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(72) Inventor; and
(71) Applicant : **TAY, Hiok Nam** [SG/SG]; Blk. 409 Woodlands St. 41, #13-109, Singapore 730409 (SG).

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(54) **Title**: AUTO-FOCUS IMAGE SYSTEM

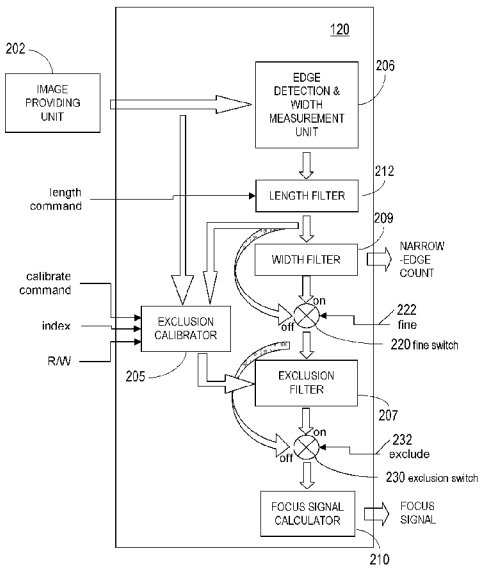

FIG. 3

(57) **Abstract**: An auto focus image system that includes a pixel array coupled to a focus signal generator. The pixel array captures an image that has at least one edge with a width. The focus signal generator may generate a focus signal that is a function of the edge width and/or statistics of edge widths. A processor receives the focus signal and/or the statistics of edge widths and adjust a focus position of a focus lens. The edge width can be determined by various techniques including the use of gradients. A histogram of edge widths may be used to determine whether a particular image is focused or unfocused. A histogram with a large population of thin edge widths is indicative of a focused image.

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AUTO-FOCUS IMAGE SYSTEM

This patent application claims priority to United States Provisional Patent Application No. 61/348,699, filed May 26, 2010, and Japan Patent Application No. 2010-122100, filed May 27, 2010.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The subject matter disclosed generally relates to auto-focusing electronically captured images.

2. Background Information

Photographic equipment such as digital cameras and digital camcorders may contain electronic image sensors that capture light for processing into still or video images, respectively. Electronic image sensors typically contain millions of light capturing elements such as photodiodes.

Many image capturing devices such as cameras include an auto-focusing system. The process of auto-focusing includes the steps of capturing an image, processing the image to determine whether it is in focus, and if not, generating a feedback signal that is used to vary a focus position of a focus lens. There are two primary auto-focusing techniques. The first technique involves contrast measurement, the other technique looks at a phase difference between a pair of images. In the contrast method the intensity difference between adjacent pixels is analyzed and the focus is adjusted until a maximum contrast is detected. Although acceptable for still pictures the contrast technique is not suitable for motion video.

The phase difference method includes splitting an incoming image into two images that are captured by separate image sensors. The two images are compared to determine a phase difference. The focus position is adjusted until the two images match. The phase difference method requires additional parts

such as a beam splitter and an extra image sensor. Additionally, the phase difference approach analyzes a relatively small band of fixed detection points. Having a small group of detection points is prone to error because noise may be superimposed onto one or more points. This technique is also ineffective if the detection points do not coincide with an image edge. Finally, because the phase difference method splits the light the amount of light that impinges on a light sensor is cut in half or even more. This can be problematic in dim settings where the image light intensity is already low.

BRIEF SUMMARY OF THE INVENTION

An auto focus image system that includes a pixel array coupled to a focus signal generator. The pixel array captures an image that has at least one edge with a width. The generator generates a focus signal that is a function of the edge width and various statistics of edge width.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of an embodiment of an auto-focus image pickup apparatus

FIG. 2 is a schematic of an alternate embodiment of an auto-focus image pickup apparatus

FIG. 3 is a block diagram of a focus signal generator.

FIG. 4 is an illustration of a horizontal Sobel operator's operation on a image signal matrix.

FIG. 5 illustrates a calculation of edge width from a horizontal gradient.

FIG. 6A, 6B are illustrations of a calculation of an edge width of a vertical edge in a boundary having a slant angle ϕ.

FIG. 6C, 6D are illustrations of a calculation of an edge width of a horizontal edge in a boundary having a slant angle ϕ.

FIG. 7 is a flowchart of a process to calculate a slant angle ϕ and correct an edge width for a vertical edge in a boundary having a slant.

FIG. 8 is an illustration of a vertical concatenated edge.

FIG. 9A is an illustration of a group of closely-packed vertical bars.

FIG. 9B is a graph of an image signal across FIG. 9A;

FIG. 9C is a graph of a horizontal Sobel gradient across FIG. 9A.

FIG. 10 is a flowchart of a process to eliminate closely-packed edges having shallow depths of modulation.

FIG. 11 is a histogram of edge widths illustrating a range of edge widths for calculating a fine focus signal.

FIG. 12 is an illustration of a scene.

FIG. 13 is a graph illustrating a variation of a narrow-edge count during a focus scan of the scene of FIG. 12

FIG. 14 is a graph illustrating a variation of a gross focus signal during a focus scan of the scene of FIG. 12.

FIG. 15 is a graph illustrating a variation of a fine focus signal across a range of focus positions.

FIG. 16 is an illustration of an apparatus displaying multiple objects in a scene and a selection mark over one of the objects.

FIG. 17 is a block diagram of a first embodiment of an exclusion calibrator.

FIG. 18 is a block diagram of a second embodiment of an exclusion calibrator.

FIG. 19 is a flowchart of a process to determine exclusion ranges for one edge characteristic.

FIG. 20 is a flowchart of a process to determine a chain of exclusion ranges for multiple edge characteristics.

FIG. 21 is an illustration of a scene having edges at different focus distances each under a different illumination.

FIG. 22 is a first histogram of maximal luminance of edges and a second histogram for only sharp-enough edges within a region (wall clock) of FIG. 21.

FIG. 23 is a first histogram of a hue of edges and a second histogram for only sharp-enough edges within a region (wall clock) of FIG. 21.

FIG. 24 is a first histogram of luminance change magnitude across edges and a second histogram for only sharp-enough edges within a region (wall clock) of FIG. 21.

FIG. 25 is a flowchart of a process of focus scan.

FIGs. 26-28 are illustrations of images of the scene of FIG. 12 captured at different focus positions.

FIG. 29 is a graph illustrating a sharp-edge count versus a hue at focus positions FA, FB, and FC of FIG. 13.

FIG. 30A is a graph showing hue exclusion ranges for focus position FA ("mountains, sun & horizon").

FIG. 30B is a graph showing hue exclusion ranges for focus position FB ("car").

FIG. 30C is a graph showing hue exclusion ranges for focus position FC ("person").

FIG. 31 is an illustration showing edges in sharp focus corresponding to the focus position FA of FIG. 13 being highlighted on a display.

FIG. 32 is an illustration showing edges in sharp focus position FB of FIG. 14 being highlighted on a display.

