

[0195] That is, the reduction of shot noise and the reduction of the amount of stored image data can be achieved using the property that the shot noise is equal to or proportional to the square root of the pixel signal value (luminance value) and the property that the number of significant digits of the pixel signal value is halved by calculation of the square root of the pixel signal value.

[0196] In this way, by mathematically adjusting the image data so that the quantization error is equivalent to the shot noise that cannot be suppressed in principle, the inevitable shot noise component is removed from the image data, and the image data amount is reduced.

[0197] Therefore, for any pixel, data compression is performed so that the minimum value (**1**

[LSB]) of each pixel becomes the shot noise floor, and a signal component meaningful as the subject image is basically maintained. Thus, in any pixel, data amount compression in a state in which the dynamic range is substantially maintained is achieved. For example, in a case where the image data is a biological tissue image, it is possible to suppress the amount of stored data to half or less of the original amount of image data while ensuring a wide dynamic range and maintaining the texture unique to the tissue image.

[0198] As described above, the image compression processing and the image decompression processing of the present embodiment do not or hardly sacrifice intrinsic information in image data.

[0199] In addition, since the operation in the image compression processing and the image decompression processing of the present embodiment is relatively simple, and the operation of each pixel data is a single operand operation, high-speed processing can be performed, and parallel processing by a graphics processing unit (GPU) or the like can be easily achieved.

[0200] As described above, the above-described image compression technology and image decompression technology according to the present embodiment are based on a very simple method, but have physical and mathematical precise rationality, and are also excellent in versatility.

[0201] In addition, since the image data amount and the information entropy can be reduced, the efficiency of the additional compression processing is also improved.

[0202] Furthermore, since the data amount of the image data stored in the storage unit **13** is greatly reduced, the storage cost can be reduced. In addition, since the data transfer time is shortened and the storage processing time can be greatly shortened, stagnation of other processing performed before and after the storage processing can be suppressed, and improvement in processing efficiency of the entire system and shortening of the processing time can also be expected.

[0203] In particular, a wide-area image such as a multispectral image or slide imaging tends to have an enormous amount of data, but according to the present embodiment, it is possible to perform high-speed image storage processing and image decompression processing of an image having such an enormous amount of data.

Application Example

[0204] The device and the method of the above-described embodiments are merely examples, and an object to which the above-described image compression technology and image decompression technology can be applied is not limited.

[Microscope System]

[0205] FIG. **14** is a block diagram illustrating a configuration example of a microscope system.

[0206] The microscope system illustrated in FIG. **14** includes a microscope **101** and a data processing unit **107**. FIG. **14** illustrates an example of a measurement system capable of capturing an image of a wide visual field region of fluorescent-stained specimen **30** and a fluorescent-unstained specimen, and the measurement system is also applicable to, for example, Whole Slide Imaging (WSI).

[0207] The microscope **101** includes a stage **102**, an optical system **103**, a light source **104**, a stage drive unit **105**, a light source drive unit **106**, and a fluorescence signal acquisition unit **112**.

[0208] The stage **102** has a placement surface on which the fluorescent-stained specimen **30** and the fluorescent-unstained specimen can be placed, and is provided to be movable in a horizontal direction (an x-y plane direction) parallel to the placement surface and a vertical direction (a z-axis direction), by driving of the stage drive unit **105**. The fluorescent-stained specimen **30** has a thickness of, for example, several μm to several tens μm in the Z-axis direction, and is fixed by a predetermined technique while being sandwiched between a slide glass SG and a cover glass (not illustrated).

[0209] The optical system **103** is disposed above the stage **102**. The optical system **103** includes an objective lens **103**A, an imaging lens **103**B, a dichroic mirror **103**C, an emission filter **103**D, and an excitation filter **103**E. The light source **104** is, for example, a light bulb such as a mercury lamp, a light emitting diode (LED), or the like, and emits light by driving of the light source drive unit

106. The light emitted from the light source **104** is guided to the fluorescent-stained specimen **30** or the fluorescent-unstained specimen on the placement surface of the stage **102**, via the optical system **103**.

