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(71) Applicant: **LEICA MICROSYSTEMS INC.** [US/US];
1700 Leider Lane, Buffalo Grove, Illinois 60089 (US).

(71) Applicant (for AL only): **LEICA MICROSYSTEMS
CMS GMBH** [DE/DE]; Ernst-Leitz-Str. 17-37, 35578 Wet-
zlar (DE).

(72) Inventor: **BRANCO, Dorothy**; 204 Fallenwood Ave.,
Durham, North Carolina 27713 (US).

(74) Agent: **DEHNSGERMANY PARTNERSCHAFT VON
PATENTANWÄLTEN**; Theresienstr. 6-8, 80333
München (DE).

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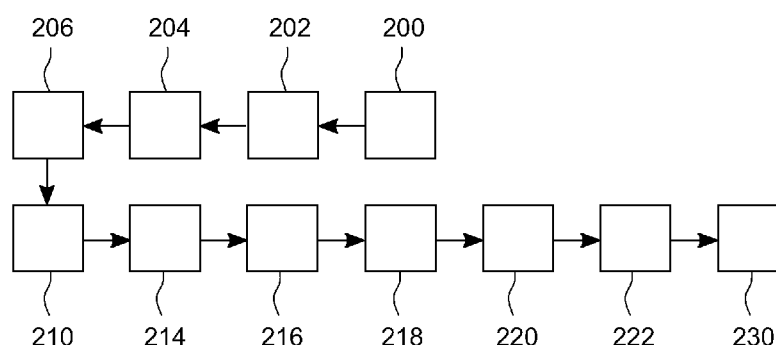


FIG. 2

(57) Abstract: The invention relates to a processing system for use with optical coherence tomography imaging means for imaging a subject, the processing system being configured to perform the following steps: receiving (210) initial image data for an image of the subject acquired by means of optical coherence tomography, applying (214) a de-noising process to the image data in order to receive de-noised image data, combining (216) the de-noised image data with the image data, to which the de-noising process was applied, in order to receive combined image data applying (218) a smoothing filter to the combined image data in order to receive smoothed image data, applying (220) a contrast enhancement process to the smoothed image data in order to receive contrast enhanced image data, and providing (230) final image data for the image of the subject to be displayed, to a further processing system, a control system for OCT, a OCT imaging system and corresponding methods.



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**Processing systems for OCT imaging, OCT imaging systems and methods for OCT
imaging**

Technical Field

10 The present invention essentially relates to processing systems for use with optical coherence tomography (OCT) imaging means for imaging a subject, to a control system for controlling OCT imaging means, to OCT imaging systems including such processing system, and to methods for imaging a subject, using OCT.

15 Background

Optical coherence tomography (in the following also called OCT, its typical abbreviation) is an imaging technique that uses low-coherence light to capture two- and three-dimensional images from within optical scattering media (e.g., biological tissue) with high resolution. It is, inter alia, used for medical imaging. Optical coherence tomography is based on low-coherence interferometry, typically employing near-infrared light. The use of relatively long wavelength light allows it to penetrate into the scattering medium. A medical field of particular interest for OCT is ophthalmology, a branch of medicine related to (in particular human) eyes and its disorders and related surgeries.

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Summary

According to the invention, processing systems, a control system, OCT imaging systems and method for imaging a subject with the features of the independent claims are
30 proposed. Advantageous further developments form the subject matter of the dependent claims and of the subsequent description.

35 The present invention relates to a processing system for use with optical coherence tomography (OCT) imaging means for imaging a subject, in particular, for real-time imaging of the subject. This subject, preferably, includes or is an eye. The type of OCT to be

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used is, preferably, spectral domain OCT (also known as Fourier domain OCT), as will also be described later. The early portion of the description discusses Fourier domain and spectral domain OCT. While spectral or Fourier domain OCT can be based on a broad band light source and a spectrometer system (e.g., with a diffraction grating or other dispersive detector), also swept-source OCT (SS-OCT) can be used, in which a frequency of the light is varied over time (i.e., a spectrally scanning system). Generally, also other types of OCT like time domain OCT may be used.

A control system for OCT imaging means typically is configured to control optical coherence tomography imaging means to scan the subject by means of optical coherence tomography for acquiring scan data or a scan data set. Data processing is performed on the scan data and includes, for example, DC or baseline removal, spectral filtering, wavenumber resampling, dispersion correction, Fourier transform, scaling, image filtering, and optionally additional image enhancement steps, in order to obtain image data for an image of the subject. Typically, a set of image data – or a frame (in the sense of a two-dimensional image, in particular, in live or real-time imaging) – is combined to a two-dimensional OCT image, a B-scan. The underlying scan data thus includes several spectra or A-scans.

In OCT, areas of the sample (subject) or tissue that reflect back a lot of light will create greater interference than areas that do not. Any light that is outside the short coherence length will not interfere. This reflectivity profile is called an A-scan and contains information about the spatial dimensions and location of structures within the sample or tissue. A cross-sectional tomograph, called B-scan, may be achieved by laterally combining a series of these axial depth scans (A-scan). The B-scan can then be used to create a two-dimensional OCT image to be viewed.

The most widely used application of OCT is in ophthalmology for acquiring images of the cornea and for viewing the layers of the retina. OCT is subject to speckle noise which can degrade image quality and reduce visibility of the underlying structures. In addition, the illumination of the biological tissue (the subject) may vary depending on its absorption and scattering properties. Thus, reducing speckle noise and improving the contrast of the morphological structures in OCT images is desired, which would result in a de-noised and/or enhanced OCT image that will improve the image quality.

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A common approach to reducing speckle noise in OCT images is to acquire multiple B-scans (frames) at the same location and averaging them together. There are several multi-frame denoising methods like in "Mayer et al., Wavelet denoising of multi-frame optical coherence tomography data", Biomedical Optics Express, Vol. 3, Issue 3, (20012)". Another solution given to reduce speckle noise is based on adaptive bilateral described in CN 102 800 064 A.

A disadvantage to averaging multiple frames, however, is that it takes longer to acquire a volume since multiple scans at each location are required. A longer acquisition time makes the scan more prone to motion artefacts which will need to be corrected prior to averaging or the end result will appear blurred. A disadvantage of the adaptive bilateral filtering method is that it requires a known noise model for the speckle noise. The speckle noise can vary from system to system; therefore, a noise model would need to be established for each system for optimal performance.

