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DESCRIPTION

[Technical Field]

[0001] The present invention generally relates to the field of image processing and, more particularly, to the processing of images of a retina acquired by an ophthalmic device having an imaging section to generate retinal position tracking information that is indicative of a movement of the retina during the image acquisition.

[Background]

[0002] Ophthalmic devices having an imaging section such as a scanning laser ophthalmoscope (SLO), which can use the imaging section to generate a stream of retinal images for tracking eye movements, are often used in optical coherence tomography (OCT) and other kinds of ophthalmic work. The imaging section typically acquires the images at high frame rates and under relatively low levels of infrared (IR) illumination. The acquired images therefore tend to be of low dynamic range and exhibit poor signal-to-noise. In addition, small eye movements can affect the image lighting in such a way that retinal feature variation and fragmentation can occur from one image frame to another. These factors can make it difficult to achieve satisfactory positional confidence, repeatability, accuracy and stability during eye movement tracking or in post-processing of the images.

[0003] Further background is provided in the following documents.

[0004] EP 2 702 930 A1 discloses an ophthalmic apparatus comprising: fundus image acquisition means for acquiring a first fundus image of an eye and a second fundus image of the eye which is captured at a time different from that of the first fundus image; first generation means for generating, by performing processing of enhancing contrast of a first characteristic region of a part of the first fundus image, an image which corresponds to the first characteristic region; second generation means for generating, by performing processing of enhancing contrast of a second characteristic region of a part of the second fundus image which corresponds to the first characteristic region, an image which corresponds to the second characteristic region; and position correction means for correcting an acquisition position of a tomographic image of the eye based on a positional displacement between the image which corresponds to the first characteristic region and the image which corresponds to the second characteristic region.

[0005] US 2017/0206657 A1 discloses a method, controller, and non-transitory medium for obtaining images of a moving subject, estimating changes in position of the subject based on the images, calculating a quality metric of the estimation of the change, and comparing the quality metric to a threshold. In a first case in which the quality metric is less than the threshold,

the position of the scanning area is adjusted based on the estimated change in position. In a second case in which the quality metric is not less than the threshold, a new second image is obtained.

[0006] US 2014/0226130 A1 discloses a line scan imager, which is used to determine the motion of a subject. Each line of image data from the line scan imager is compared with a reference image. The location of a matching line in the reference image reveals the displacement of the subject. The current subject displacement can be determined based on each line of image data. The resulting displacement information can be used to correctly place other optical beams on the subject. The method can be applied to tracking the human eye to facilitate measurement, imaging, or treatment with a beam of optical radiation.

[Summary]

[0007] The inventors have devised a method of processing a sequence of images of a retina acquired by an ophthalmic device having an imaging section to generate retinal position tracking information that is indicative of a movement of the retina during the acquisition of the sequence of images. The method comprises: (i) receiving one or more images of the retina from the sequence; (ii) calculating a cross-correlation between a reference image and an image based on one or more of the received images to acquire an offset between the image and the reference image; and repeating processes (i) and (ii) to acquire, as the retinal position tracking information, respective offsets for further images that are based on further respective one or more received images from the sequence. The method further comprises modifying the reference image while processes (i) and (ii) are being repeated, by determining a measure of similarity between correspondingly located regions of pixels in two or more of the received images and accentuating features in the reference image representing structures of the imaged retina in relation to other features in the reference image based on the determined measure of similarity.

[0008] The inventors have further devised a non-transitory computer-readable storage medium and a signal carrying computer program instructions which, when executed by a processor, cause the processor to perform the method set out above.

[0009] The inventors have further devised an image processing apparatus configured to process a sequence of images of a retina acquired by an ophthalmic device to generate retinal position tracking information indicative of a movement of the retina during the acquisition of the sequence of images, the image processing apparatus comprising a processor and a memory storing computer program instructions which, when executed by the processor, cause the processor to perform the method set out above.

[0010] The inventors have further devised an ophthalmic device comprising an optical coherence tomography, OCT, imaging module configured to acquire OCT images of a retina of an eye by scanning a beam of light across the retina and processing a reflection of the beam

from the retina, and a tracking image acquisition module configured to acquire a sequence of images of the retina for tracking a movement of the retina while the OCT imaging module acquires the OCT images. The ophthalmic device further comprises a controller comprising the image processing apparatus set out above that is configured to process the sequence of images in accordance with the method set at above to generate retinal position tracking information indicative of the movement of the retina during the acquisition of the OCT images. The controller is configured to control the OCT imaging module using the retinal position tracking information so as to at stabilise the beam during the acquisition of the OCT images.

[Brief Description of the Drawings]

[0011] Embodiments of the invention will now be explained in detail, by way of example only, with reference to the accompanying figures, in which:

Fig. 1 is a schematic illustration of an ophthalmic device according to an embodiment of the present invention;

Fig. 2 is a schematic illustration of an implementation of the image processing apparatus of the controller of the ophthalmic device in programmable signal processing hardware;

Fig. 3 is a flow diagram illustrating a process by which a sequence of images of a retina acquired by the ophthalmic device is processed by the image processing apparatus to generate retinal position tracking information in a first embodiment of the present invention;

Fig. 4 is a flow diagram illustrating a process by which the reference image used in the process of Fig. 3 is modified to accentuate features therein representing structures of the imaged retina in relation to other features in the reference image;

Fig. 5 is a flow diagram illustrating a process by which two received images are registered with respect to one another;

Fig. 6 is a schematic illustration of a correlation surface representing the result of cross-correlating a pair of images;

Fig. 7 is a schematic illustrating an aspect of how the accumulator array is processed in process S200 in Fig. 4;

Fig. 8 is a schematic illustrating an aspect of how the accumulator array is processed in a variant of process S200 in Fig. 4;

Fig. 9 shows images representative of the accumulator array described herein that illustrate how the accumulator array varies as the number of image frames processed by the image processing apparatus of the embodiment increases from 1 to 15;

Fig. 10 illustrates the improvement in latch strength when tracking relative to the reference image in accordance with the embodiment, as compared to a fixed (unchanging) reference

frame; and

Fig. 11 is a flow diagram illustrating a process by which the reference image used in the process of Fig. 3 is modified to accentuate features therein representing structures of the imaged retina in relation to other features in the reference image in a second embodiment of the present invention.

[Detailed Description of Embodiments]

[0012] Figure 1 is a schematic illustration of an ophthalmic device 100 according to an embodiment of the present invention.

[0013] The ophthalmic device 100 comprises an optical coherence tomography (OCT) imaging module 110 operable to acquire OCT images of a retina of an eye by scanning across the retina an OCT sample beam generated by a super luminescent diode (SLD) or other light source, which may operate in any part of the near-infrared or infrared spectrum, and processing a reflection of the sample beam from the retina. The ophthalmic device 100 also includes a tracking image acquisition module 120 configured to acquire image data in any suitable format that represents a sequence of images of the retina for tracking a movement of the retina while the OCT imaging module 110 acquires the OCT images. The tracking image acquisition module 120 may, as in the present embodiment, comprise a scanning laser ophthalmoscope (SLO). The tracking image acquisition module 120 may be configured to acquire the tracking images (as infrared (IR) SLO images, for example) at a high frame rate, typically 50 to 100 Hz. The acquired images may thus form, in effect, a real-time movie of the scanned region of the retina.

[0014] The ophthalmic device 100 also has a controller 130 comprising an image processing apparatus 140, which is configured to process the sequence of images to generate retinal position tracking information that is indicative of the movement of the retina during the acquisition of the OCT images as described in more detail below. An advantage of the image processing algorithm of the embodiment is its ability to acquire reliable retinal position tracking information even from low illumination, low resolution and poor signal-to-noise images that are typically acquired when IR illumination is used for the comfort of the patient and to avoid distracting the patient from maintaining a fixed gaze. An additional advantage of the algorithm in at least some embodiments is its potential to accentuate valid features for tracking in relation to features that are not valid for tracking, which may not move in correspondence with the retinal position, such as reflex and lid and lash etc. (tracking to these invalid features would not provide accurate, consistent information on how the retina is moving and could bias the tracking algorithm away from the true retinal motion). The algorithm involves using inter-image frame information, automatically identified as been common and consistent, but not necessarily at the same position, across multiple image frames, being accentuated in the reference image

whilst at the same time attenuating information in the reference image that is not common. The noise- and artefact-tolerant nature of the algorithm is particularly important since design constraints (for example, the need to use IR illumination and laser power constraints) for fast frame rate SLO images tend to mean the tracking data will generally be of relatively low quality and poor signal-to-noise relative to a diagnostic SLO image. An additional problem is that small eye movements can affect the image lighting in such a way that feature variation from frame to frame can make it difficult to acquire reliable retinal position tracking information. As will be described in more detail below, the image processing method of an embodiment involves using frame-to-frame information, automatically identified as been common and valid across more than one frame, being accentuated in a reference frame relative to information that is not common to the frames.

[0015] The controller 130 is configured to control the OCT imaging module 110 using the retinal position tracking information generated by the image processing apparatus 140 so as to stabilise the OCT sample beam (in other words, at least partially compensate for movements of the retina as indicated by the retinal position tracking information) during the acquisition of the OCT images, and therefore improve sharpness and detail in the OCT images. By way of a non-limiting example, a combined SLO-OCT imaging system comprising such an OCT imaging module and tracking image acquisition module is described in more detail in International Patent Application No. PCT/BG2013/052556 (published as WO2014/053824 A1).

[0016] It should be noted, however, that the retinal position tracking information acquired by the image processing apparatus 140 need not be used for control of the OCT imaging module 110 or other kind of imaging device or part thereof to compensate for eye movements, and may instead be used in post-processing of the acquired sequence of images, for example. It should be noted that the retinal position tracking information may be used not only in ophthalmic imaging devices but also in other kinds of ophthalmic device (such as those used in laser eye surgery and other types of ophthalmic intervention) to compensate for and/or track eye movements.

[0017] Figure 2 is a schematic illustration of an exemplary implementation of the image processing apparatus 140 in programmable signal processing hardware. The controller 130 of the ophthalmic device 100 may be implemented in the same way.

[0018] The signal processing apparatus 200 shown in Fig. 2 comprises an input/output (I/O) section 210 for receiving the images from the tracking image acquisition module 120. The signal processing apparatus 200 further comprises a processor 220, a working memory 230 (e.g. a random access memory) and an instruction store 240 storing computer-readable instructions which, when executed by the processor 220, cause the processor 220 to perform the processing operations hereinafter described to process a sequence of the acquired retinal images to generate the retinal position tracking information. The instruction store 240 may comprise a ROM (e.g. in the form of an electrically-erasable programmable read-only memory (EEPROM) or flash memory) which is pre-loaded with the computer-readable instructions. Alternatively, the instruction store 240 may comprise a RAM or similar type of memory, and the

computer-readable instructions can be input thereto from a computer program product, such as a computer-readable storage medium 250 such as a CD-ROM, etc. or a computer-readable signal 260 carrying the computer-readable instructions.

[0019] Figure 3 is a flow chart illustrating a process by which the image processing apparatus 140 processes a sequence of images of a retina acquired by an ophthalmic device 100 to generate the retinal position tracking information.

[0020] In process S10, the image processing apparatus 140 receives one or more images of the retina. The image processing apparatus 140 may, as in the present embodiment, receive a single image of the retina in process S10, or may alternatively receive two or more images of the retina in process S10.

[0021] In process S20, the image processing apparatus 140 calculates a cross-correlation between the received image and a reference image to acquire an offset between the received image and the reference image, using any well-known cross-correlation algorithm. The offset between the received image and the reference image may be acquired only when the calculated cross-correlation fulfils a predetermined condition (e.g. when the value of the cross-correlation peak exceeds a threshold). The acquired offset may, as in the present embodiment, comprise a translational offset (Δx in an x-direction, and Δy in a y-direction), as well as a rotational (angular) offset ($\Delta\theta$), between the received image and the reference image. The offset thus defines a transformation for mapping one image onto the other, so that, e.g. vasculature and/or other features of the imaged retina would overlap in a superposition of the two images. The degree of translation Δx, Δy can be determined from the location of a peak in the calculated cross-correlation surface, and the angular offset $\Delta\theta$ can be computed from a rotation of the second image at fixed increments from a zero rotation and determining which increment provides the highest cross-correlation peak.