[0210] In a case of obtaining fluorescence images of the fluorescent-stained specimen **30** and the fluorescent-unstained specimen, the excitation filter **103**E generates excitation light by transmitting only light having an excitation wavelength for exciting the fluorescent dye among light emitted from the light source **104**. The dichroic mirror **103**C reflects the excitation light transmitted through the excitation filter **103**E and incident thereon, and guides the excitation light to the objective lens **103**A. The objective lens **103**A condenses the excitation light on the fluorescent-stained specimen **30**. The objective lens **103**A and the imaging lens **103**B magnify the image of the fluorescent-stained specimen **30** to a predetermined magnification, and form the magnified image on the imaging surface of the fluorescence signal acquisition unit **112**.

[0211] When the fluorescent-stained specimen **30** is irradiated with excitation light, a stain (fluorescent reagent) and an autofluorescence component bound to each tissue of the fluorescent-stained specimen **30** emit fluorescence. This fluorescence is transmitted through the dichroic mirror **103**C via the objective lens **103**A, and reaches the imaging lens **103**B via the emission filter **103**D. The emission filter **103**D absorbs a part of the light enlarged by the objective lens **103**A and transmitted through the excitation filter **103**E, and transmits only a part of color light. As described above, an image of the color light in which the external light is lost is enlarged by the imaging lens **103**B, and formed on the fluorescence signal acquisition unit **112**.

[0212] Note that a spectroscope (not illustrated) may be provided instead of the imaging lens **103**B illustrated in FIG. **14**. The spectroscope can be configured using one or more prisms, lenses, and the like, and disperses fluorescence from the fluorescent-stained specimen **30** or the fluorescent-unstained specimen in a predetermined direction. In this case, the fluorescence signal acquisition unit **112** is configured as a photodetector that detects light intensity for each wavelength of fluorescence dispersed by the spectroscope, and inputs a detected fluorescence signal to the data processing unit **107**.

[0213] The data processing unit **107** drives the light source **104** via the light source drive unit **106**, acquires fluorescence spectra/fluorescence images of the fluorescent-stained specimen **30** and the fluorescent-unstained specimen by using the fluorescence signal acquisition unit **112**, and performs various types of processing by using the acquired fluorescence spectra/fluorescence images.

[0214] As described above, in the microscope system illustrated in FIG. **14**, at least the light source **104**, the excitation filter **103**E, the dichroic mirror **103**C, and the objective lens **103**A serve as a light irradiation unit that emits excitation light for exciting the fluorescent reagent. Furthermore, the fluorescence signal acquisition unit **112** serves as an imaging device that images a specimen (the fluorescent-stained specimen **30** or the fluorescent-unstained specimen) being irradiated with excitation light to acquire a specimen fluorescence spectrum. Furthermore, the data processing unit **107** serves as an information processing device that analyzes the specimen fluorescence spectrum.

[0215] Note that the above-described device described with reference to FIG. **14** is merely an example, and the measurement system according to the above-described embodiment and modifications is not limited to the example illustrated in FIG. **14**. For example, the microscope system may not necessarily include all of the configurations illustrated in FIG. **14**, or may include a configuration not illustrated in FIG. **14**.

[0216] The above-described embodiment and modifications can be implemented using a measurement system capable of acquiring image data (hereinafter referred to as "wide visual field image data") with a sufficient resolution for the entire image-capturing target region or a necessary region (hereinafter also referred to as "region of interest") in the image-capturing target region. For example, the above-described embodiments and modifications can be implemented using a measurement system capable of capturing an image of the entire image-capturing target region or a necessary region of the image-capturing target region at one time, or a measurement system that