In order to reducing speckle noise and improving the contrast of the morphological structures in OCT images, the following techniques, in particular in two different aspects, for further processing of image data is proposed within the present invention. Note that the image data provided by the control system mentioned above – or also any other image data acquired by means of OCT – can be further processed before used for displaying an image based on it, within the present invention. For such further processing a separate processing system can be used. However, also the control system can be used, i.e., the control system could comprise such processing system.

Irrespective of the specific configuration, the processing system is configured to perform, in a first one of the aspects of the invention, the following steps, which may be considered part of an image processing process. Initial image data for an image of the subject acquired by means of optical coherence tomography is received. These initial image data can be the image data required by the aforementioned processing within the control system. Then, a de-noising process is applied to (or performed on) the image data in order to receive de-noised image data. The image data, to which this de-noising process is applied, may be the initial image data. However, also thresholding can be applied to the initial image data, the resulting image data then to be provided to de-noising process. Thresholding typically is a

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process of segmenting images. From a grayscale image, thresholding can be used to create binary images. For example, pixels with an image intensity above a certain threshold are replaced with a black pixel, the others with a white pixel. This allows to better process the image.

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The de-noising process can comprise performing a morphological transformation and/or performing or applying a non-local means algorithm. A morphological transformation typically includes operations based on the image shape. It is normally performed on binary images. It needs two inputs, a first one is the original image, and a second one is called structuring element or kernel which decides the nature of operation. Two basic morphological operators are Erosion and Dilation. Then, its variant forms like Opening, Closing, Gradient etc. also comes into play. The result of such morphological transformation is reduced noise.

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The non-local means algorithm is an algorithm in image processing for image de-noising. Unlike "local mean" filters, which take the mean value of a group of pixels surrounding a target pixel to smooth the image, non-local means filtering takes a mean of all pixels in the image, weighted by how similar these pixels are to the target pixel. This results in much greater post-filtering clarity, and less loss of detail in the image compared with local mean algorithms. For further details of such non-local means algorithm, it is also referred to "Antoni Buades, Bartomeu Coll, and Jean-Michel Morel, Non-Local Means Denoising, Image Processing Online, 1 (2011), pp. 208-212".

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Further, the de-noised image data is combined with the image data, to which the de-noising process was applied (i.e., the initial image data or the initial image data after thresholding), in order receive combined image data. Two images or image data for two images are combined, for example, by multiplying them together (element by element). This results in brighter areas becoming brighter and darker areas becoming darker. The multiplication of the two images can be performed one time such combination step.

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Then, a smoothing filter is applied to the combined image data in order to receive smoothed image data. Such smoothing filter like a Gaussian filter can be used to improve quality of the intermediate image data for the further processing steps by, e.g., by adding

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blur and, thus, reducing noise. Note that application of such smoothing filter may also be omitted.

Further, a contrast enhancement process is applied to (or performed on) the smoothed
5 image data in order to receive contrast enhanced image data. The contrast enhancement process can comprise performing contrast limited adaptive histogram equalization and/or performing gamma correction.

Histogram equalization usually increases the global contrast of an image, especially when
10 the usable data of the image is represented by close contrast values. Through this adjustment, the intensities can be better distributed on the histogram. This allows for areas of lower local contrast to gain a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values. Adaptive histogram equalization (AHE) is a computer image processing technique used to improve
15 contrast in images. It differs from ordinary histogram equalization in the respect that the adaptive method computes several histograms, each corresponding to a distinct section of the image, and uses them to redistribute the lightness values of the image. It is therefore suitable for improving the local contrast and enhancing the definitions of edges in each region of an image. However, AHE has a tendency to overamplify noise in relatively
20 homogeneous regions of an image. A variant of adaptive histogram equalization called contrast limited adaptive histogram equalization (CLAHE) prevents this by limiting the amplification.

Gamma correction typically is used to optimize the usage of bits when encoding an image,
25 or bandwidth used to transport an image, by taking advantage of the non-linear manner in which humans perceive light and color. The human perception of brightness (lightness), under common illumination conditions (neither pitch black nor blindingly bright), follows an approximate power function (note: no relation to the gamma function), with greater sensitivity to relative differences between darker tones than between lighter tones,
30 consistent with the so-called Stevens power law for brightness perception. If images are not gamma-encoded, they allocate too many bits or too much bandwidth to highlights that humans cannot differentiate, and too few bits or too little bandwidth to shadow values that humans are sensitive to and would require more bits/bandwidth to maintain the same visual quality.

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Thus, both methods allow enhancing the contrast of the OCT image. These contrast enhanced image data can then, preferably after normalizing, be provided as final image data for the image of the subject to be displayed, for example, to display means to be displayed.

Preferably, however, the contrast enhanced image data is combined with the smoothed image data in order to receive second combined image data, and applying a further contrast enhancement process to the second combined image. This further contrast enhancement process can again comprise performing contrast limited adaptive histogram equalization and/or performing gamma correction, as they were explained before. This helps to further improve image quality. This further contrast enhanced image data can then be provided as the final image data.

The steps can be executed once. Multiple iterations of the steps, however, could be performed to further enhance the image. Further, brightness and/or contrast can be optimized after applying such image enhancement method and prior to providing the final image data.

The technical features described aim and help to produce an OCT image that both reduces the speckle noise and improves image contrast of the morphological structures. Combining the respective images or image data sets allows the structures to be brighter and enhanced while also reducing the background speckle noise. This method eliminates the need for acquiring multiple frames at the same location and the need for correcting motion artifacts when averaging multiple B-scans. This approach also does not need the speckle noise model to be established and can be applied on any OCT image.

The steps described above allow – by combining specific variants in some steps – two specific preferred embodiments of a method, preferably, to be performed by the processing means. Both variants reduce speckle noise and improve contrast of the structures being imaged. The first variant offers a smoother result and an overall brighter structure, the second variant preserves the original image quality and very fine structures.