[0022] Although the acquired offset comprises both a translational offset and a rotational offset between the received image and the reference image in the present embodiment, in other embodiments, the acquired offset may be either a translational offset (in one or both of the x-direction and the y-direction), or a rotational offset, between the received image and the reference image, depending on the type(s) of relative movement of the retina and the ophthalmic device that are anticipated to occur during imaging.

[0023] In process S20, the image processing apparatus may more generally calculate a cross-correlation between the reference image and an image that is based on one or more of the received images (in other words, a cross-correlation between the reference image and an image of the received images (as described above), or a cross-correlation between the reference image and an image that is derived from the one or more received images), to acquire an offset between said image and the reference image. For example, the image that is cross-correlated with the reference image may be obtained by averaging two or more of the received images (e.g. two or more consecutive received images in the sequence), or otherwise processing two or more of the received images.

[0024] In process S30, the image processing apparatus 140 determines whether there are any more retinal images to process. If there are one or more further images to process, then the process loops back to process S10, otherwise the process is terminated. Through repeated performance of processes S10 and S20, the image processing apparatus 140 acquires respective offsets for the images in the sequence as the retinal position tracking information. The process may alternatively lock (thereby locking the reference frame) in cases where the confidence value F described below has risen and then remains unchanging as frames are processed. This would be indicative that, in a particular case (where there is little change occurring), there are no more improvements to be made.

[0025] While processes S10 and S20 are being repeated, the image processing apparatus 140 modifies the reference image by determining a measure of similarity between the content of correspondingly located and identically shaped regions of pixels in two or more of the received images and, based on the determined measure of similarity, accentuating at least some features in the reference image representing structures of the imaged retina in relation to other features in the reference image. The reference image is thus adaptive to changing conditions of the images being processed, which may enable a high degree of robustness in tracking to be achieved since the signal-to-noise (or other indicator of a ratio of 'useful information' for tracking to 'non-useful information' for tracking) in the reference image improves and the adverse effect of variable lighting between images can be reduced. As will be explained in the following, the reference image represents an accumulation of selected information from a number of image frames, with some points in the reference image being accentuated in relation to other points, depending on the analysis of the images herein described.

[0026] By way of a non-limiting example, the process by which the image processing apparatus 140 of the present embodiment modifies the reference image will now be described with reference to Figs. 4 to 10.

[0027] Referring firstly to Fig. 4, in process S100, the image processing apparatus 140 receives from the tracking image acquisition module 120 a first image based on one or more of the received images and a second image based on another one or more of the received images, and registers the first and second images with respect to each other. It is noted that the first image may be acquired and/or stored before or after the second image. By way of an example, the first image may be obtained by averaging two or more of the received images, and the second image may be obtained by averaging two or more other received images. In the present embodiment, however, the image processing apparatus receives from the tracking image acquisition module 120 a first and a second of the received images (which may, as in the present embodiment, be adjacent to each other in the sequence of acquired images) and registers the first and second images with respect to each other. The image processing apparatus 140 may calculate a cross-correlation between the first and second images and, based on the calculated cross-correlation, co-register the two images. The image processing apparatus 140 thus generates a registered second image 2-2 that is co-registered with the first image 2-1, as illustrated in Fig. 7. It should be noted, however, that the received images may

alternatively be registered with each other by registering each of these images with respect to the reference image, so that the first and second images are registered with respect to the reference image and therefore with respect to one another.

[0028] It should also be noted that, although the retinal images processed by the image processing apparatus 140 are obtained directly from the tracking image acquisition module 120 in the present embodiment, the image processing apparatus 140 may alternatively perform the image processing operations described herein on images from the tracking image acquisition module 120 that have been pre-processed, for example to accentuate image features that are helpful for establishing co-alignment with the reference image in the manner described in US Patent No. 9,454,817. In the described preprocessing method, image information can be considered to exist at a range of spatial frequencies and being accordingly partitioned into four classifications, namely: (i) large-scale information; (ii) medium-scale information relating to coarse (mainly choroidal) features; (iii) medium-scale information relating to fine (mainly vascular) features; and (iv) small-scale (textural) information. The information used in the present algorithm is mainly from the medium scale information consisting of vasculature and choroidal layers. The extraction of this information involves comparing (through 2D convolution) an image frame with a 'matched' kernel. In simple terms, this matched kernel can be thought of as having a 'shape' which is equivalent to the 'shape' being extracted. In order to extend the range of information being extracted, the kernel shape can be adjusted in a range between 'fine' and 'coarse'. These kernels can also be rotated and convolutions repeated at each alternative step in rotation, taking the maximum value for each convolution as the value that is assigned in the pre-processed image frame. Further details of the preprocessing algorithm are provided in US Patent No. 9,454,817.

[0029] Although the image processing apparatus 140 may proceed to co-register each pair of retinal images without discrimination (i.e. non-selectively), the image processing apparatus 140 preferably only proceeds to co-register the images when the calculated cross-correlation between the two images satisfies a prescribed condition. This prescribed condition may, for example, be that a peak value of the cross-correlation exceeds a predetermined threshold. As another alternative, the prescribed condition may, as in the present embodiment, be that the value of a confidence F, which provides a measure of the likelihood of the translational and rotational offset values being correct, exceeds a predetermined threshold, F_{Th}. In this case, the threshold F_{Th} may be set so that the number of true-negative occurrences (i.e. cases where values are reported with high confidence but are actually incorrect) is close to zero. The process by which the image processing apparatus 140 of the present embodiment registers the first and second images in process S100 will now be described in more detail with reference to Fig. 5.

[0030] In process S110, the image processing apparatus 140 calculates a cross-correlation between a pair of adjacent images in the sequence of images. The values of the calculated cross-correlation define a correlation surface having a peak, as illustrated in Fig. 6.

[0031] In process S120, the image processing apparatus 140 calculates a confidence value, F,

based on the calculated cross-correlation. The confidence value F may be obtained by parameterisation of the correlation surface, for example as described in US 9,454,817.

[0032] In process S130, the image processing apparatus 140 determines whether the calculated confidence value F exceeds the threshold value F_{Th}. In case the magnitude of the calculated confidence value F is determined in process S130 not to exceed the threshold value F_{Th}, the image processing apparatus 140 repeats processes S110 and S120 for first and second images in the next adjacent pair of images in the sequence (or, more generally, first and second images that based on respective one or more different received images). The loop comprising processes S110 to S130 is thus repeated until the calculated confidence value F exceeds the threshold value F_{Th}.

[0033] In process S140, the image processing apparatus 140 registers a first of the images with a second of the images, whose calculated cross-correlation value yields a confidence value F that exceeds the threshold value F_{Th}, to generate the registered second image 2-2 that is registered with the first image 2-1, as illustrated in Fig. 7.

[0034] It should be noted that the process of image registration described above with reference to Fig. 5 could additionally or alternatively be used by the image processing apparatus 140 to selectively output acquired offsets to the controller 130 for control of the OCT imaging module 110 to stabilise the scan location on the retina during the acquisition of the OCT images, so that only offsets associated with confidence values of $F > F_{Th}$ can be used for stabilising the scan location.

[0035] Referring again to Fig. 4, in process S200, the image processing apparatus 140 processes an array of pixels, referred to here as an "accumulator array of pixels", whose pixels values may all initially be set to zero, for example. As illustrated in Fig. 7, each pixel (e.g. the $(i, j)^{th}$ illustrated at "10") in the accumulator array 8 is associated with a correspondingly located pixel (in this example, the $(i, j)^{th}$ pixel labelled 4-1) in the first image 2-1 and a correspondingly located pixel (in this example, the $(i, j)^{th}$ pixel labelled 4-2) in the registered second image 2-2.

[0036] More particularly, the image processing apparatus 140 processes the accumulator array 8 by determining, for each pixel in the first image 2-1 and a correspondingly located pixel in the registered second image 2-2, whether the measure of similarity between a region of pixels (e.g. 6-1 in the case of pixel 4-1) surrounding the pixel in the first image 2-1 and an identically shaped region of pixels (e.g. 6-2 in the case of pixel 4-2) surrounding the corresponding pixel in the registered second image 2-2 exceeds a predefined level of similarity and, only when the measure of similarity exceeds the predefined level of similarity, changing (in this example, incrementing) a value of the pixel 10 in the accumulator array 8 associated with said pixel 4-1 in the first image 2-1 and with said correspondingly located pixel 4-2 in the registered second image 2-2. Although the pixel regions 6-1 and 6-2 in the present embodiment are 3 × 3 arrays of pixels in the present embodiment, the shape and size of the pixels regions is not so limited, and differently sized arrays (e.g. 9 × 9 pixels), which need not

be square in shape, may alternatively be employed.

[0037] The image processing apparatus 140 may determine the degree of similarity between the corresponding pixel regions (e.g. as shown at 6-1 and 6-2 in Fig. 7), in one of a number of different ways. For example, the image processing apparatus 140 may, as in the present embodiment, use values of the pixels in the pixel regions 6-1 and 6-2 to determine the similarity between pixel value gradients (the pixel value gradient specifying a rate of change of pixel value with pixel location) in the x-direction and in the y-direction at correspondingly-located pixels 4-1 and 4-2 in the first and second co-registered images 2-1 and 2-2, and, only when (i) the gradients in the x-direction are the same for the two regions to within a first predefined margin, and (ii) the gradients in the y-direction are the same for the two regions to within a second predefined margin (which may or may not be the same as the first predefined margin), increment the value of the pixel 10 in the accumulator array 8 associated with pixel 4-1 in the first image 2-1 and with correspondingly located pixel 4-2 in the registered second image 2-2. The measure of similarity may additionally or alternatively be based on at least one of (i) a similarity between average pixel values, and (ii) a similarity between pixel value histograms, of the correspondingly located regions of pixels 6-1, 6-2 in the co-registered pairs of images 2-1, 2-2 in the sequence.

[0038] In the case of the pixel value histogram, the image processing apparatus 140 may generate a pixel value histogram of pixels values in each of pixel regions 6-1 and 6-2 (for example, by dividing the range of possible values that a pixel can take into a predetermined number of bins (e.g. 20 bins), and determining a respective cumulative count for each of these bins in accordance with the values of the pixels in the region), and, only when the similarity between the histograms is greater than a predefined level of similarity, increment the value of the pixel 10 in the accumulator array 8 associated with pixel 4-1 in the first image 2-1 and with correspondingly located pixel 4-2 in the registered second image 2-2. The similarity between the histograms may, for example, be determined by any suitable distance function, such as the Hellinger distance, Manhattan distance, Euclidian distance, Chebyshev distance, etc. This histogram-based similarity test may provide the most effective accentuation of retinal features in the reference image, although the other similarity tests described above may have the advantage of being less demanding of processing resources to implement and may therefore be preferably in cases where computational loading is a concern.

[0039] In a variant of process S200, the image processing apparatus 140 may also determine, for each pixel (e.g. 4-1) in the first image 2-1 and the correspondingly located pixel (e.g. 4-2) in the registered second image 2-2, whether a difference between a weighted average of pixel values in a region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 and a weighted average of pixel values in a region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2 is less that a predefined threshold. In this variant of the process S200, the image processing apparatus 140 changes (e.g. increments) the value of the pixel 10 in the accumulator array 8 associated with the pixel 4-1 in the first image 2-1 and with the corresponding pixel 4-2 in the registered second image 2-2 only when the measure of similarity exceeds the predefined level of similarity and the difference between the weighted

averages is less than the predefined threshold. In this variant, the weighted average of pixel values in the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1, and the weighted average of pixel values in the region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2, are both calculated using a structuring element (as shown at "12" in Fig. 8) comprising pixel value weightings w to be applied to respective pixels in an arrangement of pixels as provided in pixel regions 6-1 and 6-2, wherein the structuring element 12 is set in a common one of a plurality of different orientations relative to the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 and the region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2 such that the weighted average of pixel values in the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 calculated for the common orientation is higher than the weighted averages of pixel values in the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 calculated for the other orientations. In other words, the orientation of the structuring element is varied among a plurality of different orientations (e.g. 10 different orientations) relative to the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 in order to identify the orientation that yields the greatest weighed average of pixel values in the first region of pixels 6-1, and that same orientation of the structuring element is then used to determine the weighted average of pixel values in the region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2. The additional 'structural' similarity test used in this variant of process S200 may be used to effectively reinforce pixel locations in the accumulator array 8 that are part of a characteristic shape (typically the vasculature or choroid features, or pathology structure which may depend on the wavelength of the illuminating light source) of the retinal features, with static features that are not part of the retina (e.g. edges of the eyelid or an eyelash, for example) being attenuated.