acquires an image of the entire image-capturing region or the region of interest by line scanning.
[0217] In the microscope system illustrated in FIG. **14**, in a case where the entire image-capturing region is WSI exceeding a region where image data can be acquired in one time of image-capturing (hereinafter referred to as "visual field"), image-capturing of each visual field is sequentially performed by moving the stage **102** for each time of image-capturing. By tiling image data (hereinafter referred to as "visual field image data") obtained by image-capturing of each visual field, wide visual field image data of the entire image-capturing region is generated.
[0218] The imaging processing system **10** illustrated in FIG. **7** described above may be applied to the microscope system illustrated in FIG. **14**. That is, in the microscope system illustrated in FIG. **14**, the "fluorescence signal acquisition unit **112**" may be used as the imaging element **11** illustrated in FIG. **7**, and the "data processing unit **107**" may be used as the image processing device **12**, the storage unit **13**, the display device **14**, and the imaging processing control unit **15** illustrated in FIG. **7**. Alternatively, other devices in addition to the "data processing unit **107**" or in place of the "data processing unit **107**" may be used as the image processing device **12**, the storage unit **13**, the display device **14**, and the imaging processing control unit **15** illustrated in FIG. **7**.
[Imaging Device]
[0219] FIG. **15** is a diagram illustrating an example of the imaging device **200**.
[0220] An imaging device **200** illustrated in FIG. **15** includes an imaging optical system **202** and an imaging light emitting unit **203** mounted on an imaging main body unit **201**.
[0221] The imaging device **200** is configured as what is called a digital camera, and can be configured as a compact camera with no interchangeable lens or an interchangeable lens camera (for example, a single-lens reflex camera or a mirrorless camera). However, the specific configuration and application of the imaging device **200** are not limited.
[0222] The imaging processing system **10** illustrated in FIG. **7** described above may be applied to the imaging device **200** illustrated in FIG. **15**. That is, the imaging element **11**, the image processing device **12**, the storage unit **13**, the display device **14**, and the imaging processing control unit **15** illustrated in FIG. **7** may be mounted on the imaging main body unit **201** illustrated in FIG. **15**.
[Mobile Device]
[0223] FIG. **16** is a diagram illustrating an example of the mobile device **300**.
[0224] A mobile device **300** illustrated in FIG. **16** includes a device imaging unit **302** mounted on a device main body unit **301**. The device imaging unit **302** illustrated in FIG. **16** is configured as what is called a front camera, but the mobile device **300** may include a rear camera (not illustrated) mounted on the back side of the device main body unit **301**.
[0225] The mobile device **300** is typically configurable as a mobile phone, smartphone or other tablet terminal. However, a specific configuration and application of the mobile device **300** are not limited.
[0226] The imaging processing system **10** illustrated in FIG. **7** described above may be applied to the mobile device **300** illustrated in FIG. **16**. That is, the imaging element **11**, the image processing device **12**, the storage unit **13**, the display device **14**, and the imaging processing control unit **15** illustrated in FIG. **7** may be mounted on the device main body unit **301** illustrated in FIG. **16**.
[Client Server System]
[0227] FIG. **17** is a diagram illustrating an example of the client server system **400**.
[0228] A client server system **400** illustrated in FIG. **17** includes a client **401**, an information processing device **403**, and a server **404** connected to each other via a network **405**.
[0229] The client **401** and the information processing device **403** can upload and store various data to the server **404** via the network **405**, and can download and acquire various data stored in the server **404** and/or calculated by the server **404**.
[0230] In response to a request (command signal) from the client **401** and the information processing device **403**, the server **404** can store various kinds of data transmitted from the client

401 and the information processing device **403**, transmit various kinds of stored data, or perform various kinds of data processing.

[0231] For example, the image data do may be transmitted from the client **401** and/or the information processing device **403** to the server **404** via the network **405**. In this case, the server **404** may function as the image processing device **12** and the storage unit **13** described above. That is, the server **404** may acquire the compressed image data d**50** by performing the above-described image compression processing (see FIGS. **8** and **10**) on the image data do transmitted from the information processing device **403**, and store the compressed image data d**50** in a storage unit (not illustrated) included in the server itself. Furthermore, the server **404** may acquire the decompressed image data d**100** by performing the above-described image decompression processing (see FIGS. **9** and **13**) on the compressed image data d**50**, and transmit the decompressed image data d**100** to the client **401** and/or the information processing device **403**.

[0232] Note that the server **404** may perform only one of the above-described image compression processing (see FIGS. **8** and **10**) and image decompression processing (see FIGS. **9** and **13**).