FIG. 33 is an illustration showing buttons on the image capture device for the user to request jumping to the next farther or nearer sharp focus positions.

FIG. 34 is a flowchart for a focus control system in seek mode.

FIG. 35 is a graph of a narrow-edge count versus focus position during a seek to the focus position FB and a subsequent switch to a tracking mode.

FIG. 36 is a graph showing the gross focus signal during a seek to the focus position FB corresponding to FIG. 35.

FIG. 37 is a graph of narrow-edge count versus focus position for an alternate embodiment wherein the focus system switches to tracking mode.

FIG. 38 is a flowchart for focus control system in seek mode for FIG. 37.

FIG. 39 is a graph illustrating a variation of the fine focus signal during tracking of a moving object for an embodiment of a focus control system that maintains the fine focus signal at a minimum.

FIG. 40 is a graph illustrating how a fine focus signal varies with time during a sharp focus acquisition.

FIG. 41 is a graph illustrating a variation of the fine focus signal during a tracking of a moving object for an alternate embodiment of focus control system that maintains the fine focus signal at an offset from a minimum.

FIG. 42A is an illustration showing a first image captured when a selection region selects a bird in a scene and the exclusion calibrator calibrates for the bird when in sharp focus.

FIG. 42B is an illustration showing a second image captured after the bird has moved to a second location of the image capture frame.

FIG. 42C is an illustration showing a third image captured after the bird has moved to a third location from the second location.

FIG. 43 is a first histogram of a length of concatenated edges and a second histogram of only concatenated sharp-enough edges (bird) of FIG. 42A.

FIG. 44 is a first histogram of slant angle from the vertical axis of edges and a second histogram of only sharp-enough edges (bird) of FIG. 42A.

FIG. 45 is a block diagram of an alternate embodiment of a focus signal generator.

FIG. 46 is a schematic of an alternate embodiment of an auto-focus image pickup apparatus.

FIG. 47 is a schematic of an embodiment of an auto-focus image pickup apparatus having a main pixel array and an auxiliary pixel array.

FIG. 48 is a schematic of an alternate embodiment of an auto-focus image pickup apparatus having a main pixel array and an auxiliary pixel array.

FIG. 49 is a schematic of an alternate embodiment of an auto-focus image pickup apparatus having a main pixel array and an auxiliary pixel array.

FIG. 50 is a illustration of a variation of an edge width from a main pixel array and a variation of an edge width from an auxiliary pixel array at different focus positions.

DETAILED DESCRIPTION

Disclosed is an auto focus image system that includes a pixel array coupled to a focus signal generator. The pixel array captures an image that has at least one edge with a width. The focus signal generator may generate a focus signal that is a function of the edge width and/or statistics of edge widths. A processor receives the focus signal and/or the statistics of edge widths and adjust a focus position of a focus lens. The edge width can be determined by various techniques including the use of gradients. A histogram of edge widths may be used to determine whether a particular image is focused or unfocused. A histogram with a large population of thin edge widths is indicative of a focused image.

Architecture

Referring to the drawings more particularly by reference numbers, Figure 1 shows an embodiment of an auto-focus image capture system 102. The system 102 may be part of a digital still camera, but it is to be understood that the system can be embodied in any device that requires controlled focusing of an image. The system 102 may include a focus lens 104, a pixel array and circuits 108, an A/D converter 110, a processor 112, a display 114, a memory card 116 and a drive motor/circuit 118. Light from a scene enters through the lens 104. The pixel array and circuits 108 generates an analog signal that is converted to a digital signal by the A/D Converter 110. The pixel array 108 may incorporate a mosaic color pattern, e.g. the Bayer pattern. The digital signal may be sent to the processor 112 that performs various processes, e.g. color

interpolation, focus position control, color correction, image compression/decompression, user interface control, and display control, and to the focus signal generator 120. Where the focus signal generator 120 and the processor 112 reside within different packages, a color interpolation unit 148 may be implemented to perform color interpolation on the digital signal 130 to estimate the missing color signals on each pixel for the focus signal generator 120. Alternately, where the focus signal generator 120 and the processor 112 reside together within a package 144, the focus signal generator 120 may input interpolated color images from the processor 112 on bus 146 as shown in Figure 2 or a single image signal derived from the original image signal generated from the A/D converter 110, for example a grayscale signal.

The focus signal generator 120 receives a group of control signals 132 from the processor 112, in addition, and may output signals 134 to the processor 112. The output signals 134 may comprise one or more of the following: a focus signal 134, a narrow-edge count, and a set of numbers representing a statistics of edge width in the image. The processor 112 may generate a focus control signal 136 that is sent to the drive motor/circuit 118 to control the focus lens 104. A focused image is ultimately provided to the display 114 and/or stored in the memory card 116. The algorithm(s) used to adjust a focus position may be performed by the processor 112.

The pixel array and circuits 108, A/D Converter 110, focus signal generator 120, and processor 112 may all reside within a package. Alternately, the pixel array and circuits 108, A/D Converter 110, and focus signal generator

120 may reside within a package 142 as image sensor 150 shown in Figure 1, separate from the processor 112. Alternately, the focus signal generator 120 and processor 112 may together reside within a package 144 as a camera controller 160 shown in Figure 2, separate from the pixel array 108 and A/D Converter 110.

Focus Signal Generator

Figure 3 shows an embodiment of a focus signal generator 120 receiving image(s) from a image providing unit 202. The image providing unit 202 may be the color interpolator 148 in Figure 1 or the processor 212 in Figure 2. The focus signal generator 120 may comprise an edge detection & width measurement (EDWM) unit 206, a focus signal calculator 210, a length filter 212, a width filter 209, an exclusion filter 207, and an exclusion calibrator 205. It may further comprise a fine switch 220 and an exclusion switch 230, controlled by inputs 'fine' 222 and 'exclude' 232, respectively. The focus signal generator 120 may provide a narrow-edge count from the width filter 209 and a focus signal from the focus signal calculator 210, the focus signal being configurable between a fine focus signal and a gross focus signal, selectable by input 'fine' 222. Alternately, both fine focus signal and gross focus signal may be calculated and output as part of output signals 134. The edge detection & width measurement unit 206 receives image(s) provided by the image providing unit 202. The exclusion calibrator 205 receives command and control signals (calibrate command, index, and R/W) input to the focus signal generator 120. In the context of Figures 1 and 2, these command and control signals, along with control signal 'fine' 222 and 'exclude' 232, may be

provided by the processor 112 in signals 132. Also in the context of Figures 1 and 2, the output signals 134 may be provided to the processor 112, which functions as a focus system controller that controls the focus position of the focus lens 104 to bring images of objects into sharp focus on the pixel array 108 by analyzing the output signals 134 to detect a sharp object in the image. Various components of the focus signal generator 120 are described below.