[0040] The reference image processed in process S20 in Fig. 3 may be defined by the accumulator array of pixels. Alternatively, the reference image may be obtained by processing the accumulator array. For example, the reference image may, as in the present embodiment, be obtained by generating a binarised version of the accumulator array. Accordingly, in (optional) process S300, the image processing apparatus 140 generates a binary reference image by setting the value of each pixel of the binary reference image to a first pixel value (e.g. "1") when a correspondingly located pixel 10 in the accumulator array 8 has a pixel value that exceeds a binarising threshold, and setting the value of each pixel of the binary reference image to a second value (e.g. "0") that is different from the first value when a correspondingly located pixel in the accumulator array has a pixel value that does not exceed the binarising threshold. The binary reference image may speed up the calculation of the cross-correlation with the received image in process S20.

[0041] In an alternative embodiment, the image processing apparatus 140 may generate a reference (grey scale) image by setting the value of each pixel of the reference image to the value of a correspondingly located pixel in the accumulator array 8 when the correspondingly located pixel in the accumulator array 8 has a pixel value that exceeds a second threshold, and setting the value of each pixel of the reference image to a first value (e.g. zero) when a correspondingly located pixel in the accumulator array 8 has a pixel value that does not exceed

the second threshold. In this case, the accumulator array 8 may be processed such that the value of each pixel 10 therein is an accumulation (e.g. sum) of the values of correspondingly located pixels in all of the processed arrays of pixels, and the second threshold is typically smaller than, and increases with, the number of processed arrays of pixels.

[0042] In process S400, the image processing apparatus 140 determines whether there are at least two more images in the sequence to process. If there are, then processes S100 to S400 are repeated, as illustrated in Fig. 4, otherwise the process terminates.

[0043] As the values of some of the pixels in the accumulator array 8 increase with the repeated performance of process S200, the binarising threshold increases with the number of repetitions of process S200 in the present embodiment. For example, the binarising threshold may be half (or another predetermined fraction) of the number of repetitions of process S200.

[0044] Fig. 9 shows a sequence of images that are each representative of the content of the accumulator array, and illustrates how the accumulator array varies as the number of image frames processed by the image processing apparatus of the embodiment increases from 1 to 15. During the processing the accumulator array, the accumulation and enhancement of features (mainly vasculature in this example, but could be other features) can be readily seen.

[0045] Fig. 10 illustrates the improvement in latch strength when tracking relative to the reference image in accordance with the embodiment, as compared to a fixed (unchanging) reference frame. In Fig. 10, the variation of the confidence values achieved when tracking relative to the evolving reference image frame over the first 31 frames of tracking is illustrated by the upper set of points, while the variation of the confidence values achieved when tracking relative to the fixed reference image frame is illustrated by the lower set of points. A clear improvement in confidence in the case of the evolving reference image as compared to the unchanging reference image can be observed.

[0046] In the above-described embodiment, the result of each comparison of pixel regions surrounding correspondingly located pixels in the co-registered images in process S200 is not stored after it has been determined to change or leave unchanged the correspondingly located pixel in the accumulator array, which has the advantage of requiring a relatively small amount of data to be stored while the sequence of retinal images is being processed. However, in another embodiment, the results of these comparisons of the co-registered images may be stored in a respective array of pixels, and all or only a predetermined number of most recent ones of these arrays of pixels may be stored in the image processing apparatus 140. Such an alternative second embodiment will now be described in more detail with reference to Fig. 11.

[0047] Process S100 in Fig. 11 is the same as process S100 in Fig. 4 of the first embodiment, and its description will therefore not be repeated here.

[0048] In process S210, the image processing apparatus 140 generates an array of pixels, each pixel in the array being associated with a correspondingly located pixel (e.g. pixel 4-1 in

Fig. 7) in the first image 2-1 and a correspondingly located pixel (4-2) in the registered second image 2-2.

[0049] In process S220, the image processing apparatus 140 processes the array of pixels by determining, for each pixel in the first image 2-1 and a correspondingly located pixel in the registered second image 2-2, whether the measure of similarity between the region of pixels (e.g. region 6-1 in Fig. 7) surrounding the pixel 4-1 in the first image 2-1 and the (identically shaped) region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2 exceeds the predefined level of similarity. The measure of similarity determined in this process is similar to that in process S200 in Fig. 4, and will therefore not be described again in detail. The image processing apparatus 140 changes (e.g. increments, as in the present example) a value of the pixel in the array associated with the pixel 4-1 in the first image 2-1 and with the correspondingly located pixel 4-2 in the registered second image 2-2 only when the measure of similarity exceeds the predefined level of similarity.

[0050] Similar to the variant of process S200 described above, the image processing apparatus 140 of the present embodiment may determine in process S220, for each pixel (e.g. 4-1) in the first image 2-1 and a correspondingly located pixel (4-2) in the registered second image 2-2, whether a difference between a weighted average of pixel values in a region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 and a weighted average of pixel values in a region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2 is less that a predefined threshold and, only when the measure of similarity exceeds the predefined level of similarity and the difference is less than the predefined threshold, changing (e.g. incrementing) the value of the pixel in the array associated with said pixel 4-1 in the first image 2-1 and with said correspondingly located pixel 4-2 in the registered second image 2-2. The weighted average of pixel values in the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1, and the weighted average of pixel values in the region of pixels 6-2 surrounding the correspondingly located pixel 4-2 in the registered second image 2-2, are both calculated using a structuring element 12 as described above with reference to Fig. 8.

[0051] In process S230, for each pixel in the processed array of pixels whose value has been incremented, the image processing apparatus 140 changes the value of the correspondingly located pixel 10 in the accumulator array 8. The image processing apparatus 140 may, as in the present embodiment, increment the value of the correspondingly located pixel 10 in the accumulator array 8 by the same amount (e.g. by 1) as the increment to the processed array, or alternatively by a different amount.

[0052] In process S300, the image processing apparatus 140 generates a binary reference image as in process S300 of the embodiment, and similarly determines (in process S400) whether there are at least two more images in the sequence of images to process. If not, then the processing terminates, as illustrated in Fig. 11. On the other hand, if the image processing apparatus 140 determines in process S400 that there are at least two more images in the sequence of images to process, the processing proceeds to process S500, wherein the image

processing apparatus determines whether a predetermined number N (e.g. 10) of arrays of pixels have been generated and processed as described above. If fewer than N such arrays have been generated and processed, the processing loops back to process S100, as illustrated in Fig. 11. On the other hand, if the image processing apparatus determines in process S500 that N arrays of pixels have been generated and processed, then the image processing apparatus 140 undoes changes to the accumulator array 8 that were performed on the basis of the earliest processed one of the N stored arrays in process S600 (and optionally deletes the earliest processed one of the N stored arrays in process S600), and the processing then loops back to process S100. The image processing device 140 thus stores only the N most recently processed arrays of pixels, with the accumulator array 8 representing the combined results of only those N most recently processed arrays.

[0053] In a modification of process S300 in the second embodiment, the image processing apparatus 140 may generate a reference (grey scale) image by setting the value of each pixel of the reference image to the value of a correspondingly located pixel in the accumulator array 8 when the correspondingly located pixel in the accumulator array 8 has a pixel value that exceeds a second threshold, and setting the value of each pixel of the reference image to a first value (e.g. zero) when a correspondingly located pixel in the accumulator array 8 has a pixel value that does not exceed the second threshold.

[0054] In the above-described second embodiment, the accumulator array is thus processed such that the value of each pixel therein is an accumulation (e.g. sum) of the values of correspondingly located pixels in the N most recently processed arrays of pixels, with the binarising threshold used in process S300 (or the second threshold used in the above-described modification of process S300) being a fixed number.

[0055] In a modification of the above-described second embodiment, processes S500 and S600 may be omitted and processing may loop back from process S400 directly to process S100 when there are at least two more images in the sequence to be processed, and the accumulator array 8 may be processed such that the value of each pixel therein is an accumulation (e.g. sum) of the values of correspondingly located pixels in all of the processed arrays of pixels. In this modification, the binarising threshold (or the second threshold used in the above-described modification of process S300) would typically be smaller than, and increase with, the number of processed arrays of pixels. For example, the binarising threshold (or second threshold) may be 50% (or another predetermined fraction) of the number of processed arrays of pixels. This threshold may, however, increase with the number of processed arrays of pixels only until a predetermined number of arrays of pixels have been processed, and then stay fixed as the accumulator array is subsequently processed such that the value of each pixel therein is an accumulation (e.g. sum) of the values of correspondingly located pixels in a predetermined number of the most recently processed arrays of pixels, as described above.

[Modifications and Variations]

[0056] Many modifications and variations can be made to the embodiments described above.

[0057] In the above-described embodiments, the reference image is defined by or based on an accumulator array of pixels. However, the image processing apparatus 140 need not make use of such pixel value array in order to modify the reference image. In a variant of the embodiments, the image processing apparatus may generate and modify a binary reference image for acquiring the offsets, based on a stored set of pixel value arrays, wherein each array contains the results of the operations performed in process S220 described above. More particularly, in a variant, the binary reference image is generated and modified by processes of:

1. (a) registering a first image 2-1 based on one or more of the received images with a second images based on another one or more of the received images to generate a registered second image 2-2 that is registered with the first image 2-1;
2. (b) generating an array of pixels, each pixel in the array being associated with a correspondingly located pixel 4-1 in the first image 2-1 and a correspondingly located pixel 4-2 in the registered second image 2-2;
3. (c) processing the array of pixels by determining, for each pixel 4-1 in the first image 2-1 and a correspondingly located pixel 4-2 in the registered second image 2-2, whether the measure of similarity between the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 and the region of pixels 6-2 surrounding the corresponding pixel 4-2 in the registered second image 2-2 exceeds the predefined level of similarity and, only when the measure of similarity exceeds the predefined level of similarity, changing (e.g. incrementing) a value of the pixel in the array associated with said pixel 4-1 in the first image 2-1 and with said correspondingly located pixel 4-2 in the registered second image 2-2 (the measures of similarity may be determined as described in the above-described embodiments and variants thereof);

repeating processes (a) to (c) for different ones of the first and second images to generate a plurality of arrays of pixels;
generating the binary reference image by setting each pixel of the binary reference image to a first pixel value (e.g. "1") when correspondingly located pixels in the plurality of arrays of pixels have pixel values whose accumulated value (e.g. sum) exceeds a binarising threshold, and by setting the value of each pixel of the binary reference image to a second pixel value (e.g. "0") different from the first pixel value when correspondingly located pixels in the plurality of arrays of pixels have pixel values whose accumulated value does not exceed the binarising threshold; and
modifying the binary reference image by repeating processes (a) to (c) at least once, and setting each pixel of the binary reference image to the first pixel value when correspondingly located pixels in the plurality of arrays of pixels have pixel values whose accumulated value (e.g. sum) exceeds a second binarising threshold, and by setting the value of each pixel of the binary reference image to the second pixel value when correspondingly located pixels in the plurality of arrays of pixels have pixel values whose accumulated value does not exceed the second binarising threshold.