[0233] For example, the server **404** may perform the above-described image compression processing (see FIGS. **8** and **10**) on the image data do transmitted from the client **401** and/or the information processing device **403** via the network **405**, and store the compressed image data d**50**. Then, the server **404** may transmit the compressed image data d**50** to the client **401** and/or the information processing device **403** in response to the request without performing the image decompression processing. In this case, the client **401** and/or the information processing device **403** functions as the above-described image processing device **12**, and performs the above-described image decompression processing (see FIGS. **9** and **13**) on the received compressed image data d**50** to acquire the decompressed image data d**100**.

[0234] Furthermore, the server **404** may store the compressed image data d**50** transmitted from the client **401** and/or the information processing device **403** via the network **405**, perform image decompression processing on the compressed image data d**50** in response to a request, and transmit the decompressed image data d**100**. In this case, the client **401** and/or the information processing device **403** functions as the above-described image processing device **12**, and performs the above-described image compression processing (see FIGS. **8** and **10**) on the image data do to acquire the compressed image data d**50**. On the other hand, the server **404** also functions as the above-described image processing device **12**, and performs the above-described image decompression processing (see FIGS. **9** and **13**) on the compressed image data d**50** to acquire the decompressed image data d**100**.

[0235] Furthermore, the server **404** need not function as the above-described image processing device **12**, and may function only as the above-described storage unit **13**. That is, the server **404** may store the compressed image data d**50** transmitted from the client **401** and/or the information processing device **403** via the network **405**, and transmit the compressed image data d**50** to the client **401** and/or the information processing device **403** in response to a request. In this case, the client **401** and/or the information processing device **403** function as the above-described image processing device **12**.

[0236] Note that the client **401** and the information processing device **403** may have functions equivalent to each other or may play roles different from each other. For example, the information processing device **403** may exclusively transmit the image data do or the compressed image data d**50** to the server **404**, while the client **401** may exclusively acquire the compressed image data d**50** or the decompressed image data d**100** from the server **404**.

[0237] It should be noted that the embodiments and modifications disclosed in the present description are illustrative only in all respects and are not to be construed as limiting. The above-described embodiments and modifications can be omitted, replaced, and changed in various forms without departing from the scope and spirit of the appended claims. For example, the above-described embodiments and modifications may be combined in whole or in part, and other

embodiments may be combined with the above-described embodiments or modifications. Furthermore, the effects of the present disclosure described in the present description are merely exemplification, and other effects may be provided.
[0238] A technical category embodying the above technical idea is not limited. For example, the above-described technical idea may be embodied by a computer program for causing a computer to execute one or a plurality of procedures (steps) included in a method of manufacturing or using the above-described device. Furthermore, the above-described technical idea may be embodied by a computer-readable non-transitory recording medium in which such a computer program is recorded.
Supplementary Note
[0239] The present disclosure can also have the following configurations.
Item 1
[0240] An image processing device including: [0241] a square root calculation unit that acquires first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data; and [0242] a fraction processing unit that acquires second compressed image data by performing fraction processing of the plurality of pixel square roots.
Item 2
[0243] The image processing device according to item 1, in which [0244] the plurality of original pixel values is derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data.
Item 3
[0245] The image processing device according to item 1 or 2, in which [0246] the fraction processing unit acquires the second compressed image data by rounding a numerical value after a decimal point of each of the plurality of pixel square roots on a basis of rounding off.
Item 4
[0247] The image processing device according to any one of items 1 to 3, in which [0248] the fraction processing unit obtains an approximation original pixel value that is n{circumflex over ( )}}2 (n is a natural number) having a smallest difference with respect to an original pixel value corresponding to each of the pixel square roots for each of the plurality of pixel square roots, and employs n of the approximation original pixel value as a pixel value of the second compressed image data.
Item 5
[0249] The image processing device according to any one of items 1 to 4, further including: [0250] a word length adjustment unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data.
Item 6
[0251] The image processing device according to item 5, in which [0252] the word length adjustment unit acquires the third compressed image data by reducing the word length of the second compressed image data according to a number of significant digits of a maximum value among the plurality of pixel values included in the second compressed image data.
Item 7
[0253] The image processing device according to item 5 or 6, in which [0254] the second compressed image data has a word length equal to or more than 16 bits, and [0255] the third compressed image data has a word length equal to or less than 8 bits.
Item 8
[0256] The image processing device according to any one of items 1 to 7, further including: [0257] a compression processing unit that acquires fourth compressed image data by performing