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The first variant is directed to OCT image enhancement using morphological operations and contrast limited adaptive histogram equalization. It comprises the steps: (a) applying morphological transformations to the image data, (b) combining the original image with the image from (a), applying a smoothing filter to the image from (b), (d) performing a contrast limited adaptive histogram equalization (CLAHE) to the image from (c), and (e) normalizing the image from (d).

The second variant is directed to OCT image enhancement using non-local means de-noising and gamma correction. It comprises the steps: (a) applying thresholding to the image, (b) apply non-local means de-noising algorithm, (c) combining the image from (a) with the image from (b), (d) applying a smoothing filter to the image from (c), (e) performing a gamma correction of the image from (d), (f) combining the images from (d) and (e), and (g) performing another gamma correction of the image from (f).

As is clear from the explanation before, the de-noising steps in each variant can be interchanged. For example, morphological transformations in the first variant could be replaced by non-local means de-noising from the second variant or vice versa. Similarly, the contrast enhancement steps in each variant can be interchanged. For example, the contrast limited adaptive histogram equalization in the first variant could be replaced with the Gamma correction from the second variant or vice versa.

In a second one of the aspects of the invention, the processing system is configured to perform following steps, which may be considered part of an image processing process. Initial image data for an image of the subject acquired by means of optical coherence tomography is received. These initial image data can be the image data required by the aforementioned processing within the control system. Then, a gradient filter is applied to the initial image data in order to receive gradient filtered image data. This step, in particular, comprises applying the gradient filter with derivatives only applied in horizontal direction. A gradient filter typically looks at the derivatives in a specific direction (vertical or horizontal), typically using a kernel (e.g., 3x3 or 5x5), a neighborhood of pixels. Then, a variance filter is applied to the initial image data in order to receive variance filtered image data. A variance filter typically looks at the local variance and standard deviation around a neighborhood of pixels.

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Based on or using the gradient filtered image data and the variance filtered image data, a binary mask isolating pixels containing an autocorrelation signature with a specific likelihood is created, in particular, by thresholding (thresholding is explained above).

Based on or using this binary mask, at least part of (or all of) the masked pixels are replaced in the initial image data with a median value (any kind of mean or median value might be used) of the unmasked neighboring pixels. These image data with replaced pixels can then be provided as final image data for the image of the subject to be displayed, for example, to display means to be displayed.

These technical features also aim and help to remove the artefacts that cannot be removed by averaging multiple B-scans. These artefacts may, in particular, be an auto-correlation signature. Autocorrelation, also known as serial correlation, is the correlation of a signal with a delayed copy of itself as a function of delay. Informally, it is the similarity between observations as a function of the time lag between them. The analysis of autocorrelation is a mathematical tool for finding repeating patterns, such as the presence of a periodic signal obscured by noise, or identifying the missing fundamental frequency in a signal implied by its harmonic frequencies. It is often used in signal processing for analyzing functions or series of values, such as time domain signals. In OCT images, however, such auto-correlation parts or signatures are decreasing image quality.

The autocorrelation signature appears as a collection of bright and sharp vertical lines at the top of the image. A gradient filter looking at the first derivative along the horizontal direction will detect the sharp changes between the background and the correlation signature which will not be present in the rest of the image. The variance filter will help identify regions of high contrast (greater variance between neighboring dark and bright pixels). The variance is greater around the autocorrelation signature due to the very bright vertical lines compared to the dark background.

The steps described above allow – by combining specific variants in some steps – a specific preferred embodiment of a method, preferably, to be permed by the processing means. It is directed to removal of the auto-correlation signature and it comprises the steps: (a) acquiring an OCT scan (or scan data), (b) applying a gradient filter on the original image with the derivatives only applied in the horizontal direction., (c) applying a variance filter to the original image, (d) using the results from (a) and (b) and, by thresholding, creating a

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binary mask that isolates the pixels likely to contain the autocorrelation signature, and (e) using the mask from (d) and replacing each of the masked pixels with the median value of the unmasked neighboring pixels.

- 5 The invention also relates to a control system for controlling optical coherence tomography imaging means for imaging a subject comprising the processing system, as mentioned above.

10 The invention also relates to an optical coherence tomography (OCT) imaging system for (in particular, real-time) imaging a subject, e.g. an eye, comprising a control system, and optical coherence tomography imaging means in order to perform the OCT scan (for a more detailed description of such OCT imaging means it is referred to the drawings and the corresponding description). Preferably, the OCT imaging system is configured to display an image of the subject on display means. Such display means can be part of the
15 OCT imaging system. As mentioned before, the control system can comprise the processing system. Alternatively, the processing system can be provided separately from the control system. Basically, such processing system for performing the steps mentioned above can also be formed by a server or cloud computing system, connected to the remaining parts of the OCT imaging system via Ethernet or internet or the like.

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The invention also relates to methods method for imaging a subject like an eye, using optical coherence tomography (OCT). The steps of the method correspond to the steps described above with respect to the control system, in particular, in every variant and aspect. For sake of clarity, the steps are not repeated at this point.

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The invention also relates to a computer program with a program code for performing a method according to the invention when the computer program is run on a processor, processing system or control system, in particular, like described before.

- 30 With respect to further preferred details and advantages of the OCT imaging system and the method, it is also referred to the remarks for the control system above, which apply here correspondingly.

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Further advantages and embodiments of the invention will become apparent from the description and the appended figures.

It should be noted that the previously mentioned features and the features to be further
5 described in the following are usable not only in the respectively indicated combination, but also in further combinations or taken alone, without departing from the scope of the present invention.

Short Description of the Figures

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Fig. 1 shows a schematic overview of an OCT imaging system according to the invention in a preferred embodiment.

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Fig. 2 shows, schematically, a flow scheme describing a method according to the invention in a preferred embodiment.

Fig. 3 shows, schematically, a flow scheme describing a method according to the invention in a further preferred embodiment.

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Fig. 4 shows OCT images of a subject acquired by OCT without improvement and with improvement with different methods according to the invention.

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Fig. 5 shows OCT images of a subject acquired by OCT without improvement and with improvement with different methods according to the invention.

Fig. 6 shows, schematically, a flow scheme describing a method according to the invention in a further preferred embodiment.

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Fig. 7 shows an OCT image of a subject acquired by OCT for explaining a method according to the invention.