The EDWM unit 206 may transform the input image such that the three signals of the image, red (R), green (G) and blue (B) are converted to a single image signal. Several techniques can be utilized to transform an image to a single image. RGB values can be used to calculate a luminance or chrominance value or a specific ratio of RGB values can be taken to form the single image signal. For example, the luminance value can be calculated with the equation Y=0.2126*R + 0.7152*G + 0.0722*B, where Y is luminance value. The single image signal may then be processed by a Gaussian filter or any lowpass filter to smooth out pixel signal values among neighboring pixels to remove a noise.

The focus signal generator 120, 120', 120" is not limited to grayscale signal. It may operate on any one image signal to detect one or more edges in the image signal. Or it may operate on any combination of the image signals, for example Y, R-G, or B-G. It may operate on each and every one of the R, G, B image signals separately, or any one or more combinations thereof, to detect edges. It may form statistics of edge widths for each of the R, G, B image signals, or any combination thereof. It may form a

focus signal from statistics of edge widths from one or more image signals.

A gradient of the processed image is then calculated. There are various methods available to calculate the gradient, including Laplacian, and Sobel. Gradients across the columns and the rows may be calculated to detect vertical and horizontal edges respectively, for example using a Sobel-X operator and a Sobel-Y operator, respectively. Sobel X-operator at pixel location $[k, q]$ where k is a row number and q is a column number, is given by the equation $Sx[k, q] = U[k, q+1] - U[k, q-1]$. Sobel Y-operator at the same location is given by the equation $Sy[k,q] = U[k+1,q] - U[k-1,q]$, where U is an image signal of the processed image.

Orientation Tagging

Each pixel is tagged either a horizontal edge ('H') or a vertical edge ('V') if either vertical or horizontal gradient magnitude exceeds a predetermined lower limit ("elimination threshold"), e.g. 5 for an 8-bit image, or no edge if neither is true. This lower limit eliminates spurious edges due to gentle shading or noise. A pixel is tagged a vertical edge if its horizontal gradient magnitude exceeds its vertical gradient magnitude by a predetermined hysteresis amount or more, e.g. 2 for an 8-bit image, and vice versa. If both gradient magnitudes differ less than the hysteresis amount, the pixel gets a direction tag same as that of its nearest neighbor that has an direction tag already determined. For example, if the image is scanned from left to right in each row and from row to row downwards, a sequence of inspection of neighboring pixels may be the pixel above first, the pixel above left second,

and the pixel on the left third, and the pixel above right last. Applying this hysteresis helps to ensure that adjacent pixels get similar tags if each of them has nearly identical horizontal and vertical gradient magnitudes. Figure 4 illustrates the result of tagging on a 6-by-6 array of horizontal and vertical gradients. In each cell, the horizontal gradient is in the upper-left, vertical gradient is on the right, and direction tag is at the bottom. Only pixels that have either horizontal or vertical gradient magnitude exceeding 5 qualify at this step as edge pixels are printed in bold and get direction tags.

The image, gradients and tags may be scanned horizontally for vertical edges, and vertically for horizontal edges. Each group of consecutive pixels in a same row, having a same horizontal gradient polarity and all tagged for vertical edge may be designated a vertical edge if no adjacent pixel on left or right of the group are likewise. Likewise, each group of consecutive pixels in a same column having a same vertical gradient polarity and all tagged for horizontal edge may be designated a horizontal edge if no adjacent pixel above or below the group satisfies the same. Thus horizontal and vertical edges may be identified.

Edge Width

Each edge may be refined by removing pixels whose gradient magnitudes are less than a given fraction of the peak gradient magnitude within the edge. Figure 5 illustrates this step using a refinement threshold equal to one third of the edge's peak gradient magnitude, refining the edge width down to 3 from the original 9. This edge

refinement distinguishes the dominant gradient component that sets the apparent edge width that dominates visual perception of the edge's sharpness despite an image having multiple overlapping shadings that may cause gradients to gently decay over many pixels.

Edge width may be calculated in any one of known methods. One method of calculating edge width is simply counting the number of pixels within an edge. An alternate method of calculating edge width is shown in Figure 5. In Figure 5, a first fractional pixel position (2.4) is found between a first outer pixel (pixel 3) of a refined edge and the adjacent outside pixel (pixel 2) by an interpolation from the refinement threshold 304. Likewise, a second fractional pixel position (5.5) is found between a second outer pixel (pixel 5) and its adjacent outside pixel (pixel 6). The edge width is found as the difference between these two fractional pixel positions, 5.5 - 2.4 = 3.1.

Slant Correction

In an image, a boundary between two regions that have different brightness or hue becomes thicker or thinner as the image becomes more focused or becomes less focused. The thickness of this boundary is a width across the boundary in a direction perpendicular to the boundary.

If the boundary is vertical, the direction perpendicular to the boundary is the horizontal direction. If the boundary is horizontal, the direction perpendicular to the boundary is the vertical direction.

Within the boundary, an image signal (e.g. luminosity, blue chroma signal, or red chroma signal) has a transition from one side of the boundary to the other side. The

visually perceived extent of the boundary covers a vicinity of where the transition is steepest.

If the boundary is vertical, the steepness of the transition is reflected in a gradient signal generated horizontally across the boundary, from one side to the other. A neighborhood of where the gradient signal peaks and a width of the neighborhood therefore correspond to the visually perceived extent of the boundary and a thickness of the boundary, respectively. The neighborhood is a group of adjacent pixels whose horizontal gradients are above a predetermined fraction of a peak gradient. The neighborhood is a vertical edge, as defined earlier in this description, and the width of the neighborhood is an edge width of the vertical edge. The vertical boundary then can be seen as comprising a plurality of such vertical edges arrayed vertically.

Likewise, if the boundary is horizontal, it can be seen as comprising a plurality of horizontal edges arrayed horizontally and their edge widths represent the thickness of the horizontal boundary.

However, not all boundaries between regions in an image are oriented vertically or horizontally. Many boundaries are inclined with respect to the vertical and horizontal directions, and usually less inclined with respect to one than the other. This situation is illustrated in Figures 6A to 6D. In Figure 6A, boundary 410 is a straight boundary between region 420 and region 430 and is inclined from a vertical dashed line at a slant angle ϕ in a clockwise manner. In Figure 6B, boundary 412 is a straight boundary between region 422 and region 432 and is inclined from a

vertical dashed line at a slant angle ϕ in an anti-clockwise manner. In Figure 6C, boundary 414 is a straight boundary between region 424 and region 434 and is inclined from a horizontal dashed line at a slant angle ϕ in an anti-clockwise manner. In Figure 6D, boundary 416 is a straight boundary between region 426 and region 436 and is inclined from a horizontal dashed line at a slant angle ϕ in a clockwise manner.