compression processing on compressed image data based on the second compressed image data.
Item 9
[0258] The image processing device according to item 8, further including: [0259] a word length adjustment unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data, in which [0260] the compression processing unit acquires fourth compressed image data by performing compression processing on the third compressed image data.
Item 10
[0261] The image processing device according to any one of items 1 to 9, further including: [0262] a storage processing unit that causes compressed image data (for example, the second compressed image data, the third compressed image data, or the fourth compressed image data) based on the second compressed image data to be stored in a storage unit.
Item 11
[0263] The image processing device according to any one of items 1 to 10, further including: [0264] a decoding unit that performs processing of squaring a plurality of pixel values included in compressed image data (for example, the second compressed image data, the third compressed image data, or the fourth compressed image data) based on the second compressed image data.
Item 12
[0265] The image processing device according to item 11, further including: [0266] a word length restoration unit that increases a word length of the compressed image data based on the second compressed image data, in which [0267] the decoding unit performs processing of squaring a plurality of pixel values included in the compressed image data based on the second compressed image data after the word length of the compressed image data based on the second compressed image data is increased by the word length restoration unit.
Item 13
[0268] The image processing device according to item 11 or 12, further including: [0269] a compression processing unit that acquires fourth compressed image data by performing compression processing of the compressed image data based on the second compressed image data; and [0270] a decompression processing unit that performs decompression processing on the compressed image data based on the second compressed image data, in which [0271] the compressed image data to be decompressed is based on the fourth compressed image data, and [0272] the decompression processing is processing corresponding to the compression processing performed by the compression processing unit.
Item 14
[0273] The image processing device according to any one of items 11 to 13, in which [0274] the plurality of original pixel values is derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data, and [0275] the decoding unit acquires a plurality of decompressed pixel values by multiplying a plurality of squared pixel values obtained by squaring a plurality of pixel values included in the compressed image data based on the second compressed image data by the reference pixel value.
Item 15
[0276] The image processing device according to any one of items 1 to 14, in which [0277] the image data is biological tissue image data.
Item 16
[0278] The image processing device according to item 15, in which [0279] the biological tissue image data is fluorescent antibody image data.
Item 17
[0280] An image processing method including: [0281] a step of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original

pixel values based on a plurality of pixel values included in image data; and [0282] a step of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.
Item 18
[0283] A program for causing a computer to execute: [0284] a procedure of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data; and [0285] a procedure of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.
REFERENCE SIGNS LIST
[0286] **10** Imaging processing system [0287] **11** Imaging element [0288] **12** Image processing device [0289] **13** Storage unit [0290] **14** Display device [0291] **15** Imaging processing control unit [0292] **21** Square root calculation unit [0293] **22** Fraction processing unit [0294] **23** Word length adjustment unit [0295] **24** Compression processing unit [0296] **25** Storage processing unit [0297] **31** Decompression processing unit [0298] **32** Word length restoration unit [0299] **33** Decoding unit [0300] **34** Output processing unit [0301] **80** Photon [0302] **81** Pixel [0303] **82** Electron [0304] **83** Electronic storage unit [0305] **101** Microscope [0306] **102** Stage [0307] **103** Optical system [0308] **103**A Objective lens [0309] **103**B Imaging lens [0310] **103**C Dichroic mirror [0311] **103**D Emission filter [0312] **103**E Excitation filter [0313] **104** Light source [0314] **105** Stage drive unit [0315] **106** Light source drive unit [0316] **107** Data processing unit [0317] **112** Fluorescence signal acquisition unit [0318] **200** Imaging device [0319] **201** Imaging main body unit [0320] **202** Imaging optical system [0321] **203** Imaging light emitting unit [0322] **300** Mobile device [0323] **301** Device main body unit [0324] **302** Device imaging unit [0325] **400** Client server system [0326] **401** Client [0327] **403** Information processing device [0328] **404** Server [0329] **405** Network [0330] d**0** Image data [0331] d**1** Pixel value [0332] d**11** First compressed image data [0333] d**12** Second compressed image data [0334] d**13** Third compressed image data [0335] d**14** Fourth compressed image data [0336] d**21** First decompressed image data [0337] d**22** Second decompressed image data [0338] d**23** Third decompressed image data [0339] d**50** Compressed image data [0340] d**100** Decompressed image data