Detailed Description

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In Fig. 1, a schematic overview of an optical coherence tomography (OCT) imaging system 100 according to the invention in a preferred embodiment is shown. The OCT imaging system 100 comprises a light source 102 (e.g., a low coherence light source), a beam splitter 104, a reference arm 106, a sample arm 112, a diffraction grating 118, a detector 120 (e.g., a camera), a control system 130 and display means 140 (e.g., a display or monitor).

Light originating from the light source 102 is guided, e.g., via fiber optic cables 150, to the beam splitter 104 and a first part of the light is transmitted through the beam splitter 104 and is then guided, via optics 108 (which is only schematically shown and represented by a lens) in order to create a light beam 109 to a reference mirror 110, wherein the optics 108 and the reference mirror 110 are part of the reference arm 106.

Light reflected from the reference mirror 110 is guided back to the beam splitter 104 and is transmitted through the beam splitter 104 and is then guided, via optics 116 (which is only schematically shown and represented by a lens) in order to create a light beam 117 to the diffraction grating 118.

A second part of the light, originating from the light source 102 and transmitted through the beam splitter 104 is guided via optics 114 (which is only schematically shown and represented by a lens) in order to create a light beam 115 (for scanning) to the subject 190 to be imaged, which, by means of example, is an eye. The optics 114 are part of the sample arm 112. In particular, optics 114 are used to focus the light beam 115 on a desired focal plane, i.e., the focal position can be set.

Light reflected from the subject 190 or the tissue material therein is guided back to the beam splitter 104 and is transmitted through the beam splitter 104 and is then guided, via optics 116 to the diffraction grating 118. Thus, light reflected in the reference arm 106 and light reflected in the sample arm 112 are combined by means of the beam splitter 104 and are guided, e.g., via a fiber optic cable 150, and in a combined light beam 117 to the diffraction grating 118.

Light reaching the diffraction grating 118 is diffracted and captured by the detector 120. In this way, the detector 120, which acts as a spectrometer, creates or acquires scan data or

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scan data sets 122 that are transmitted, e.g., via an electrical cable 152, to the control system 130 comprising a processing system or processing means 132. A scan data set 122 is then processed to obtain image data set 142 that is transmitted, e.g., via an electrical cable 152, to the display means 140 and displayed as a real-time image 144, i.e., an image that represents the currently scanned subject 190 in real-time.

The process in which the intensity scan data set 122 is processed or converted to the image data set 142 that allows displaying of the scanned subject 190 on the display means 140 will be described in more detail in the following. In particular, the further steps for improving the image quality can either be performed on the processing system 132 comprised by the control system 130 or by a processing system 132' provided separately and connected via e.g., Ethernet.

In Fig. 2, a flow scheme describing a method according to the invention in a preferred embodiment is shown schematically. For providing a real-time OCT image, scan data is acquired and image data is provided to be displayed as an image or OCT image on display means, e.g., continually in an imaging acquisition and processing process, and as described with respect to Fig. 1.

In step 200, scan data is acquired from the subject by means of optical coherence tomography, and, in step 202, received at the control or processing system, In step 204, data processing (pre-processing) is performed on the scan data, and, in step 206, image data for an image of the subject to be used is provided to, for example, the processing system.

Further, in a step 210, the image data is received at the processing system as initial image data on which further image processing is to be performed. Note that steps 206 and 210 might be combined in a single step if the processing system is used for both, pre-processing and the further image processing, for example.

In step 214, a morphological transformations as a de-noising process is applied to the initial image data, in order to receive de-noised image data. In step 216, the de-noised image data is combined with the initial image data (the data to which the de-noising process was applied) in order receive combined image data. In step 218, a smoothing filter

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is applied to the combined image data in order to receive smoothed image data. In step 220, a contrast limited adaptive histogram equalization (CLAHE) as a contrast enhancement process is applied to the smoothed image data in order to receive contrast enhanced image data. In step 222, the contrast enhanced image data is normalized. In step 230, the final image data for the image of the subject to be displayed is provided to, e.g. the display means shown in Fig. 1. The method described here corresponds to the first variant described above.

In Fig. 3, a flow scheme describing a method according to the invention in a further preferred embodiment is shown schematically. In this embodiment, steps 200 to 206 of Fig. 2 can also be used, however, the following image processing steps deviate.

In a step 310, the image data is received at the processing system as initial image data on which further image processing is to be performed. Note that steps 206 and 310 might be combined in a single step if the processing system is used for both, pre-processing and the further image processing, for example.

In step 312, thresholding is applied to the initial image data. In step 314, a non-local means de-noising algorithm as a de-noising process is applied to the thresholded image data, in order to receive de-noised image data. In step 316, the de-noised image data is combined with the thresholded image data (the data to which the de-noising process was applied) in order to receive combined image data. In step 318, a smoothing filter is applied to the combined image data in order to receive smoothed image data. In step 320, gamma correction as a contrast enhancement process is applied to the smoothed image data in order to receive contrast enhanced image data. In step 322, the contrast enhanced image data is combined with the smoothed image data in order to receive a second combined image. In step 324, a further gamma correction is applied to the second combined image. In step 330, the final image data for the image of the subject to be displayed is provided to, e.g. the display means shown in Fig. 1. The method described here corresponds to the second variant described above.

In Figs. 4 and 5, OCT images of a subject acquired by OCT without and with improvement with different methods according to the invention are shown. Image 400 is an unprocessed OCT image (i.e., an OCT image correspond to, for example, image data

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received in step 210 or 310) of a retina. Image 402 shows the result after applying image enhancement according to the first variant described with respect to Fig. 2, and image 404 shows the result after applying image enhancement according to the second variant described with respect to Fig. 3.

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Image 500 is an unprocessed OCT image (i.e., an OCT image correspond to, for example, image data received in step 210 or 310) of a cornea. Image 502 shows the result after applying image enhancement according to the first variant described with respect to Fig. 2, and image 504 shows the result after applying image enhancement according to the second variant described with respect to Fig. 3.

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From Figs. 4 and 5 it becomes clear that the method described above help to improve an OCT image. The first variant of Fig. 2 offers a smoother result and an overall brighter structure (see images 402, 502) and the second variant preserves the original image quality and very fine structures (see images 404, 504).