[0058] In the variant, the binary reference image may be modified by setting each pixel of the binary reference image to the first pixel value when correspondingly located pixels in a predetermined number of most recently processed ones of the processed arrays of pixels have pixel values whose accumulated value (e.g. sum) exceeds the second binarising threshold, and by setting the value of each pixel of the binary reference image to the second pixel value when correspondingly located pixels in the predetermined number of most recently processed ones of the processed arrays of pixels have pixel values whose accumulated value does not exceed the second binarising threshold, the second binarising threshold being a fixed number. Alternatively, the binary reference image may be modified by setting each pixel of the binary reference image to the first pixel value when correspondingly located pixels in all the processed arrays of pixels have pixel values whose accumulated value exceeds the second binarising threshold, and by setting the value of each pixel of the binary reference image to the second pixel value when correspondingly located pixels in all the processed arrays of pixels have pixel values whose accumulated value does not exceed the second binarising threshold, the second binarising threshold being smaller than, and increasing with, the number of processed arrays of pixels.

[0059] In another variant, instead of a binary reference image, a grey scale reference image is generated and modified by processes of:

1. (a) registering a first image 2-1 based on one or more of the received images with a second image based on another one or more of the received images to generate a registered second image 2-2 that is registered with the first image 2-1;
2. (b) generating an array of pixels, each pixel in the array being associated with a correspondingly located pixel 4-1 in the first image 2-1 and a correspondingly located pixel 4-2 in the registered second image 2-2;
3. (c) processing the array of pixels by determining, for each pixel 4-1 in the first image 2-1 and a correspondingly located pixel 4-2 in the registered second image 2-2, whether the measure of similarity between the region of pixels 6-1 surrounding the pixel 4-1 in the first image 2-1 and the region of pixels 6-2 surrounding the corresponding pixel 4-2 in the registered second image 2-2 exceeds the predefined level of similarity and, only when the measure of similarity exceeds the predefined level of similarity, changing a value of the pixel in the array associated with said pixel 4-1 in the first image 2-1 and with said correspondingly located pixel 4-2 in the registered second image 2-2;
4. (d) repeating processes (a) to (c) for different ones of the first and second images to generate a plurality of arrays of pixels;
5. (e) generating the reference image by setting each pixel of the reference image to an accumulation (e.g. sum) of the pixel values of correspondingly located pixels in the plurality of arrays of pixels when said accumulation exceeds a threshold, and by setting the value of each pixel of the reference image to a first pixel value when said accumulation does not exceed the threshold;
6. (f) modifying the reference image by repeating processes (a) to (c) at least once, and setting each pixel of the reference image to an accumulation (e.g. sum) of the pixel

values of correspondingly located pixels in the plurality of arrays of pixels when said accumulation exceeds a second threshold, and by setting the value of each pixel of the reference image to the first pixel value when correspondingly located pixels in the plurality of arrays of pixels have pixel values whose accumulation (e.g. sum) does not exceed the second threshold.

[0060] In this variant, the grey scale reference image may be modified by setting each pixel of the reference image to an accumulation (e.g. sum) of the pixel values of correspondingly located pixels in the plurality of arrays of pixels when the correspondingly located pixels in a predetermined number of most recently processed ones of the processed arrays of pixels have pixel values whose accumulation (e.g. sum) exceeds the second threshold, and by setting the value of each pixel of the reference image to the first pixel value when correspondingly located pixels in the predetermined number of most recently processed ones of the processed arrays of pixels have pixel values whose accumulation (e.g. sum) does not exceed the second threshold, the second threshold being a fixed number. Alternatively, the grey scale reference image may be modified by setting each pixel of the reference image to an accumulation (e.g. sum) of the pixel values of correspondingly located pixels in the plurality of arrays of pixels when the correspondingly located pixels in all the processed arrays of pixels have pixel values whose accumulation (e.g. sum) exceeds the second threshold, and by setting the value of each pixel of the reference image to the first pixel value (such as zero) when correspondingly located pixels in all the processed arrays of pixels have pixel values whose accumulation (e.g. sum) does not exceed the second threshold, the second threshold being smaller than, and increasing with, the number of processed arrays of pixels.

REFERENCES CITED IN THE DESCRIPTION

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Patentkrav

1. Fremgangsmåde til at bearbejde en sekvens af billeder af en nethinde opnået med en oftalmisk indretning (100) for at generere nethindepositionssporings-information, som indikerer en bevægelse af nethinden under opnåelsen af sekvensen af billeder, hvilken fremgangsmåde omfatter:

(i) at modtage (S10) et eller flere billeder af nethinden fra sekvensen;

(ii) at beregne (S20) en krydskorrelation mellem et referencebillede og et billede baseret på det ene eller flere modtagne billeder for at opnå et offset mellem billedet og referencebilledet; og

at gentage processerne (i) og (ii) for som nethindepositionssporingsinformationen at opnå respektive offsets for yderligere billeder, som er baseret på yderligere respektive et eller flere modtagne billeder fra sekvensen; og

at modificere referencebilledet, mens processerne (i) og (ii) gentages, ved at bestemme et lighedsmål mellem tilsvarende placerede områder (6-1, 6-2) af pixels i to eller flere af de modtagne billeder og fremhæve kendetegn i referencebilledet, som repræsenterer strukturer af den afbildede nethinde i forhold til andre kendetegn i referencebilledet baseret på det bestemte lighedsmål.

2. Fremgangsmåden ifølge krav 1, hvor referencebilledet er defineret af eller baseret på et akkumulatorarray af pixels (8), og referencebilledet modificeres ved at bearbejde akkumulatorarrayet af pixels (8) ved:

(a) at registrere et første billede (2-1) baseret på et eller flere af de modtagne billeder med et andet billede baseret på et andet eller flere af de modtagne billeder for at generere et registreret andet billede (2-2), som er registreret med det første billede (2-1), idet hver pixel i akkumulator-arrayet (8) er associeret med en tilsvarende placeret pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2);

(b) at bearbejde akkumulatorarrayet (8) ved at bestemme, for hver pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2), om lighedsmålet mellem et område af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og et område af pixels (6-2) omgivende den tilsvarende pixel (4-2) i det registrerede

andet billede (2-2) overstiger et foruddefineret lighedsniveau og, kun når lighedsmålet overstiger det foruddefinerede lighedsniveau, at ændre en værdi af pixlen (10) i akkumulatorarrayet (8) associeret med nævnte pixel (4-1) i det første billede (2-1) og med nævnte tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2); og

at gentage processerne (a) og (b) for forskellige af det første billede og det andet billede.

3. Fremgangsmåden ifølge krav 2, hvor bearbejdning af akkumulatorarrayet (8) i proces (b) yderligere omfatter:

at bestemme, for hver pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2), om en forskel mellem et vægtet gennemsnit af pixelværdier i et område af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og et vægtet gennemsnit af pixelværdier i et område af pixels (6-2) omgivende den tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2) er mindre end en foruddefineret tærskel og, kun når lighedsmålet overstiger det foruddefinerede lighedsniveau, og forskellen er mindre end den foruddefinerede tærskel, at ændre værdien af pixlen (10) i akkumulator-arrayet (8) associeret med nævnte pixel (4-1) i det første billede (2-1) og med nævnte tilsvarende pixel (4-2) i det registrerede andet billede (2-2), hvor det vægtede gennemsnit af pixelværdier i området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1), og det vægtede gennemsnit af pixelværdier i området af pixels (6-2) omgivende den tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2), begge beregnes under anvendelse af et struktureringselement (12) omfattende pixelværdivægtninger, idet struktureringselementet (12) er indstillet i en fælles af en flerhed af forskellige orienteringer i forhold til området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og området af pixels (6-2) omgivende den tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2), således at det vægtede gennemsnit af pixelværdier i området af pixler (6-1) omgivende pixlen (4-1) i det første billede (2-1) beregnet for den fælles orientering er højere end de vægtede gennemsnit af pixelværdier i området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) beregnet for de andre orienteringer.

4. Fremgangsmåden ifølge krav 2, hvor akkumulatorarrayet (8) bearbejdes ved:

(a) at registrere et første billede (2-1) baseret på et eller flere af de modtagne billeder med et andet billede baseret på et andet eller flere af de modtagne billeder for at generere et registreret andet billede (2-2), som er registreret med det første billede (2-1), idet hver pixel (10) i akkumulator-arrayet (8) er associeret med en tilsvarende placeret pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2);

(b1) at generere et array af pixels, idet hver pixel i arrayet er associeret med en tilsvarende placeret pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2);

(b2) at bearbejde arrayet af pixels ved at bestemme, for hver pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2), om lighedsmålet mellem området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og området af pixels (6-2) omgivende den tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2) overstiger det foruddefinerede lighedsniveau og, kun når lighedsmålet overstiger det foruddefinerede lighedsniveau, at ændre en værdi af pixlen i arrayet associeret med nævnte pixel (4-1) i det første billede (2-1) og med nævnte tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2);

(b3) for hver pixel i det bearbejdede array af pixels, hvis værdi er blevet ændret, at ændre værdien af den tilsvarende placerede pixel (10) i akkumulatorarrayet (8); og

at gentage processerne (a) og (b1) til (b3) for forskellige af det første og det andet billede.

5. Fremgangsmåden ifølge et hvilket som helst af kravene 2 til 4, hvor reference-billedet genereres ved:

at indstille værdien af hver pixel af referencebilledet til værdien af en tilsvarende placeret pixel i akkumulatorarrayet (8), når den tilsvarende placerede pixel i akkumulatorarrayet (8) har en pixelværdi, som overstiger en anden tærskel; og

at indstille værdien af hver pixel af referencebilledet til en første værdi, når en tilsvarende placeret pixel i akkumulatorarrayet (8) har en pixelværdi, som ikke overstiger den anden tærskel.

6. Fremgangsmåden ifølge et hvilket som helst af kravene 2 til 4, hvor referencebilledet er et binært referencebillede genereret ved:

at indstille værdien af hver pixel af det binære referencebillede til en første pixelværdi, når en tilsvarende placeret pixel (10) i akkumulatorarrayet (8) har en pixelværdi, som overstiger en anden tærskel; og

at indstille værdien af hver pixel af det binære referencebillede til en anden værdi, når en tilsvarende placeret pixel (10) i akkumulatorarrayet (8) har en pixelværdi, som ikke overstiger den anden tærskel.

7. Fremgangsmåden ifølge krav 1, hvor referencebilledet er et binært referencebillede, og genereres og modificeres ved:

(a) at registrere et første billede (2-1) baseret på et eller flere af de modtagne billeder med et andet billede baseret på et andet eller flere af de modtagne billeder for at generere et registreret andet billede (2-2), som er registreret med det første billede (2-1);

(b) at generere et array af pixels, idet hver pixel i arrayet er associeret med en tilsvarende placeret pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2);

(c) at bearbejde arrayet af pixels ved at bestemme, for hver pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2), om lighedsmålet mellem området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og området af pixels (6-2) omgivende den tilsvarende pixel (4-2) i det registrerede andet billede (2-2) overstiger det foruddefinerede lighedsniveau og, kun når lighedsmålet overstiger det foruddefinerede lighedsniveau, at ændre en værdi af pixlen i arrayet associeret med nævnte pixel (4-1) i det første billede (2-1) og med nævnte tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2);

(d) at gentage processerne (a) til (c) for forskellige af det første og det andet billede for at generere en flerhed af arrays af pixels;

(e) at generere det binære referencebillede ved at indstille hver pixel af det binære referencebillede til en første pixelværdi, når tilsvarende placerede pixels i flerheden af arrays af pixels har pixelværdier, hvis akkumulering overstiger en binariseringstærskel, og ved at indstille værdien af hver pixel af det binære referencebillede til en anden pixelværdi, når de tilsvarende placerede pixels i flerheden af arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger binariseringstærsklen;

(f) at modificere det binære referencebillede ved at gentage processerne (a) til (c) mindst en gang, og at indstille hver pixel af det binære referencebillede til den første pixelværdi, når tilsvarende placerede pixels i flerheden af arrays af pixels har pixelværdier, hvis akkumulering overstiger en anden binariseringstærskel, og ved at indstille værdien af hver pixel af det binære referencebillede til den anden pixelværdi, når tilsvarende placerede pixels i flerheden af arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden binariseringstærskel.