As shown in Figures 6A to 6D, the thicknesses of the boundaries (shown as ***b***) that are the widths perpendicularly across the boundaries are independent of the slant angle ϕ. Widths measured in the horizontal direction across the boundaries (shown as ***a***) in Figures 6A and 6B, and likewise measured in the vertical direction across the boundaries in Figures 6C and 6D, are edge widths of the edges (vertical edges for Figures 6A and 6B; horizontal edges for Figures 6C and 6D) in the boundaries. But they no longer represent the thicknesses of the boundaries, unlike in the case of the vertical and horizontal boundaries. It is the thicknesses of the boundaries, not edge widths, that remains a measure of how unfocused the boundary is in the image when the boundary is neither vertical nor horizontal. Using the edge widths as they are to form the focus signal without taking into account the slant of the boundaries to which the edges belong will cause the focus signal to be affected orientations of boundaries in the image. This is an undesirable effect that is discovered and addressed in this invention.

A solution to this problem is to correct the edge width measured in a prescribed direction (e.g. horizontal

direction, or vertical direction) from the edge to obtain a width of the boundary to which the edge belongs, then to input the corrected edge widths instead of the uncorrected edge widths to the focus signal calculation. The width of the boundary is measured perpendicularly across the boundary.

The width of the boundary may be found by projecting the edge width from the prescribed direction (which is perpendicular to the edge direction) along which the edge width is measured to the direction perpendicular to the direction of the boundary. Designating the angle of slant of the boundary from edge direction as ϕ, the correction may be performed by multiplying the edge width by $\cos(\phi)$ or an approximation thereof.

There are various methods for finding the angle of slant ϕ. One class of method involves finding $\tan(\phi)$ or an approximation thereof from the vertical and horizontal gradients in the edge. One example is finding the ratio y/x, where x is a gradient perpendicular to the edge direction and y is a gradient parallel to the edge direction, for each pixel in a neighborhood (which may be within the edge or may be a 2-dimensional neighborhood overlapping the edge), followed by finding an average (which may be a weighted average) of the ratio within the neighborhood.

For purposes of calculating a focus signal from edge widths, the edge widths measured in one or the other of those prescribed directions are to be corrected by reducing them down to be widths in directions perpendicular to directions of the respective edges. The Edge Detection and

Width Measurement Unit 206 performs such a correction on edge widths. As shown in Figure 6A, the measured width ***a*** is the length of the hypotenuse of a right-angled triangle that has its base (marked with width ***b***) straddling across the shaded boundary perpendicularly (thus perpendicular to the edge direction). The corrected width ***b*** may be obtained from a projection of the measured width ***a*** to the direction perpendicular to the boundary. Such a projection may be given by $\boldsymbol{b} = \boldsymbol{a}\cos(\phi)$, but approximation may be used as long as it obtains accuracy to within 20%. The angle ϕ, or $\cos(\phi)$ itself, may be found by any method known in the art for finding a direction of an edge in an image, or by a more accurate method described in the flowchart shown in Figure 7.

Each horizontal or vertical edge's edge width may be corrected for its slant from either the horizontal or vertical orientation (the prescribed directions), respectively. Figure 6A, 6B illustrate a correction calculation for an edge width measured in the horizontal direction for a boundary (and hence edges that form the boundary) that has a slant from the vertical line. Figure 6C, 6D illustrate a correction calculation for an edge width measured in the vertical direction for a boundary (and hence edges that form the boundary) that has a slant from the horizontal line. The correction may be made by multiplying the edge width measured in a prescribed direction, such as a vertical direction or a horizontal direction, by a factor of $\cos(\phi)$, where ϕ is an angle of slant from the prescribed direction. This slant angle ϕ may be used further in the exclusion filter 207 and exclusion calibrator 205.

By way of example, Figure 7 shows a flowchart of a process to correct edge widths for slant for edges in a boundary inclined from a vertical line. (For horizontal edges in a boundary inclined from a horizontal line, substitute 'row' for 'column', and interchange 'vertical' with 'horizontal' in the flowchart.)

From step 502 to step 506, a slant angle ϕ is found. For each vertical edge, at step 502, locate the column position where the horizontal gradient magnitude peaks, and find the horizontal gradient x. At step 504, find a vertical gradient that has the largest magnitude along the column position and within two pixels away, and let y be this vertical gradient.

At step 506, find the slant angle $\phi = \tan^{-1}(y/x)$. At step 506, the slant angle may be found by looking up a lookup table. Although steps 502 to 506 present one specific procedure and method to find the slant angle, other procedures and methods known in the art may be used instead.

Finally, at step 508, scale down the edge width by multiplying with $\cos(\phi)$, or with an approximation thereto as one skilled in the art usually does in practice.

A first modification of the process shown in Figure 7 is to substitute for step 506 and part of step 508 by providing a lookup table that has entries for various combinations of input values of x and y. For each combination of input values of x and y, the lookup table returns an edge width correction factor. The edge width correction factor output by the lookup table may be an approximation to $\cos(\tan^{-1}(y/x))$ to within 20%, preferably

within 5%. The edge width is then multiplied with this correction factor to produce a slant-corrected edge width.

A second modification is to calculate a quotient y/x between a vertical gradient y and a horizontal gradient x to produce a quotient q, then to input q to a lookup table that has entries for various values of q. For each value of q, the lookup table returns an edge width correction factor. The edge width correction factor may be an approximation to $\cos(\tan^{-1}(q))$ to within 20%, preferably within 5%.

For finding the slant angle ϕ (or an approximation thereto such that the correction factor is accurate to within 20%) and subsequently the correction factor $\cos(\phi)$ (or an approximation thereto), or to directly find the correction factor without finding the slant angle ϕ (as in the first and second modifications), the values of x and y may be obtained in steps 502 to 506, but other methods may be employed instead.

A third modification is to perform the following for each one of a plurality of pixels in the edge: (a) find horizontal gradient x and vertical gradient y both for a pixel, (b) find $q = y/x$ for this pixel, and (c) find a correction factor that corresponds to q, for instance $\cos(\tan^{-1}(q))$ or an approximation thereto to within 20%. Finally, find the correction factor for the edge width by averaging across the correction factor from each of the plurality of pixels. The average may be a weighted average, such as one in which a pixel that has a larger horizontal gradient is given a larger weight than another pixel that has a lesser horizontal gradient.

A fourth modification is, at step 504, find a vertical gradient that has the largest magnitude within two columns and two rows from the peak horizontal gradient, and let *y* be this vertical gradient.

Other modifications are possible along these directions or other.

Screen Threshold

Adjacent edges may be prevented altogether from contributing to a focus signal, or have their contributions attenuated, if their peak gradient magnitudes are below a predetermined fraction of an adjacent wider edge's peak gradient magnitude. Figure 9A, 9B, and 9C illustrate a problem that is being addressed.