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In Fig. 6, a flow scheme describing a method according to the invention in a further preferred embodiment is shown schematically. In this embodiment, steps 200 to 206 of Fig. 2 can also be used, however, the following image processing steps deviate.

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In a step 610, the image data is received at the processing system as initial image data on which further image processing is to be performed. Note that steps 206 and 310 might be combined in a single step if the processing system is used for both, pre-processing and the further image processing, for example.

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In step 612, a gradient filter is applied to the initial image data in order to receive gradient filtered image data. In step 614, variance filter to the initial image data in order to receive variance filtered image data. In step 616, using the gradient filtered image data and the variance filtered image data, a binary mask is created by thresholding, the mask isolating pixels containing an autocorrelation signature with a specific likelihood. In step 618, the masked pixels are replaced with a median value of the unmasked neighboring pixels in the initial image data, using the mask. In step 630, the final image data for the image of the subject to be displayed is provided to, e.g. the display means shown in Fig. 1. The method described here corresponds to the second variant described above.

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In Fig. 7, an OCT image of a subject acquired by OCT for explaining a method according to the invention is shown. Image 700 is an unprocessed OCT image (i.e., an OCT image correspond to, for example, image data received in step 210 or 310) of a cornea, similar to image 500 in Fig. 5. Image 702 is an enlarged view of the top margin of image 700, showing the auto-correlation signature that can be removed with the method described with respect to Fig. 6.

As used herein the term “and/or” includes any and all combinations of one or more of the associated listed items and may be abbreviated as “/”.

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects described in the context of a method step also represent a description of a corresponding block or item or feature of a corresponding apparatus.

Some embodiments relate to an OCT imaging system comprising a processing system as described in connection with one or more of the Figs. 1 to 7. Alternatively, an OCT imaging system may be part of or connected to a processing system as described in connection with one or more of the Figs. 1 to 7. Fig. 1 shows a schematic illustration of an OCT imaging system 100 configured to perform a method described herein. The OCT imaging system 100 comprises OCT imaging means and a processing or computer system 132. The OCT imaging means are configured to take images and are connected to the processing system 132. The processing system 132 is configured to execute at least a part of a method described herein. The processing system 132 may be configured to execute a machine learning algorithm. The processing system 132 and OCT imaging system 100 may be separate entities but can also be integrated together in one common housing. The processing system 132 may be part of a central processing system of the OCT imaging system and/or the processing system 132 may be part of a subcomponent of the OCT imaging system 100, such as a sensor, an actor, a camera or an illumination unit, etc. of the OCT imaging system 100.

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The processing system 132 may be a local computer device (e.g. personal computer, laptop, tablet computer or mobile phone) with one or more processors and one or more storage devices or may be a distributed computer system (e.g. a cloud computing system with one or more processors and one or more storage devices distributed at various locations, for example, at a local client and/or one or more remote server farms and/or data centers). The processing system 132 may comprise any circuit or combination of circuits. In one embodiment, the processing system 132 may include one or more processors which can be of any type. As used herein, processor may mean any type of computational circuit, such as but not limited to a microprocessor, a microcontroller, a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a graphics processor, a digital signal processor (DSP), multiple core processor, a field programmable gate array (FPGA), for example, of a microscope or a microscope component (e.g. camera) or any other type of processor or processing circuit. Other types of circuits that may be included in the processing system 132 may be a custom circuit, an application-specific integrated circuit (ASIC), or the like, such as, for example, one or more circuits (such as a communication circuit) for use in wireless devices like mobile telephones, tablet computers, laptop computers, two-way radios, and similar electronic systems. The processing system 132 may include one or more storage devices, which may include one or more memory elements suitable to the particular application, such as a main memory in the form of random access memory (RAM), one or more hard drives, and/or one or more drives that handle removable media such as compact disks (CD), flash memory cards, digital video disk (DVD), and the like. The processing system 130 may also include a display device, one or more speakers, and a keyboard and/or controller, which can include a mouse, trackball, touch screen, voice-recognition device, or any other device that permits a system user to input information into and receive information from the processing system 132.

Some or all of the method steps may be executed by (or using) a hardware apparatus, like for example, a processor, a microprocessor, a programmable computer or an electronic circuit. In some embodiments, some one or more of the most important method steps may be executed by such an apparatus.

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Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software. The implementation can be performed using a non-transitory storage medium such as a digital storage medium, for example a floppy disc, a DVD, a Blu-Ray, a CD, a ROM, a PROM, and EPROM, an EEPROM or a FLASH memory, 5 having electronically readable control signals stored thereon, which cooperate (or are capable of cooperating) with a programmable computer system such that the respective method is performed. Therefore, the digital storage medium may be computer readable.

Some embodiments according to the invention comprise a data carrier having 10 electronically readable control signals, which are capable of cooperating with a programmable computer system, such that one of the methods described herein is performed.

Generally, embodiments of the present invention can be implemented as a computer 15 program product with a program code, the program code being operative for performing one of the methods when the computer program product runs on a computer. The program code may, for example, be stored on a machine readable carrier.

Other embodiments comprise the computer program for performing one of the methods 20 described herein, stored on a machine readable carrier.

In other words, an embodiment of the present invention is, therefore, a computer program 25 having a program code for performing one of the methods described herein, when the computer program runs on a computer.

A further embodiment of the present invention is, therefore, a storage medium (or a data carrier, or a computer-readable medium) comprising, stored thereon, the computer 30 program for performing one of the methods described herein when it is performed by a processor. The data carrier, the digital storage medium or the recorded medium are typically tangible and/or non-transitionary. A further embodiment of the present invention is an apparatus as described herein comprising a processor and the storage medium.

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A further embodiment of the invention is, therefore, a data stream or a sequence of signals representing the computer program for performing one of the methods described herein. The data stream or the sequence of signals may, for example, be configured to be transferred via a data communication connection, for example, via the internet.

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A further embodiment comprises a processing means, for example, a computer or a programmable logic device, configured to, or adapted to, perform one of the methods described herein.

10 A further embodiment comprises a computer having installed thereon the computer program for performing one of the methods described herein.