8. Fremgangsmåden ifølge krav 7, hvor det binære referencebillede modificeres ved at indstille hver pixel af det binære referencebillede til den første pixelværdi, når:

tilsvarende placerede pixels i et forudbestemt antal af de senest bearbejdede af de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering overstiger den anden binariseringstærskel, og ved at indstille værdien af hver pixel af det binære referencebillede til den anden pixelværdi, når tilsvarende placerede pixels i det forudbestemte antal af de senest bearbejdede af de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden binariseringstærskel, idet den anden binariseringstærskel er et fast antal; eller

tilsvarende placerede pixels i alle de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering overstiger den anden binariseringstærskel, og ved at indstille værdien af hver pixel af det binære referencebillede til den anden pixelværdi, når tilsvarende placerede pixels i alle de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden binariseringstærskel, idet den anden binariseringstærskel stiger med antallet af bearbejdede arrays af pixels.

9. Fremgangsmåden ifølge krav 1, hvor referencebilledet genereres og modificeres ved:

(a) at registrere et første billede (2-1) baseret på et eller flere af de modtagne billeder med et andet billede baseret på et andet eller flere af de modtagne billeder for at generere et registreret andet billede (2-2), som er registreret med det første billede (2-1);

(b) at generere et array af pixels, idet hver pixel i arrayet er associeret med en tilsvarende placeret pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2);

(c) at bearbejde arrayet af pixels ved at bestemme, for hver pixel (4-1) i det første billede (2-1) og en tilsvarende placeret pixel (4-2) i det registrerede andet billede (2-2), om lighedsmålet mellem området af pixels (6-1) omgivende pixlen (4-1) i det første billede (2-1) og området af pixels (6-2) omgivende den tilsvarende pixel (4-2) i det registrerede andet billede (2-2) overstiger det foruddefinerede lighedsniveau og, kun når ligheds-målet overstiger det foruddefinerede lighedsniveau, at ændre en værdi af pixlen i arrayet associeret med nævnte pixel (4-1) i det første billede (2-1) og med nævnte tilsvarende placerede pixel (4-2) i det registrerede andet billede (2-2);

(d) at gentage processerne (a) til (c) for forskellige af det første og det andet billede for at generere en flerhed af arrays af pixels;

(e) at generere referencebilledet ved at indstille hver pixel af reference-billedet til en akkumulering af pixelværdierne af tilsvarende placerede pixels i flerheden af arrays af pixels, når nævnte akkumulering overstiger en tærskel, og ved at indstille værdien af hver pixel af referencebilledet til en første pixelværdi, når nævnte akkumulering ikke overstiger tærsklen;

(f) at modificere referencebilledet ved at gentage processerne (a) til (c) mindst en gang, og at indstille hver pixel af referencebilledet til en akkumulering af pixelværdierne af tilsvarende placerede pixels i flerheden af arrays af pixels, når nævnte akkumulering overstiger en anden tærskel, og ved at indstille værdien af hver pixel af referencebilledet til den første pixelværdi, når tilsvarende placerede pixels i flerheden af arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden tærskel.

10. Fremgangsmåden ifølge krav 9, hvor referencebilledet modificeres ved at indstille hver pixel af referencebilledet til en akkumulering af pixelværdierne af tilsvarende placerede pixels i flerheden af arrays af pixels når:

de tilsvarende placerede pixels i et forudbestemt antal af de senest bearbejdede af de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering overstiger den anden tærskel, og ved at indstille værdien af hver pixel af referencebilledet til den første pixelværdi, når tilsvarende placerede pixels i det forudbestemte antal af de senest bearbejdede af de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden tærskel, idet den anden tærskel er et fast antal; eller

de tilsvarende placerede pixels i alle de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering overstiger den anden tærskel, og ved at indstille værdien af hver pixel af referencebilledet til den første pixelværdi, når tilsvarende placerede pixels i alle de bearbejdede arrays af pixels har pixelværdier, hvis akkumulering ikke overstiger den anden tærskel, idet den anden tærskel stiger med antallet af bearbejdede arrays af pixels.

11. Fremgangsmåden ifølge et hvilket som helst af kravene 2 til 10, hvor proces (a) omfatter:

(a1) at beregnet en krydskorrelation mellem et par af billeder i sekvensen af billeder, hvor værdier af den beregnede krydskorrelation definerer en korrelationsoverflade med en top;

(a2) at beregne en konfidensværdi baseret på den beregnede kryds-korrelation;

(a3) at bestemme om den beregnede konfidensværdi overstiger en konfidenstærskelværdi;

(a4) hvis størrelsen af den beregnede konfidensværdi bestemmes til ikke at overstige konfidenstærskelværdien, at gentage processerne (a1) til (a3) for det første og det andet billede i et eller flere følgende billeder i sekvensen, indtil den beregnede konfidensværdi overstiger konfidenstærskelværdien; og

at registrere et første af billederne med et andet af billederne, hvis beregnede krydskorrelationsværdi giver en konfidensværdi, som overstiger konfidenstærskel-værdien, for at generere det registrerede andet billede (2-2), som er registreret

med det første billede (2-1).

12. Fremgangsmåden ifølge et hvilket som helst foregående krav, hvor lighedsmålet er baseret på mindst en af:

(i) en lighed mellem en pixelværdigradient;

(ii) en lighed mellem en gennemsnitlig pixelværdi; og

(iii) en lighed mellem et pixelværdihistogram,

af de tilsvarende placerede områder af pixels (6-1, 6-2) i de to eller flere billeder i sekvensen.

13. Ikke-transitorisk computerlæsbart lagermedium (250) eller et signal (260), som indeholder computerprograminstruktioner, som, når de eksekveres af en processor (220), får processoren (220) til at udføre en fremgangsmåde som beskrevet i mindst et af de foregående krav.

14. Billedbearbejdningsapparat (200) konfigureret til at bearbejde en sekvens af billeder af en nethinde opnået med en oftalmisk indretning (100) for at generere nethindepositionssporingsinformation, som indikerer en bevægelse af nethinden under opnåelse af sekvensen af billeder, idet billedbearbejdningsapparatet (200) omfatter en processor (220) og en hukommelse (240), som lagrer computer-programinstruktioner, som, når de eksekveres af processoren (220), får processoren (220) til at udføre en fremgangsmåde som beskrevet i et hvilket som helst af kravene 1 til 12.

15. Oftalmisk indretning (100) omfattende:

et optisk kohærenstomografi-, OCT, billeddannelsesmodul (110) konfigureret til at opnå OCT-billeder af en nethinde af et øje ved at scanne en lysstråle henover nethinden og bearbejde en reflektion af strålen fra nethinden;

et sporingsbilledopnåelsesmodul (120) konfigureret til at opnå en sekvens af billeder af nethinden for at spore en bevægelse af nethinden, mens OCT-billeddannelsesmodulet (110) opnår OCT-billederne; og

en styreenhed (130) omfattende et billedbearbejdningsapparat (140; 200) ifølge krav 14, som er konfigureret til at bearbejde sekvensen af billeder ifølge en fremgangsmåde som beskrevet i et hvilket som helst af kravene 1

til 12, for at generere nethindepositionssporingsinformation, som indikerer bevægelsen af nethinden under opnåelsen af OCT-billederne, idet styreenheden (130) er konfigureret til at styre OCT-billeddannelsesmodulet (110) under anvendelse af nethindepositionssporingsinformationen for at stabilisere strålen under opnåelse af OCT-billederne.