Figure 9A illustrates three vertical white bars separated by two narrow black spaces each 2 pixels wide. The middle white bar is a narrow bar 2 pixels wide. Figure 9B shows an image signal plotted horizontally across the image in Figure 9A for each of a sharp image and a blurred image. Figure 9C plots Sobel-x gradients of Figure 9B for the sharp image and blurred image. In Figure 9C, the first edge (pixels 2-5) for the blurred image is wider than that for the sharp image, and likewise the last edge (pixels 13-15) as expected. However, the two narrowest edges (pixels 9 & 10, and pixels 11 & 12) have widths of two in both images. In Figure 9B, the corresponding slopes at pixels 9 & 10, and pixels 11 & 12, each takes two pixels to complete a transition. The blurred image, however, has a significant decline of peak gradient magnitude, as much as 50%, from the wider edge to the narrower edges. The sharp

image, on the other hand, changes less than 10% between the wider and the narrower edges.

The significant decline, e.g. 20% or greater, in peak gradient magnitude for a narrower edge adjacent to a wider edge having an opposite-signed gradient gives a hint that the blurred image is not well focused, and thus the narrower edge should not be relied upon as an indication that the blurred image is sharp.

Likewise, mutually adjacent edges of alternating gradient polarities should not be relied upon for such indication even if their edge width are small as long as they are in close proximity to each other, e.g. no more than 1 pixel apart ("minimum edge gap"). The minimum edge gap is in terms of a number of pixels, e.g. 1, or 2, or in between.

Furthermore, given that one edge may have been eliminated due to having a peak gradient less than the elimination threshold, two successive edges having an identical gradient polarity and spaced no more than two times the minimum edge gap plus a sharp_edge_width (sharp_edge_width is a number assigned to designate an edge width of a sharp edge) apart may be used as a condition for eliminating or demoting a contribution from one or both of the two mutually adjacent edges. either.

The adjacency in this detection may be determined by any one of the following proximity tests, such as (a) detection of a steepness of a zero-crossing adjacent to the edge by the gradient signal in excess of a pretermined zero-crossing threshold that may be a function of a peak gradient(s) of one of the edges or both edges and/or a

width of one of the edges or both edges, (b) detection of opposite-signed gradients within a minimum edge gap that may be a function of edge width(s) of one of the edges or both edges, each gradient having a magnitude exceeding a predetermined threshold that may be a function of a peak gradient(s) of one of the edges or both edges and/or a width of one of the edges or both edges, and (c) detection of a peak-to-peak spacing between peaks of the edges that is less than a peak-to-peak spacing threshold predetermined as a function of edge width(s) of one of the edges or both edges.

The Edge Detection and Width Measurement Unit 206 may execute the following algorithm for eliminating closely-packed narrower edges based on a screen threshold established from a wider edge, and a modulation screen flag that can be turned on and off.

For each edge, the screen threshold and screen flag to be used for the immediate next edge of an opposite polarity are determined according to the process of the flowchart shown in Figure 10.

Given the screen threshold and screen flag, an edge may be eliminated unless one of the following conditions is true: (a) the screen flag is off for this edge, (b) a peak gradient magnitude of the edge is not smaller than the screen threshold for this edge. To conditions (a) and (b) may be added condition (c) the edge width is not less than sharp_edge_width + 1, where a number has been assigned for sharp_edge_width to designate an edge width of a sharp edge, and where the "+1" may be varied to set a range of edge widths above the sharp_edge_width within which edges

may be eliminated if they fail (a) and (b). For the example shown in Figures 9A-9C, sharp_edge_width may be 2.

Figure 10 is a flowchart to determine a screen threshold and a screen flag for each edge. For vertical edges, assume scanning from left to right along a row, though this is not required. (For horizontal edges, assume scanning from top to bottom along a column, though this is not required.) A number is assigned for sharp_edge_width and may be 2 for the example shown in Figures 9A-9C. Starting at the first edge at step 702, each edge is queried at step 720 as to whether its edge width is greater than or equal to one plus sharp_edge_width, the value of one being the minimum edge gap value used for this illustration, but a different value may be used, such as between 0.5 and 2.0. If yes, the edge is a wider edge, and step 706 follows to set the screen threshold for the immediate next edge that has an opposite polarity to beta times a peak gradient magnitude of the edge, beta being from 0.3 to 0.7, preferably 0.55, then step 708 follows to turn on the screen flag for the next edge, then proceed to the next edge. If no, the edge is not a wider edge, and step 730 follows to check whether the spacing from the prior edge of the same gradient polarity is greater than two times the minimum edge gap (or a different predetermined number) plus sharp_edge_width and the immediate prior edge of an opposite polarity, if any, is more than the minimum edge gap away. If yes, step 710 follows to turn off the screen flag for the next edge. If no, keep the screen flag and the screen threshold for the next edge and proceed to the next edge. Beta may be a predetermined fraction, or it may be a fraction calculated following a predetermined formula, such as a function of an

edge width. In the latter case, beta may vary from one part of the image to another part.

For simplicity of illustration as well as implementation, the flowchart in Figure 10 separates edges that have edge widths greater than or equal to one plus sharp_edge_width as the wider edges away from the rest of edges (the narrower edges). But the meaning of wider edges is not thus limited: a wider edge is simply wider than a narrower edge.

Length Filter

Below describes a function of length filter 212. Broadly defined, length filter 212 creates a preference for edges that each connects to one or more edges of a similar orientation. A group of edges that are similarly oriented and mutually connected within the group ("concatenated edge") is less likely to be due to noise, compared with an isolated edge that does not touch any other edge of similar orientation. The more edges of a similar orientation thus concatenated together, the lesser the chance of them being due to noise. The probability of the group being due to noise falls off exponentially as the number of edges within the group increases, and far faster than linearly. This property can be harnessed to reject noise, especially under dim-lit or short-exposure situations where the signal-to-noise ratio is weak, e.g. less than 10, within the image or within the region of interest. The preference may be implemented in any reasonable method to express such preference. The several ways described below are merely examples.

A first method is to eliminate edges that belong to vertical/horizontal concatenated edges having lengths lesser than a concatenated length threshold. The concatenated length threshold may be larger when the region of interest is dimmer. For example, the concatenated length threshold may start as small as 2, but increases to 8 as a signal-to-noise ratio within the region of interest drops to 5. The concatenated length threshold may be provided by the processor 112, 112', 112", for example through a 'length command' signal, shown in Figure 3, as part of signals 132. Alternately, the threshold may be calculated according to a formula on the focus signal generator.

A second method is to provide a length-weight in the length filter 212 for each edge and apply the length-weight to a calculation of focus signal in the focus signal calculator 210. An edge that is part of a longer concatenated edge receives a larger weight than one that is part of a shorter concatenated edge. For example, the length-weight may be a square of the length of the concatenated edge. Thus, a contribution of each edge towards the focus signal may be multiplied by a factor A/B before summing all contributions to form the focus signal, where B is a sum of the length-weights of all edges that enter the focus signal calculation, and A is a length-weight of the edge. Likewise, the edge-width histogram, which may be output as part of signals 134, may have edges that are members of longer concatenated edges contribute more to the bins corresponding to their respective edge width, thus preferred, instead of all edges contribute the same amount, e.g. +1. Thus, for example, each edge may contribute A/C, where C is an average value of A across the

edges. Similarly, the narrow-edge count may have edges that are members to longer concatenated edges contribute more. Thus, for example, the contribution from each edge may be multiplied by A/D, where D is an average of A among edges that are counted in the narrow-edge count.