A further embodiment according to the invention comprises an apparatus or a system configured to transfer (for example, electronically or optically) a computer program for performing one of the methods described herein to a receiver. The receiver may, for example, be a computer, a mobile device, a memory device or the like. The apparatus or system may, for example, comprise a file server for transferring the computer program to the receiver.

20 In some embodiments, a programmable logic device (for example, a field programmable gate array) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may cooperate with a microprocessor in order to perform one of the methods described herein. Generally, the methods are preferably performed by any hardware apparatus.

25

List of Reference Signs

	100	OCT imaging system
	102	light source
5	104	beam splitter
	106	reference arm
	108, 114, 116	optics
	109, 115, 117	light beams
	110	reference mirror
10	112	sample arm
	118	diffraction grating
	120	detector
	122	intensity scan data
	130	control system
15	132, 132'	processing systems
	140	display means
	142	image data set
	150	fiber optic cable
	152	electrical cable
20	190	subject
	200-230	method steps
	310-330	method steps
	400-404	OCT images
25	500-504	OCT images
	610-630	method steps
	700-702	OCT images

5

Claims

1. A processing system (132, 132') for use with optical coherence tomography imaging means for imaging a subject (190), the processing system being
10 configured to perform the following steps:
 receiving (210, 310) initial image data for an image of the subject (190) acquired by means of optical coherence tomography,
 applying (214, 314) a de-noising process to the image data in order to receive de-noised image data,
15 combining (216, 316) the de-noised image data with the image data, to which the de-noising process was applied, in order receive combined image data
 applying (218, 318) a smoothing filter to the combined image data in order to receive smoothed image data,
 applying (220, 320) a contrast enhancement process to the smoothed image
20 data in order to receive contrast enhanced image data, and
 providing (230, 330) final image data for the image (144, 402, 404, 502, 504) of the subject (190) to be displayed.
2. The processing system (132, 132') of claim 1, the image processing process
25 further comprising: combining (322) the contrast enhanced image data with the smoothed image data in order to receive second combined image data, and
applying (324) a further contrast enhancement process to the second combined image.

3. The processing system (132, 132') of claim 1 or 2, the image processing process further comprising: applying thresholding (212) to the initial image data, the resulting image data to be provided to de-noising process.

5 4. The processing system (132, 132') of any one of the preceding claims, wherein the de-noising process comprises a morphological transformation.

5. The processing system (132, 132') of any one of the preceding claims, wherein the de-noising process comprises a non-local means algorithm.

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6. The processing system (132, 132') of any one of the preceding claims, wherein at least one of the contrast enhancement processes comprises a contrast limited adaptive histogram equalization.

15 7. The processing system (132, 132') of any one of the preceding claims, wherein at least one of the contrast enhancement processes comprises a gamma correction.

8. The processing system (132, 132') of any one of the preceding claims, the
20 image processing process further comprising: optimizing brightness and/or contrast of the image data in order to receive the final image data.

9. A processing system (132, 132') for use with optical coherence tomography imaging means for imaging a subject (190), the processing system being
25 configured to perform the following steps:

receiving (610) initial image data for an image of the subject a acquired by means of optical coherence tomography,

applying (612) a gradient filter to the initial image data in order to receive gradient filtered image data,

30 applying (614) a variance filter to the initial image data in order to receive variance filtered image data,

creating (616), using the gradient filtered image data and the variance filtered image data, in particular by thresholding, a binary mask isolating pixels containing an autocorrelation signature with a specific likelihood,

replacing (618), in the initial image data, using the binary mask, at least part
5 of the masked pixels with a median value of the unmasked neighboring pixels, and
providing (630) final image data for the image of the subject to be displayed.

10. The processing system (132, 132') of claim 9, wherein applying a gradient
10 filter comprises applying the gradient filter with derivatives only applied in horizontal direction.

11. A control system (130) for controlling optical coherence tomography imaging means for imaging a subject (190), comprising the processing means
15 (132) of any one of the preceding claims, and the control system being configured to perform the following steps:

receiving (200) scan data (122) from the subject being acquired by means of optical coherence tomography, performing (202) data processing on the scan data, and obtaining (204) image data for an image of the subject to be used as the
20 initial image data.

12. An optical coherence tomography imaging system (100) for imaging a subject (190) comprising optical coherence tomography imaging means, and, preferably, display means (140) configured to display the image (144) of the
25 subject (190), and further comprising the control system (130) of claim 11.

13. An optical coherence tomography imaging system (100) for imaging a subject (190) comprising optical coherence tomography imaging means, and, preferably, display means (140) configured to display the image (144) of the
30 subject (190), and

further comprising a control system (130) for controlling optical coherence tomography imaging means for imaging a subject (190), being configured to perform the following steps: receiving scan data (122) from the subject being acquired by means of optical coherence tomography, performing data processing on the scan data, and obtaining image data for an image of the subject to be used as initial image data;

the optical coherence tomography imaging system further comprising the processing system (132') of any one of claims 1 to 10.

14. A method for imaging a subject (190) using optical coherence tomography, comprising the following steps:

acquiring image data from the subject by means of optical coherence tomography as initial image data,

applying (214, 314) a de-noising process to the image data in order to receive de-noised image data,

combining (216, 316) the de-noised image data with the image data, to which the de-noising process was applied, in order receive combined image data

applying (218, 318) a smoothing filter to the combined image data in order to receive smoothed image data,

applying (220, 320) a contrast enhancement process to the smoothed image data in order to receive contrast enhanced image data, and

providing (230, 330) final image data for the image (144, 402, 404, 502, 504) of the subject (190) to be displayed.

15. The method of claim 14, wherein the image processing process further comprises: combining (322) the contrast enhanced image data with the smoothed image data in order to receive second combined image data, and applying (324) a further contrast enhancement process to the second combined image.

16. The method of claim 14 or 15, wherein the de-noising process comprises at least one of a morphological transformation and a non-local means algorithm,

and/or wherein at least one of the contrast enhancement processes comprises at least one of a contrast limited adaptive histogram equalization and a gamma correction.