DRAWINGS

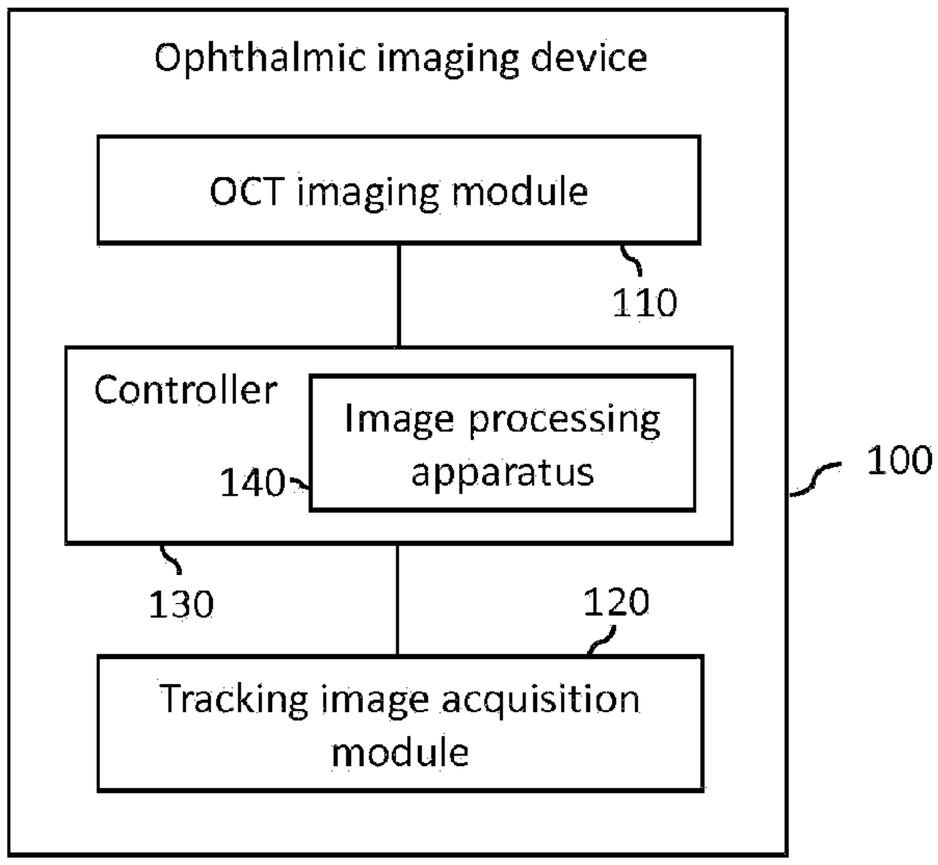


Fig. 1

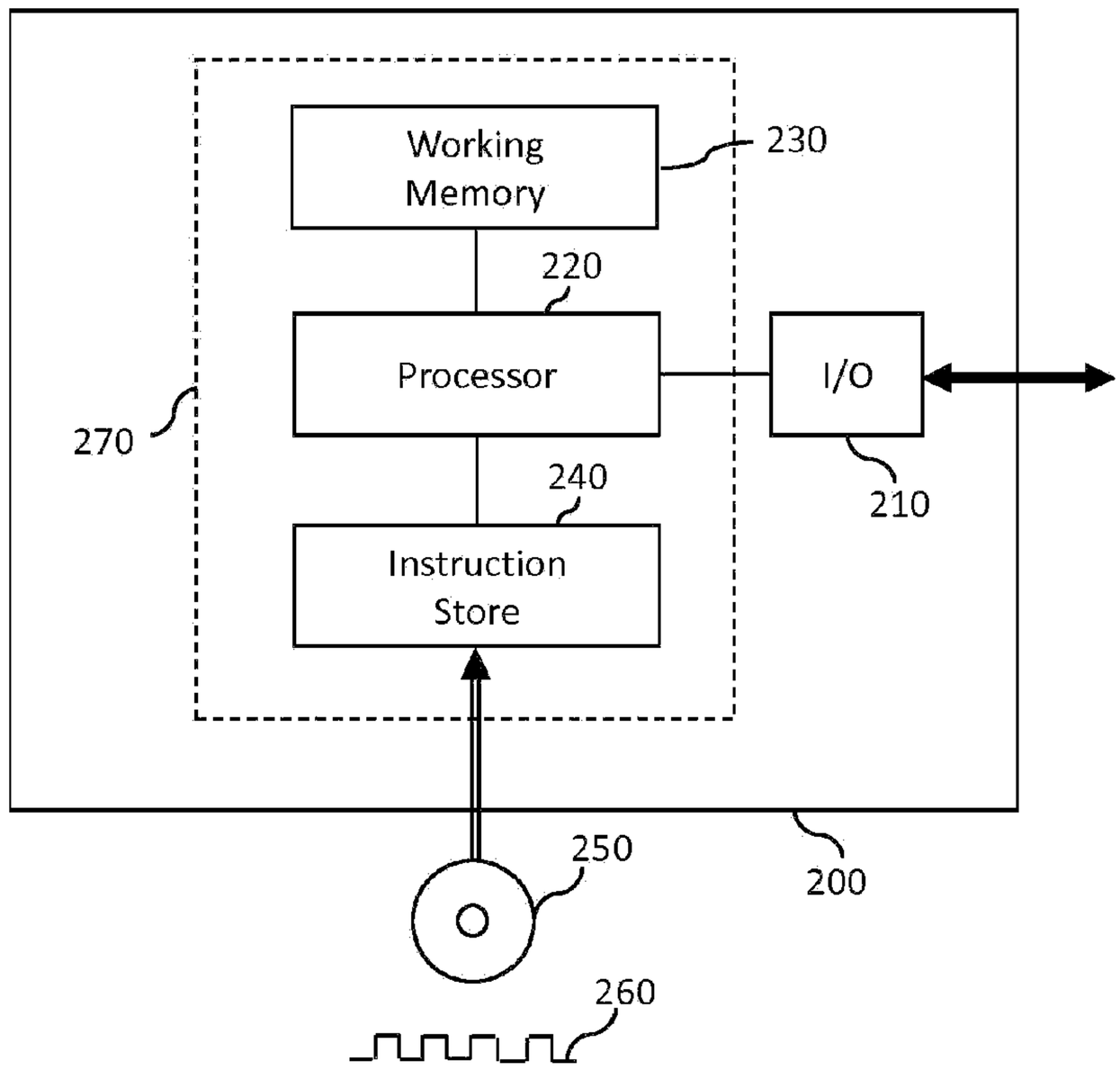

Working Memory
230
220
Processor
I/O
270
240
210
Instruction Store
250
200
260

Fig. 2

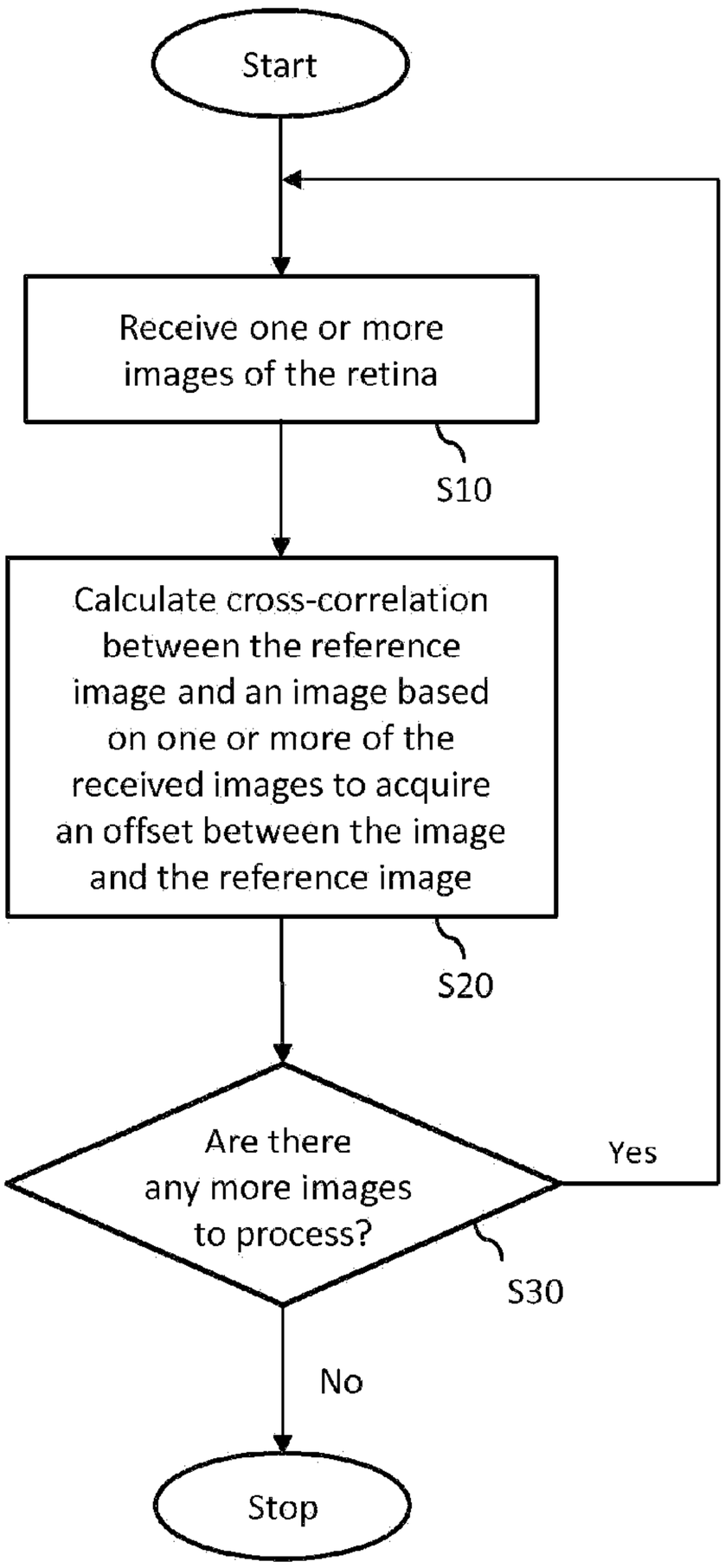

Start
Receive one or more images of the retina
S10
Calculate cross-correlation between the reference image and an image based on one or more of the received images to acquire an offset between the image and the reference image
S20
Are there any more images to process?
Yes
S30
No
Stop

Fig. 3

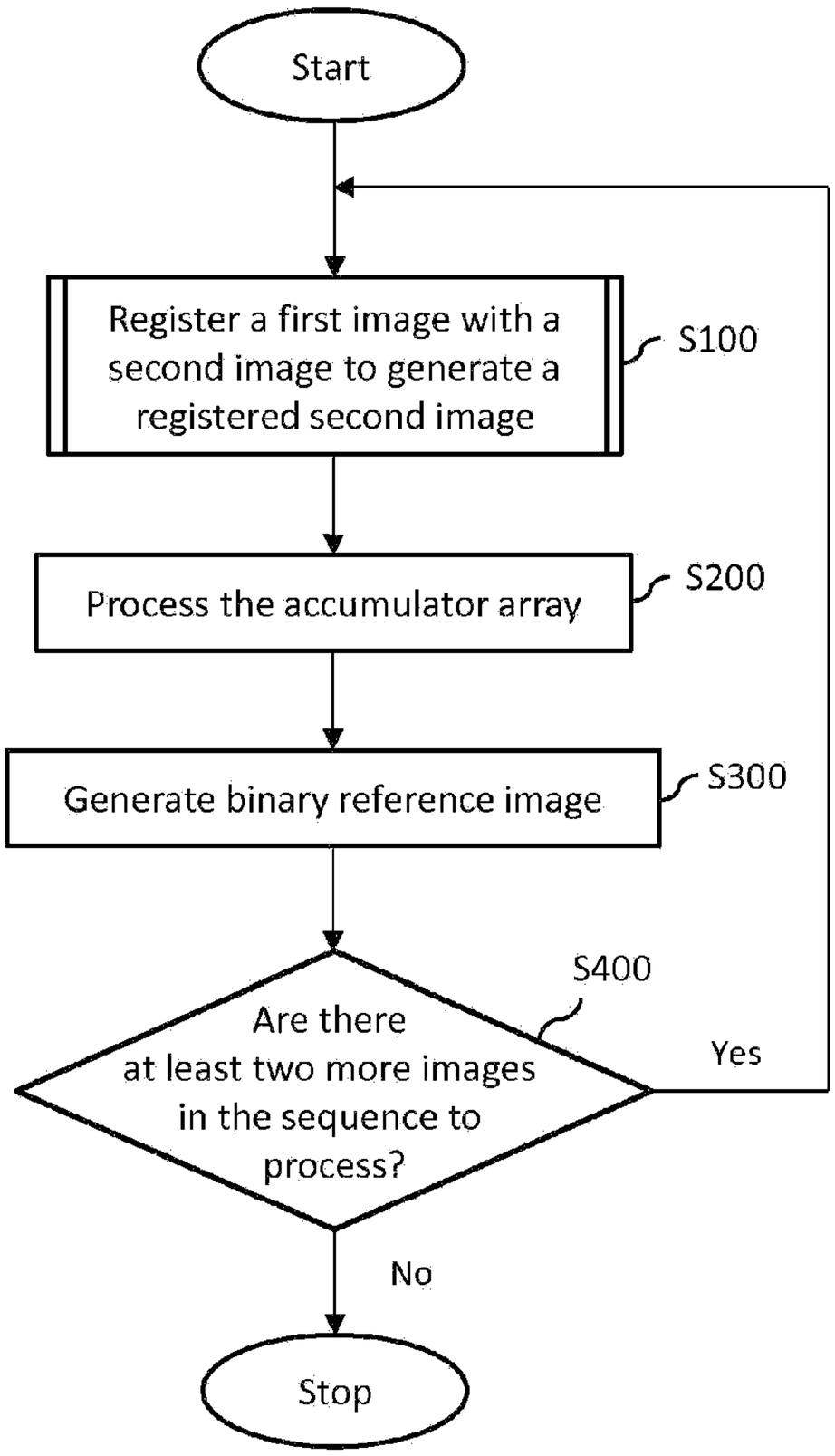

Start
Register a first image with a second image to generate a registered second image
S100
Process the accumulator array
S200
Generate binary reference image
S300
S400
Are there at least two more images in the sequence to process?
Yes
No
Stop

Fig. 4

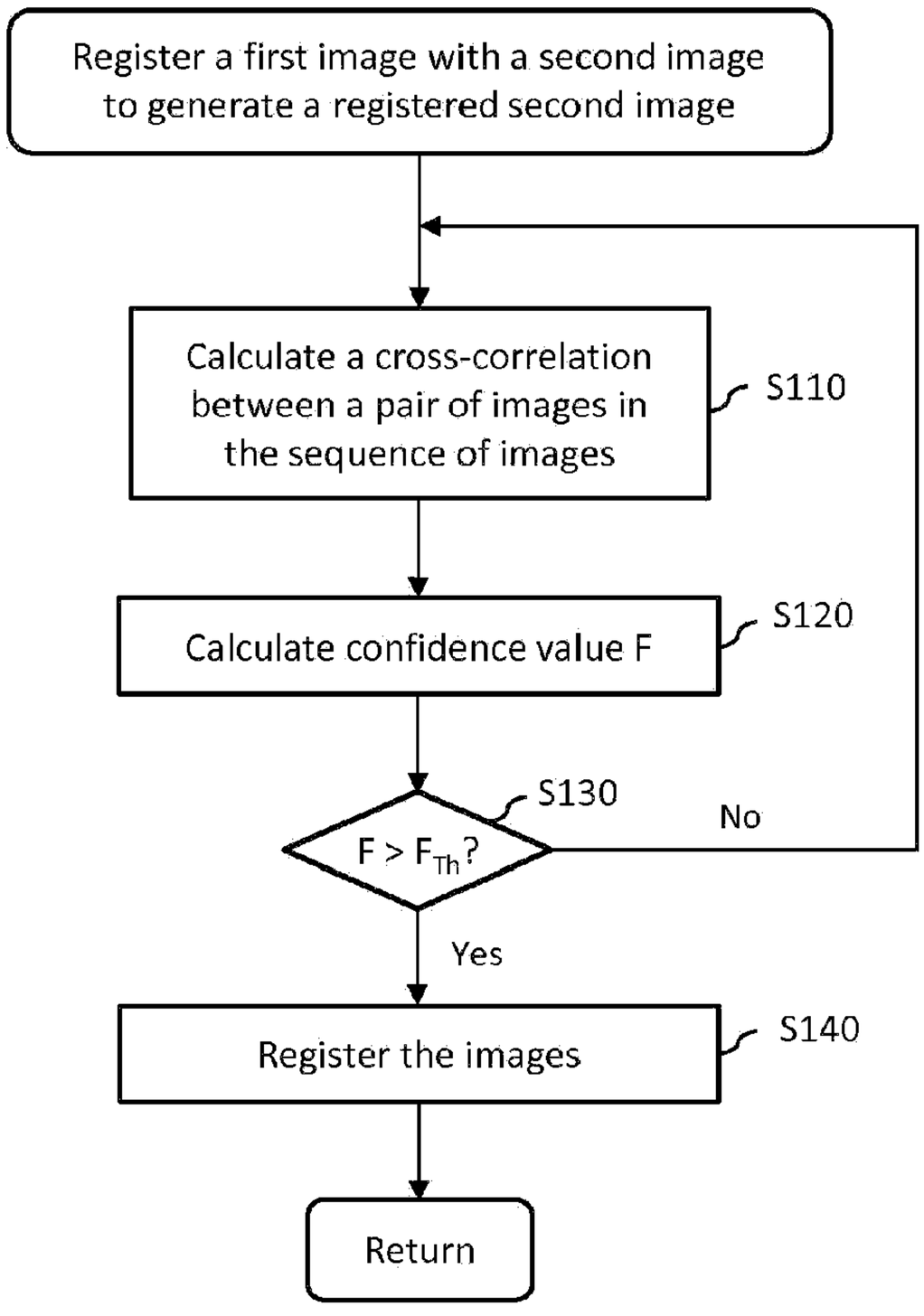

Register a first image with a second image to generate a registered second image
Calculate a cross-correlation between a pair of images in the sequence of images
S110
Calculate confidence value F
S120
S130
F > F_Th?
No
Yes
Register the images
S140
Return