A group of N vertical (horizontal) edges where, with the exception of the top (leftmost) and the bottom (rightmost) ones, each edge touches two other vertical (horizontal) edges, one above (to the left of) itself, the other below (to the right of) itself, is a vertical (horizontal) concatenated edge of length N. The top (leftmost) edge needs only touch one edge below (to the right of) itself. The bottom (rightmost) edge needs only touch one edge above (to the left of) itself.

Figure 8 illustrates a vertical concatenated edge and its length. In Figure 8, cells R2C3 and R2C4 form a first vertical edge, cells R3C3, R3C4, and R3C5 together form a second vertical edge, and cells R4C4 and R4C5 together form a third vertical edge. The first and the third vertical edges each touches only one other vertical edge, whereas the second vertical edge touches two other vertical edges. The first, second and third vertical edges together form a vertical concatenated edge having a length of 3.

In a situation (not shown) where a vertical (horizontal) concatenated edge has two or more branches, i.e. having two edges in a row (column), the length may be defined as the total number of edges within the concatenated edge. Alternately, the length may be defined as the vertical (horizontal) distance from a topmost (leftmost) edge therein to a bottommost (rightmost) edge therein plus one.

There are other possible ways to define a concatenated length other than the above proposals. For example, a definition of a length for a concatenated edge shall have a property that the length is proportional to the number of member edges within the concatenated edge at least up to three. This is to be consistent with the previously stated reasoning that more edges being mutually connected by touching each other exponentially reduces a probability that the concatenated edge is caused by a noise, and as such the length should express a proportionality to the number of member edges within the concatenated edge up to a reasonable number that sufficiently enhances a confidence in the concatenated edge beyond that for a single member. The length filter 212 may de-emphasize or eliminate and thus, broadly speaking, discriminate against an edge having a concatenated length of one. The length filter 212 may discriminate against an edge having a concatenated length of two. The length filter 212 may discriminate against an edge having a concatenated length of three, to further reduce an influence of noise. The length filter 212 may do any one of these actions under a command from the processor.

Although shown in Figure 3 to immediately follow the Edge Detection & Width Measurement Unit 206, other arrangements are possible. For example, the Length Filter 212 may be inserted before the focus signal calculator 210 and after the exclusion switch 230, wherein the edges processed by the Length Filter 212 are those that pass through either or both of the width filter 209 and exclusion filter 207 depending on the 'fine' and 'exclude' command signals.

In an alternate embodiment of a focus signal generator, the fine switch 220 may be removed so that the focus signal calculation unit 210 receives a first set of data not filtered by the width filter 209 and a second set filtered, and for each calculates a different focus signal, gross focus signal for the former, fine focus signal for the latter, and outputs both to the processor 112, 112'.

Width Filter

Refer next to Figure 3 to understand an operation of the Width Filter 209. Figure 11 plots a histogram of edge widths, i.e. a graph of edge counts against edge widths. At edge width of 2, i.e. the aforementioned sharp_edge_width, there is a peak, indicating a presence of sharp edges in the image. At edge widths of 4 and 5, however, there are peaks, indicating edges that are blurred, possibly due to the corresponding imaged objects being out of focus, being at a different distance away from the focus lens than those objects that give rise to the sharp edges. For calculating a focus signal, edges whose widths lie outside a predetermined range ("narrow-edge range") may be de-emphasized using the Width Filter 209. The Width Filter 209 may create a lesser weight for edge widths outside the narrow-edge range for use in the focus signal calculation. For example, edge widths may be assigned weight of 1.0, whereas edges widths more than +1 to the right of the upper limit 840 assigned a weight of 0, and edge widths in between assigned weights between 0 and 1.0, falling monotonically with edge width. Alternately, the Width Filter 209 may prevent such edges from entering the focus signal calculation altogether. Appropriate upper and lower limits 830, 840 depend on several factors,

including crosstalk in the pixel array 108, the interpolation method used to generate missing colors for the image received by the focus signal generator 120, and the filter coefficients used in the lowpass filter employed in the Edge Detection and Width Measurement Unit 206. Appropriate upper and lower limits 830, 840 and the parameter sharp_edge_width may be determined for the image pickup apparatus 102, 102′ by capturing images of various degrees of sharpness and inspecting the edge width histograms. For example, if a sharp image has a peak at edge width of 2, an appropriate lower and upper limit may be 1.5 and 3, respectively, and the sharp_edge_width may be set to 2.0. The lower and upper limits and sharp_edge_width may be determined as above and provided to the focus signal generator 120, 120′, 120″ by the processor 112, 112″. When 'fine command' is ON, the fine focus signal thus calculated de-emphasizes edge widths outside the narrow-edge range.

In addition, the Width Filter 209 may calculate a total count of the edges whose edge widths fall within the narrow-edge range and output as part of output signals 134. Narrow-Edge Count may be input to and used by the focus system controller (processor 112) to detect a presence of sharp image and/or for initiating tracking.

Focus Signal

Referring next to the focus signal calculator 210 of Figure 3, the focus signal calculator 210 receives edge widths and outputs a focus signal. The focus signal may be calculated as a weighted average of all the edge widths where the weights are the edge counts for each edge width, viz. focus signal = $\Sigma w_i e_i / \Sigma w_i$, where e_i are the edge widths,

w_i are the weights, where here $w_i=c_i$, c_i being the edge count at edge width e_i, i being a bin number of a histogram of edge widths. Alternately, the weight at each edge width may be the edge count for the edge width multiplied by the edge width itself, i.e. $w_i=c_ie_i$. In addition, preferences from the Width Filter 209 that are expressed in terms of weights may be further multiplied to each edge width. For example, for weights Ω_i produced by the Width Filter 209, $\Sigma\Omega_i=1$, focus signal may be calculated as $\Sigma\Omega_iw_ie_i / \Sigma\Omega_iw_i$. If control signal 'fine' is ON and 'exclude' is OFF, the focus signal would be a value very close to the sharp edge width of 2.0 for the example shown in Figure 11, indicating that among object details within the focus distance range that would produce edge widths between 2.0 and 3.0, most are actually in sharp focus. If control signal 'fine' is OFF and 'exclude' is OFF, the focus signal may be a value close to 5.0, indicating that there are substantial details of the image that are out of focus. Turning ON the fine switch 220 allows the focus signal to respond more to objects slightly blurred while less to those that are completely blurred. When the fine switch 220 is ON, we shall refer to the focus signal as a fine focus signal, whereas when the fine switch 220 is OFF, a gross focus signal. As aforementioned, the emphasis expressed by the Length Filter 212 may be incorporated into the focus signal in one of several ways, such as eliminating an edge that is de-emphasized from entering the focus signal calculation, or reducing a weight of the edge's contribution towards a count e_i of a corresponding edge width bin.