Claims

1. An image processing device comprising: a square root calculation unit that acquires first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data; and a fraction processing unit that acquires second compressed image data by performing fraction processing of the plurality of pixel square roots.
2. The image processing device according to claim 1, wherein the plurality of original pixel values is derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data.
3. The image processing device according to claim 1, wherein the fraction processing unit acquires the second compressed image data by rounding a numerical value after a decimal point of each of the plurality of pixel square roots on a basis of rounding off.
4. The image processing device according to claim 1, wherein the fraction processing unit obtains an approximation original pixel value that is n{circumflex over ( )}2 (n is a natural number) having a smallest difference with respect to an original pixel value corresponding to each of the pixel square roots for each of the plurality of pixel square roots, and employs n of the approximation original pixel value as a pixel value of the second compressed image data.
5. The image processing device according to claim 1, further comprising: a word length adjustment

unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data.

6. The image processing device according to claim 5, wherein the word length adjustment unit acquires the third compressed image data by reducing the word length of the second compressed image data according to a number of significant digits of a maximum value among the plurality of pixel values included in the second compressed image data.

7. The image processing device according to claim 5, wherein the second compressed image data has a word length equal to or more than 16 bits, and the third compressed image data has a word length equal to or less than 8 bits.

8. The image processing device according to claim 1, further comprising: a compression processing unit that acquires fourth compressed image data by performing compression processing on compressed image data based on the second compressed image data.

9. The image processing device according to claim 8, further comprising: a word length adjustment unit that acquires third compressed image data by reducing a word length of the second compressed image data according to sizes of a plurality of pixel values included in the second compressed image data, wherein the compression processing unit acquires fourth compressed image data by performing compression processing on the third compressed image data.

10. The image processing device according to claim 1, further comprising: a storage processing unit that causes compressed image data based on the second compressed image data to be stored in a storage unit.

11. The image processing device according to claim 1, further comprising: a decoding unit that performs processing of squaring a plurality of pixel values included in compressed image data based on the second compressed image data.

12. The image processing device according to claim 11, further comprising: a word length restoration unit that increases a word length of the compressed image data based on the second compressed image data, wherein the decoding unit performs processing of squaring a plurality of pixel values included in the compressed image data based on the second compressed image data after the word length of the compressed image data based on the second compressed image data is increased by the word length restoration unit.

13. The image processing device according to claim 11, further comprising: a compression processing unit that acquires fourth compressed image data by performing compression processing of the compressed image data based on the second compressed image data; and a decompression processing unit that performs decompression processing on the compressed image data based on the second compressed image data, wherein the compressed image data to be decompressed is based on the fourth compressed image data, and the decompression processing is processing corresponding to the compression processing performed by the compression processing unit.

14. The image processing device according to claim 11, wherein the plurality of original pixel values is derived by dividing a plurality of pixel values included in the image data by a reference pixel value that is an output value corresponding to one electron in photoelectric conversion processing of the imaging element that has acquired the image data, and the decoding unit acquires a plurality of decompressed pixel values by multiplying a plurality of squared pixel values obtained by squaring a plurality of pixel values included in the compressed image data based on the second compressed image data by the reference pixel value.

15. The image processing device according to claim 1, wherein the image data is biological tissue image data.

16. The image processing device according to claim 15, wherein the biological tissue image data is fluorescent antibody image data.

17. An image processing method comprising: a step of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data; and a step of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.

18. A program for causing a computer to execute: a procedure of acquiring first compressed image data by calculating a plurality of pixel square roots that are square roots of a plurality of original pixel values based on a plurality of pixel values included in image data; and a procedure of acquiring second compressed image data by performing fraction processing of the plurality of pixel square roots.