Fig. 5

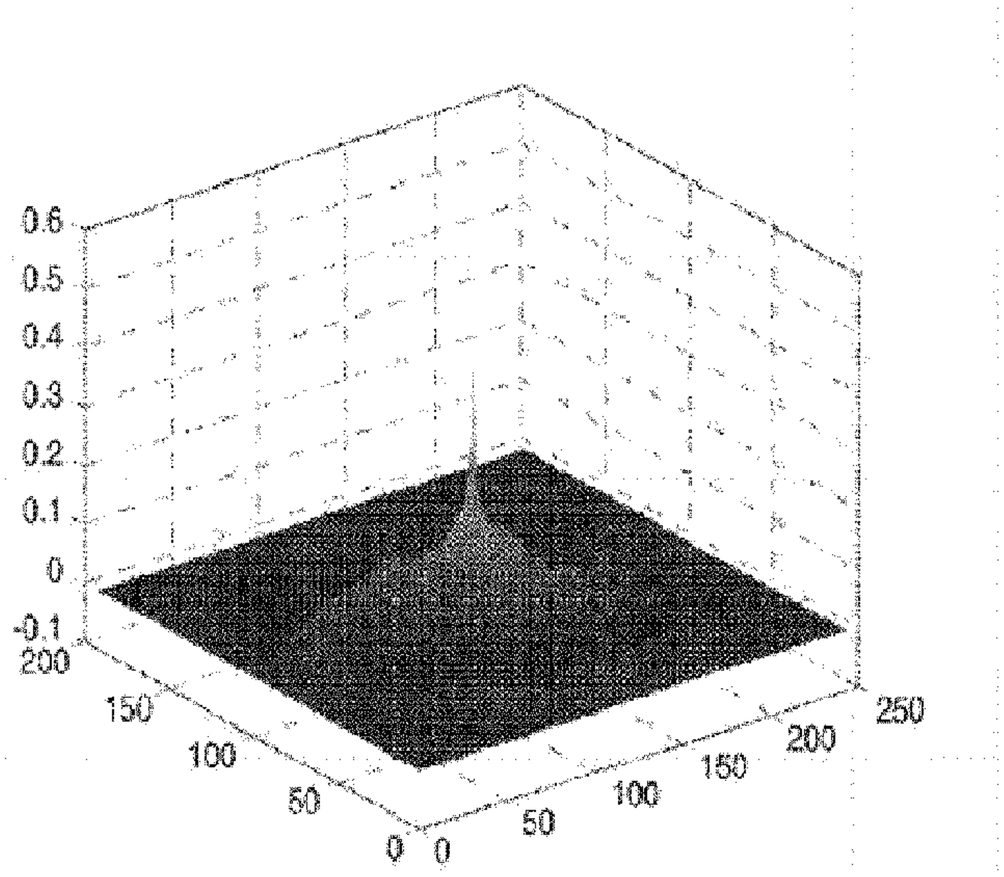
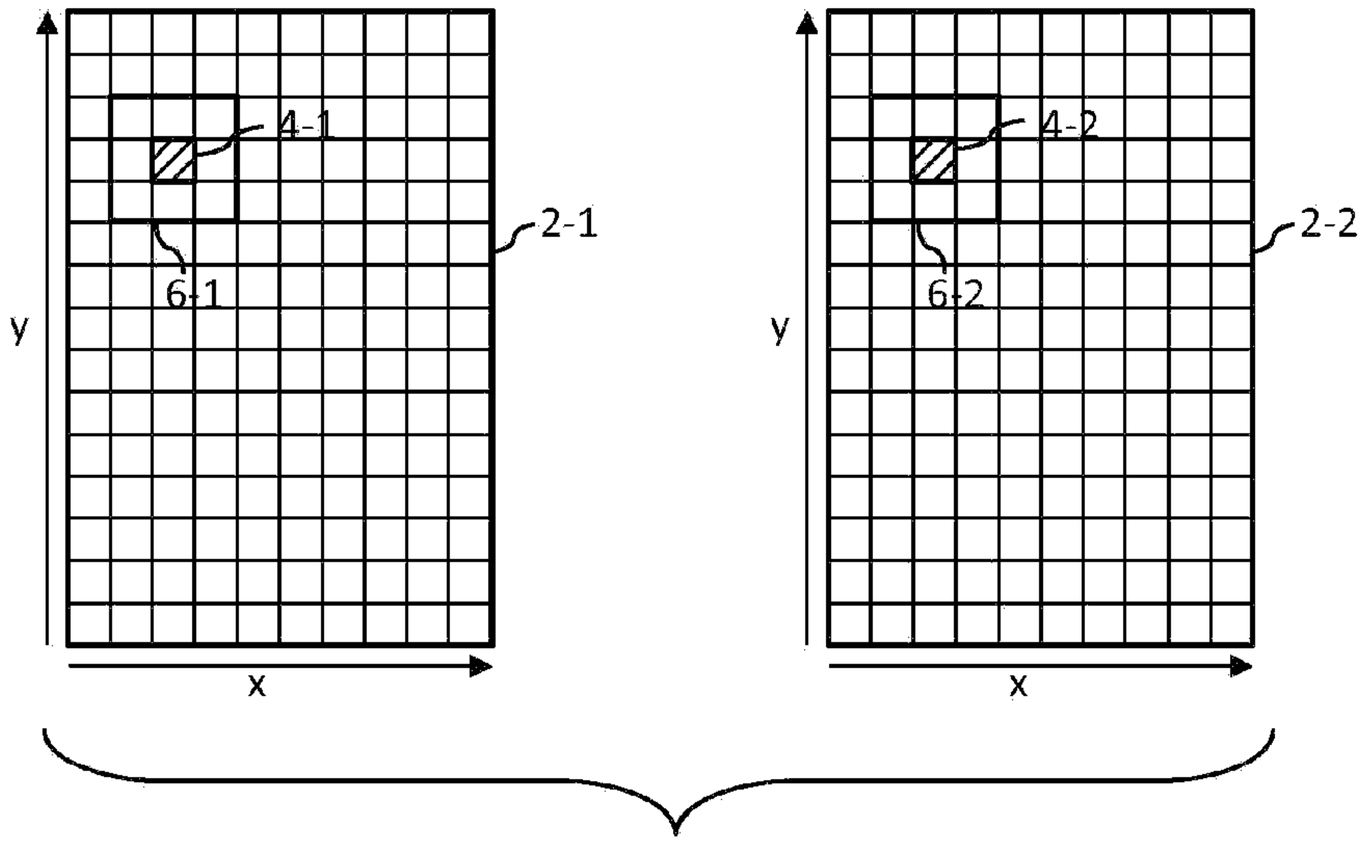


Fig. 6



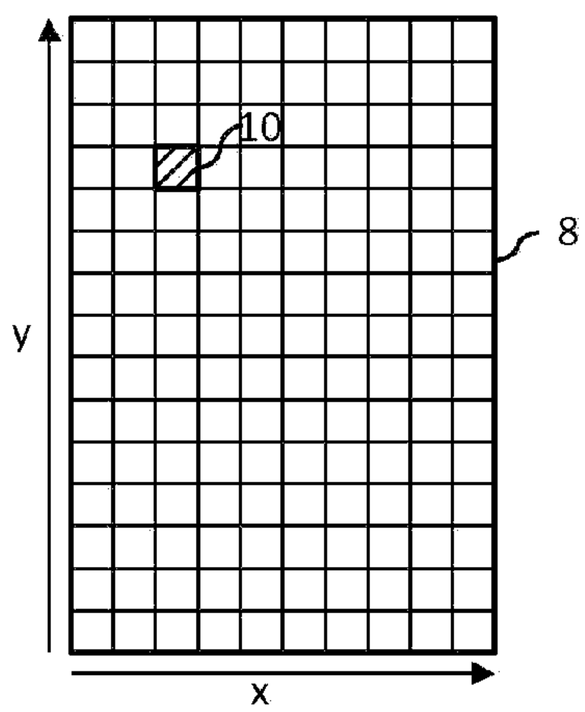


Fig. 7

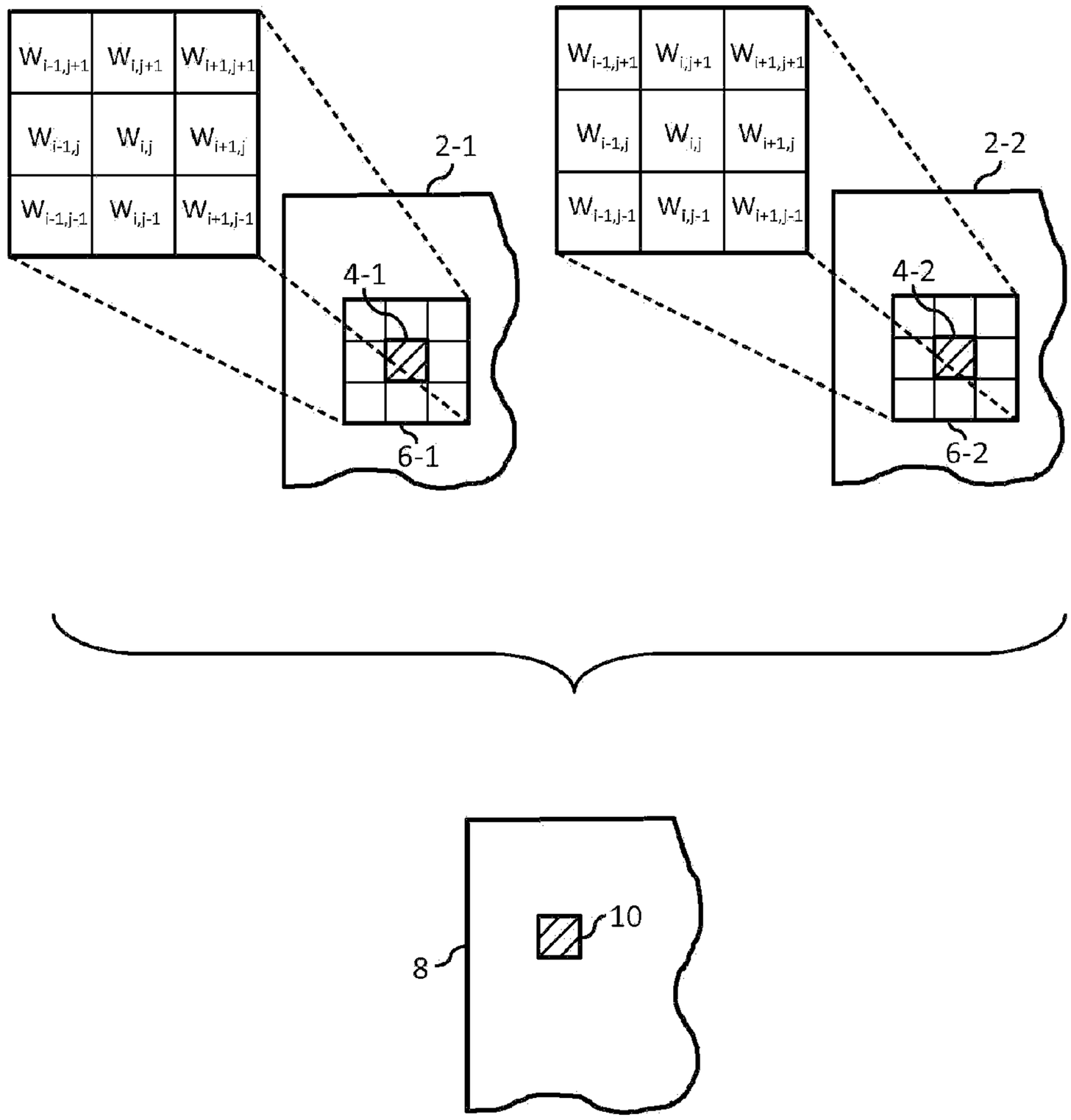

W i-1,j+1
W i,j+1
W i+1,j+1
W i-1,j
W i,j
W i+1,j
W i-1,j-1
W i,j-1
W i+1,j-1
2-1
4-1
6-1
2-2
4-2
6-2
8
10