- 5 17. A method for imaging a subject (190) using optical coherence tomography, comprising the following steps:
- acquiring image data from the subject by means of optical coherence tomography as initial image data,
 - 10 applying (612) a gradient filter to the initial image data in order to receive gradient filtered image data,
 - applying (614) a variance filter to the initial image data in order to receive variance filtered image data,
 - creating (616), using the gradient filtered image data and the variance filtered image data, in particular by thresholding, a binary mask isolating pixels
 - 15 containing an autocorrelation signature with a specific likelihood,
 - replacing (618), in the initial image data, using the binary mask, at least part of the masked pixels with a median value of the unmasked neighboring pixels, and
 - providing (630) final image data for the image of the subject to be displayed.
- 20
18. A computer program with a program code for performing the method of any one of claims 14 to 17, when the computer program is run on a processing system (130).

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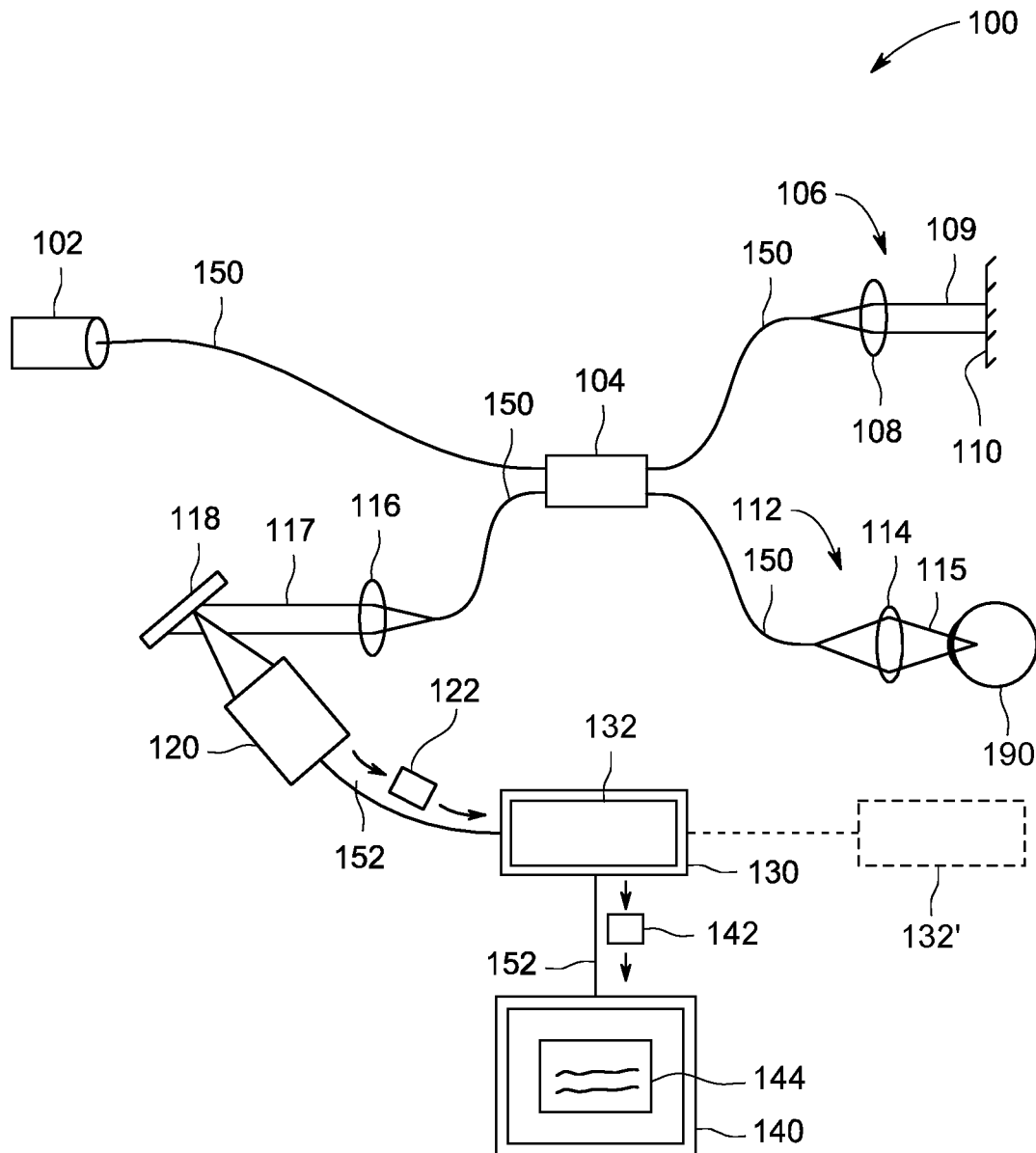


FIG. 1

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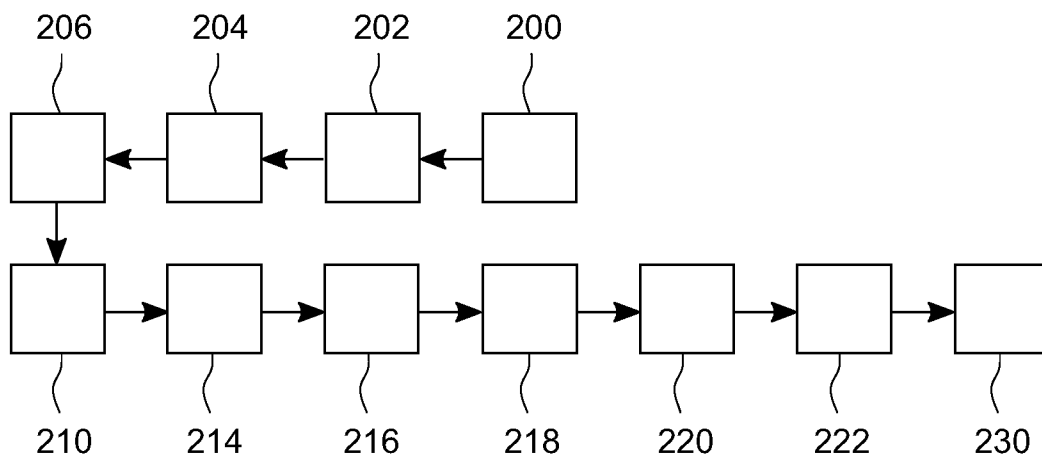