Figure 15 sketches a response of the fine focus signal to an adjustment of the focus position in the vicinity of where an object is in sharp focus. The fine focus signal

reaches a minimum value, approximately at sharp_edge_width, where the focus position brings an image into sharp focus, and increases if otherwise. The fine focus signal may be used for tracking objects already in-focus or very nearly so. For moving objects, the fine focus signal allows the focus control system to keep the objects in sharp focus even if the focus distance continues to change. Fine focus signal may also be used to acquire a sharp focus ("acquisition") of an object that is not yet in sharp focus but close enough such that the object gives rise to edges whose widths fall within the narrow-edge range. Since the edge width histogram exhibits a peak at the edge width corresponding to the object away from the sharp_edge_width, resulting in the fine focus signal being larger than the sharp_edge_width, the focus control system may respond by adjusting the focus position to bring the fine focus signal value towards the sharp_edge_width, thus centering the peak of edge width due to the object at the edge width value equal to sharp_edge_width.

Basic Use

Figures 12-16 illustrate how the narrow-edge count, gross focus signal, and fine focus signal may be used to perform focus control to achieve sharp images.

Figure 12 illustrates an outdoor scene having 3 groups of objects at different focus distances: "person" in the foreground, "mountain, sun, and horizon" in the background, and "car" in the between.

Figure 13 is an illustration of the narrow-edge count plotted against time when the focus position of the focus lens 104 sweeps from far to near for the scene illustrated

in Figure 12. The narrow-edge count peaks when the focus position brings an object into a sharp image on the pixel array 108. Thus the narrow-edge count plot exhibits 3 peaks, one each for "mountain, sun, and horizon", "car", and "person", in this order, during the sweep.

Figure 14 shows the gross focus signal plotted against time. The gross focus signal exhibits a minimum when the focus position is near each of the 3 focus positions where the narrow-edge count peaks. However, at each minimum, the gross focus signal is not at the sharp edge width level, which is 2.0 in this example, due to bigger edge widths contributed by the other objects that are out-of-focus.

Figure 15 illustrates the fine focus signal plotted against the focus position in the vicinity of the sharp focus position for "car" in the scene of Figure 12. The fine focus signal achieves essentially the sharp edge width, which is 2 in this example, despite the presence of blurred objects ("person" and "mountains, sun, and horizon"). Referring to Figure 11 again, where two peaks at widths of 4 and 5 are contributed by those two groups of blurred objects, this can be understood as the Width Filter 324 having reduced the weight or eliminated altogether the contributions from the edge widths to the right of upper-limit 840.

A focus control system may use the gross focus signal to search for the nearest sharp focus position in a search mode. It can move the focus position away from the current focus position to determine whether the gross focus signal increases or decreases. For example, if the gross focus signal increases (decreases) when the focus position moves inwards (outwards), there is a sharp focus position farther

from the current focus position. The processor 112, 112′, 112″ can then provide a focus drive signal to move the focus lens 104 in the direction towards the adjacent sharp focus position.

A focus control system may use the fine focus signal to track an object already in sharp focus to maintain the corresponding image sharp (thus a "tracking mode") despite changes in the scene, movement of the object, or movement of the image pickup apparatus. When an object is in sharp focus, the fine focus signal level is stable despite such changes. Hence a change in the fine focus signal suggests a change in focus distance of the object from the image pickup apparatus. By "locking" the focus control system to a given fine focus signal level near the minimum, for example between 2.0 to 2.5 in this example, in particular 2.1, any shift in the fine focus signal level immediately informs the processor 112, 112′, 112″ of a change in the focus distance of the object. The processor 112, 112′, 112″ can then determine a direction and cause the focus lens 104 to move to bring the fine focus signal level back to the "locked" level. Thus the image pickup apparatus 102, 103, 103′, 103″ is able to track a moving object.

A focus control system, e.g. as implemented in algorithm in processor 112, 112′, 112″, may use narrow-edge count to trigger a change from a search mode to a tracking mode. In the tracking mode, the focus control system uses the fine focus signal to "lock" the object. Before the focus position is sufficiently near the sharp focus position for the object, the focus control system may use the gross focus signal to identify the direction to move and regulate the speed of movement of the lens. When a

object is coming into sharp focus, narrow-edge count peaks sharply. The processor 112, 112', 112" may switch into the tracking mode and use the fine focus signal for focus position control upon detection of a sharp rise in the narrow-edge count or a peaking or both. A threshold, which may be different for each different sharp focus position, may be assigned to each group of objects found from an end-to-end focus position "scan", and subsequently when the narrow-edge count surpasses this threshold the corresponding group of objects is detected. For a stationary scene, e.g. for still image taking, an end-to-end focus position scan can return a list of maximum counts, one maximum count for each peaking of the narrow-edge count. A list of thresholds may be generated from the list of maximum counts, for example by taking 50% of the maximum counts.

Figure 16 illustrates an image pickup apparatus 102 having a display 114, an input device 107 comprising buttons, and selection marker 1920 highlighted in the display 114. A user can create, shape and maneuver the selection marker 1920 using input device 107. Although shown in this example to comprise buttons, input device 107 may comprise a touch-screen overlaying the display 114 to detect positions of touches or strokes on the display 114. Input device 107 and processor 112, 112', 112" or a separate dedicated controller (not shown) for the input device 107 may determine the selection region. The parameters for describing the selection region may be transmitted to the focus signal generator 120, 120', 120" over bus 132 (or internally within the processor 112 in the case where focus signal generator 120 is part of the processor 112). In response, the focus signal generator

120 may limit the focus signal calculation or the narrow-edge count or both to edges within the selection region described by said parameters or de-emphasize edges outside the selection region. Doing so can de-emphasize unintended objects from the focus signal and then even the gross focus signal will exhibit a single minimum and a minimum level within 1.0 or less of the sharp edge width.

Exclusion Filtering

Below describes exclusion filtering performed by exclusion filters 207, 910.

Broadly defined, given one or more image characteristics and one or more exclusion ranges defined for each characteristic, exclusion filtering creates a preference for edges that do not fall into any one exclusion range in any one characteristic.

The collection of image characteristics may be predetermined. The following is a non-exhaustive list: hue (Figure 23), hue pair, hue change, saturation, maximal luminance (Figure 22), luminance change (Figure 24), mean luminance, slant angle (Figures 6A-6D and 44), length of concatenated edge (Figures 8 and 43), and spacing to nearest edge.

A first embodiment of an exclusion filter is to eliminate edges that belong to any one exclusion range in any one characteristic given to the exclusion filter.