Fig. 8

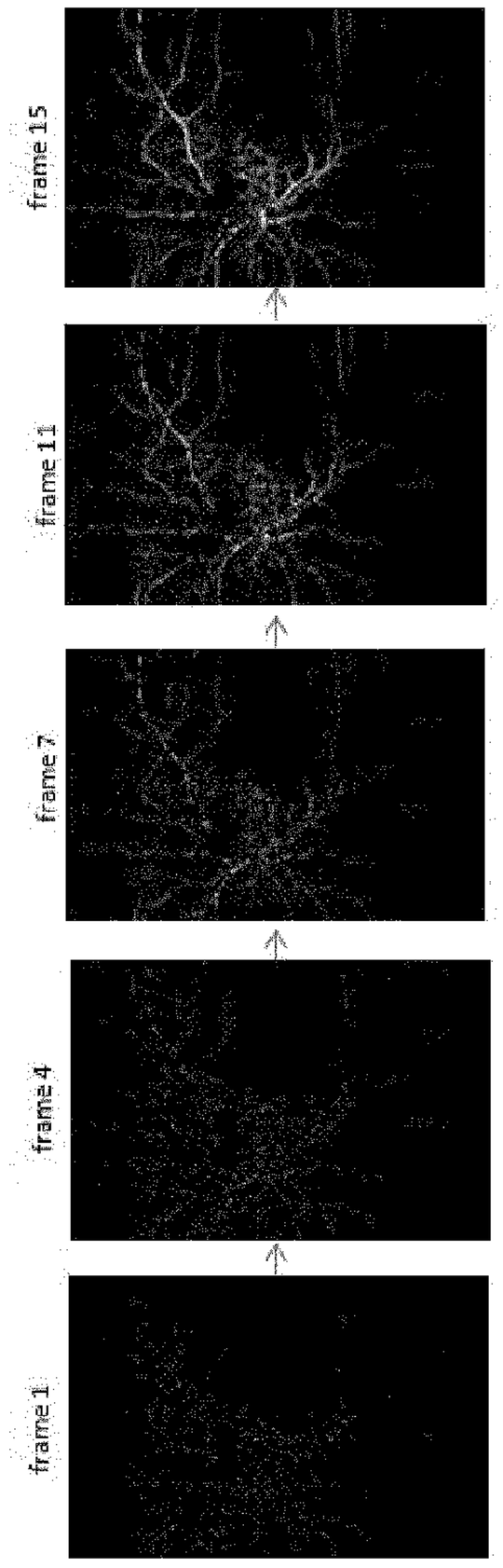


Fig. 9

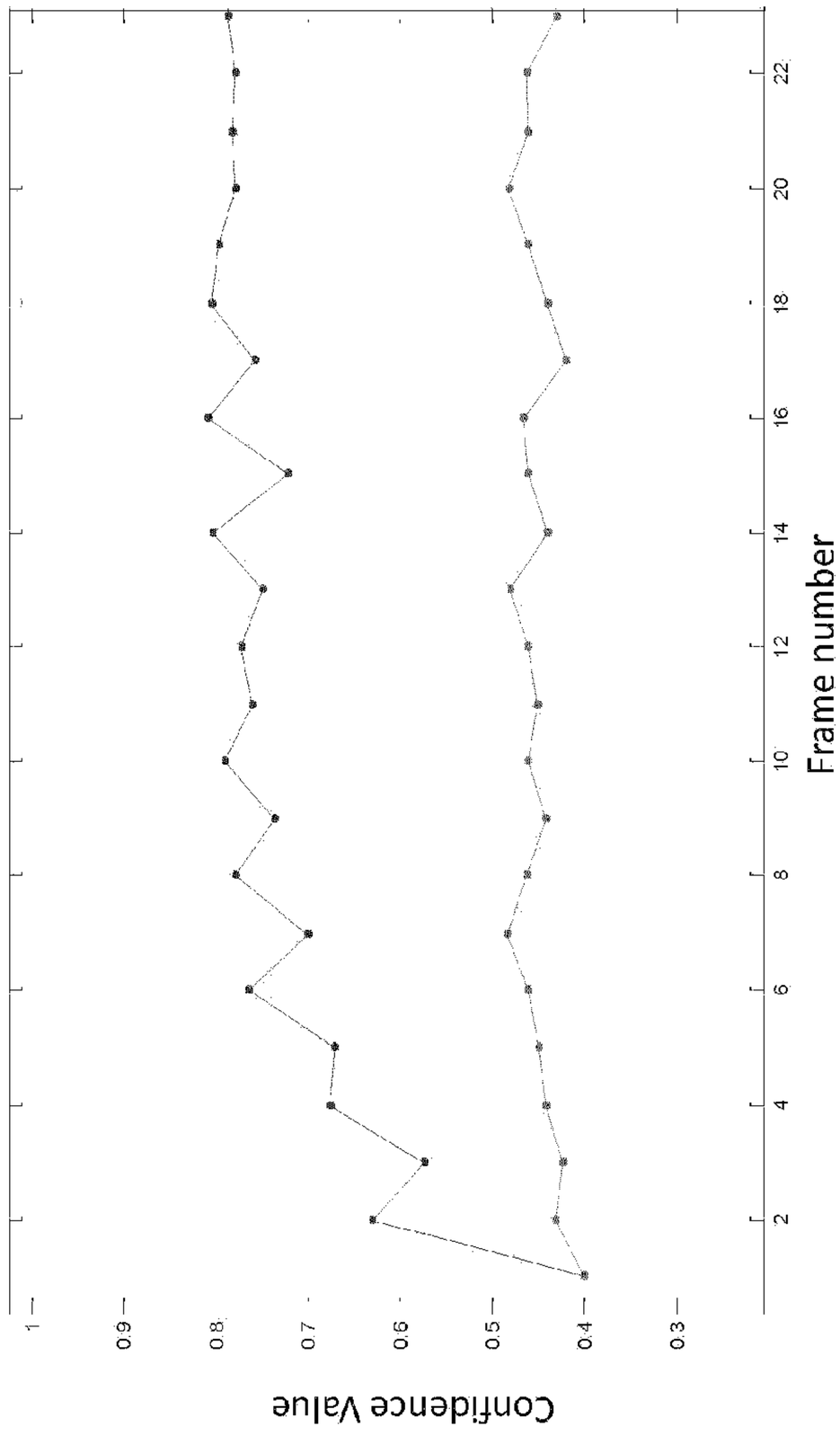

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Confidence Value
2
4
6
8
10
12
14
16
18
20
22
Frame number

Fig. 10

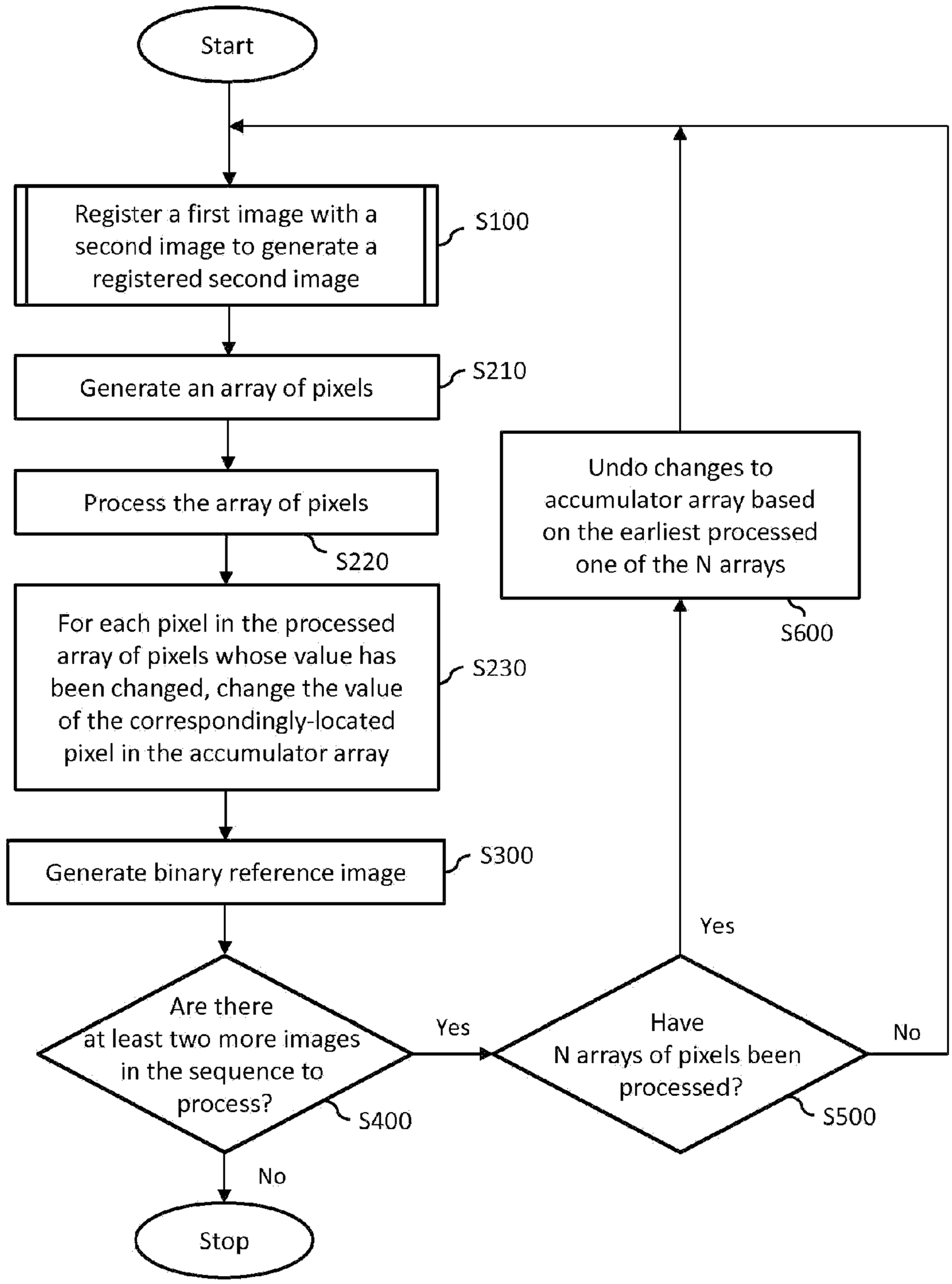

Start
Register a first image with a second image to generate a registered second image
S100
Generate an array of pixels
S210
Process the array of pixels
S220
For each pixel in the processed array of pixels whose value has been changed, change the value of the correspondingly-located pixel in the accumulator array
S230
Generate binary reference image
S300
Are there at least two more images in the sequence to process?
S400
Yes
No
Stop
Undo changes to accumulator array based on the earliest processed one of the N arrays
S600
Have N arrays of pixels been processed?
S500
Yes
No

Fig. 11