FIG. 2

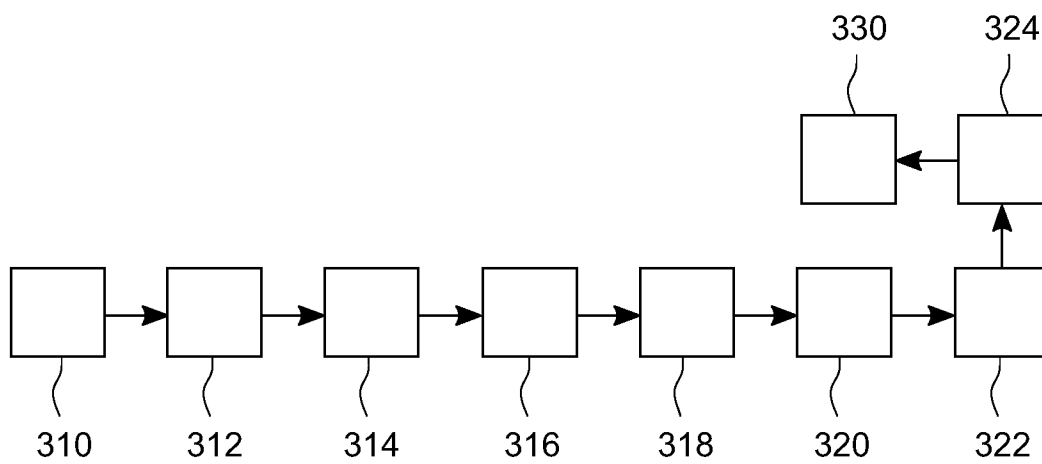


FIG. 3

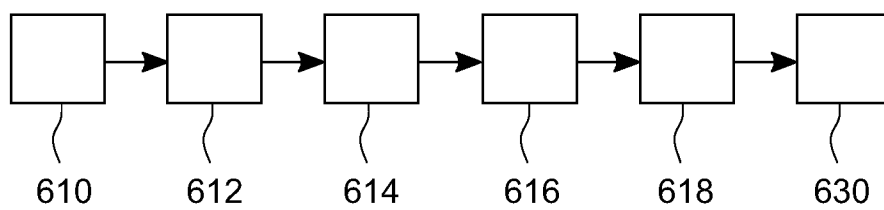


FIG. 6

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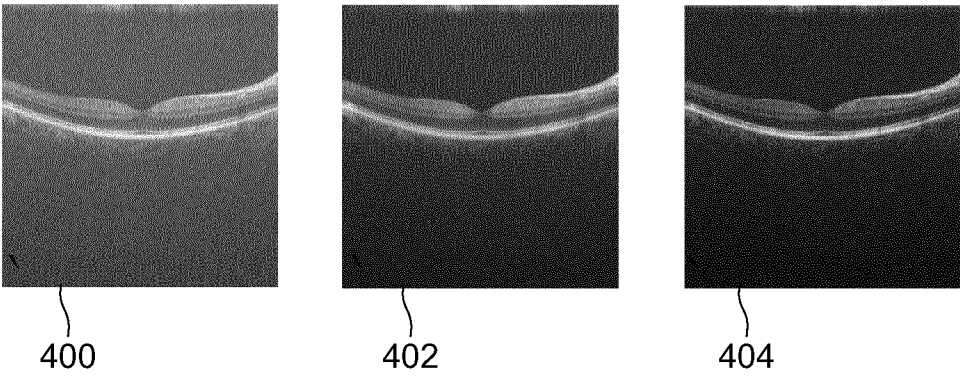


FIG. 4

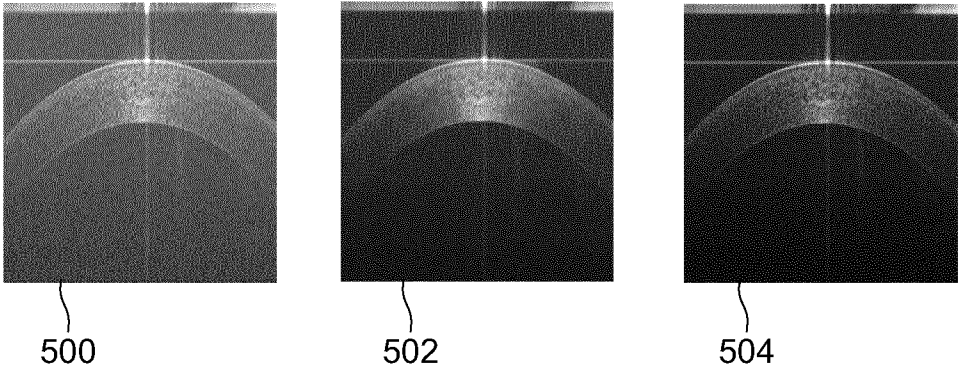


FIG. 5

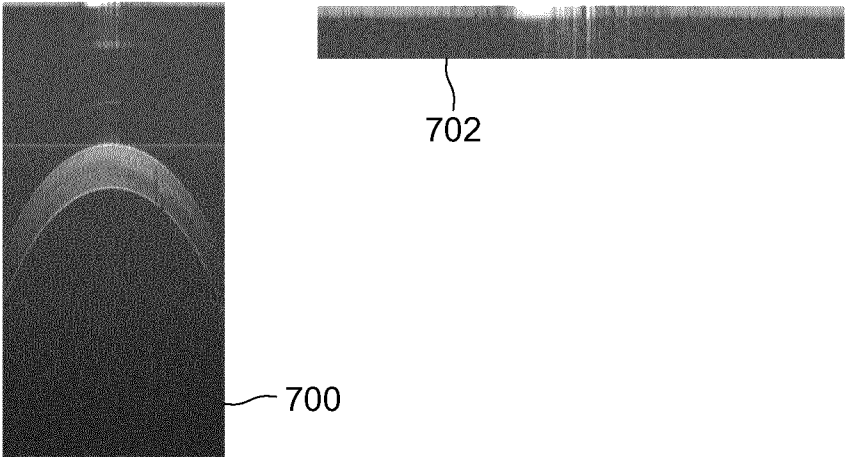


FIG. 7