Figure 22 illustrates a use of maximal luminance as a characteristic for exclusion. Figure 22 illustrates an all-edge and sharp-edge histograms for maximal luminance of an image captured of the scene illustrated in Figure 21

with only the wall clock in sharp focus. Maximal luminance is the highest luminance value within an edge. Figure 22 shows a histogram for sharp edges (associated with the wall clock in Figure 21) and a histogram for all edges, associated with other objects (lamp shade, bananas, platter, table cloth, light bulb) in the image that are not in sharp focus as well as the wall clock. In Figure 22, the wall clock occupies a lower range of maximal luminance than all other objects, which are brightly illuminated. An exclusion range (shown in Figure 22) covering approximately the upper half of the maximal luminance range de-emphasizes or even excludes altogether most edges that are not in sharp focus.

Figure 23 illustrates a use of hue as a characteristic for exclusion. Figure 23 shows a histogram for sharp edges (associated with wall clock in Figure 21) and a histogram for all edges, associated with other objects in the image that are not in sharp focus as well as the wall clock. For this hue histogram, if both sides of an edge has the same hue value, the hue bin that contains the hue value gets a count contribution of +2 from this edge; whereas if each side has a different hue value, then each hue bin that contains one of the hues gets a count contribution of +1. In Figure 23, the wall clock and the platter together occupy a small range of hue in the vicinity of a brown hue. Exclusion range 1 and exclusion range 2 (shown in Figure 23) that together cover most of the rest of the hue range would exclude most edges that are not in sharp focus except those arising from the platter, which are not a major part of non-sharp edges. An edge would be de-emphasized or even excluded altogether by an exclusion filter operating by

these two exclusion ranges if both hues on its two sides fall within any of these exclusion ranges.

Hue pair may be used as a characteristic for exclusion. A first hue from one side of an edge and a second hue from the other side of the same edge can be measured and together used to assign the edge to one of the bins in a histogram that has a two-dimensional abscissa. Each bin in the two-dimensional abscissa corresponds to a first range of hues on one side of the edge and a second range of hues on the other side of the edge.

Hue difference may be used as a characteristic for exclusion. A change of hue from one side of an edge to the other side of the same edge can be measured and used to assign the edge to one of the bins in a histogram that has a plurality of bins each for a range of hue-difference. Figure 24 illustrates a use of luminance change as a characteristic for exclusion. Luminance change is a magnitude of change of luminance across an edge. Figure 23 shows a histogram for sharp edges (associated with wall clock in Figure 21) and a histogram for all edges, associated with other objects in the image that are not in sharp focus as well as the wall clock. In Figure 24, the edges from wall clock occupy a small region at the lower range, and an exclusion range (shown in Figure 24) covering the upper range would de-emphasize or even exclude altogether most edges that are not in sharp focus.

Figure 43 illustrates a histogram of length of concatenated edges and an exclusion range for the scene of Figure 42A. Such a histogram may be used to separate objects having different sizes.

Spacing to nearest edge is another image characteristic. To each vertical (horizontal) edge is calculated and associated a spacing along a same row (column) to a nearest neighboring vertical (horizontal) edge ("edge spacing"). The edge spacings of all edges and sharp-enough edges have their respective histogram. Exclusion ranges for edge spacings are formed like for the other characteristics. Edge spacing can be used to distinguish objects that have many small details, for example a tree with many leaves and branches, from other objects that do not have similar densities of details, for example a car.

An alternate embodiment of exclusion filter is to create an exclusion-weight in the exclusion filter 212 and/or 910 for each edge and apply the exclusion weight to a calculation of focus signal in the focus signal calculator 210. An edge whose value for a first characteristic falls within an exclusion range of the first characteristic receives a lesser weight for the characteristic ("characteristic weight") than one whose value fall outside all exclusion ranges. For example, the characteristic weight may be 0 in the middle of an exclusion range, rises to 1 at the edges of the exclusion range, and 1 everywhere outside all exclusion ranges. If the exclusion filtering uses only one characteristic, the characteristic weight is the exclusion weight. If two or more characteristics are used, each characteristic has a characteristic weight for each edge, and all characteristic weights may be multiplied together to form the exclusion weight. Thus each edge may have a first, a second, and a third characteristic weight where three different characteristics are used in an exclusion chain, and the

exclusion weight would be the product of all three characteristic weights. Thus, a contribution of each edge towards the focus signal may be multiplied by a factor E/G before summing all contributions to form the focus signal, where G is the sum of exclusion weights of all edges that enter the focus signal calculation, and E is the exclusion weight of the edge. Likewise, the edge-width histogram, which may be output as part of signals 134, may have edges that are not members to any exclusion range of any characteristic contribute more to the bins corresponding to their respective edge widths instead of all edges contribute the same amount, e.g. +1. Thus, for example, each edge may contribute E/H instead of +1 towards the bin of the edge-width histogram, where H is an average of E among edges that are counted in the histogram. Similarly, the narrow-edge count may have edges that are not members to any exclusion range of any characteristic contribute more. Thus, for example, the contribution from each edge may be multiplied by E/J, where J is an average of E among edges that are counted in the narrow-edge count.

Exclusion Calibration

Referring next to the exclusion calibrator 205 of Figure 3, the exclusion calibrator 205 receives edges, edge widths, and the input image, and processes them to generate various exclusion control parameters to configure the exclusion filter 207. The exclusion calibrator 205 may further receive control signals 'calibrate command', 'index', and 'R/W'. These control signals may come from a focus system controller, e.g. processor 112 of Figures 1 or 2.

The exclusion calibrator 205 is configured to inspect one or more image characteristics of edges in general and separately of sharp edges in particular upon a command on a 'calibrate command' input control signal, and create one or more exclusion ranges in those characteristics to exclude substantial amount of edges that are not sharp enough. Sharp-enough edges are edges whose widths fall within a predetermined narrow range ("sharp-edge range") surrounding sharp_edge_width. A sharp-edge range may be contained within the narrow-edge range. For example, a sharp-edge range may be +/-0.2 around sharp_edge_width. If sharp_edge_width is 2.0, a sharp-edge range may be from 1.8 to 2.2, whereas a narrow-edge range may be from 1.5 to 3.0. The exclusion ranges may be memorized under a unique index value provided by the 'index' input control signal by providing a write command on the 'R/W' input control signal. Multiple sets of exclusion ranges may be memorized, each with a different index value. A set of exclusion ranges may be retrieved by providing its associated index value on the 'index' input control signal and a read command on the 'R/W' input control signal. The retrieved exclusion ranges may be applied by the exclusion filter 207 in Figure 3 to exclude edges that fall within these exclusion ranges. The exclusion ranges of a first characteristic may be applied before those of a second characteristic.

Figure 17 shows a block diagram of one embodiment of an exclusion calibrator. Edge Statistic unit 902 receives an image, a set of edges, and edge widths. It calculates all-edge statistics, which are histograms for one or more characteristics associated with these edges. It also calculates sharp-edge statistics, which are histograms for

the same characteristics but only on edges whose edge widths fall within the sharp-edge range. Both all-edge statistics and sharp-edge statistics may be stored in a memory-1 904. The exclusion calculator 906 receives both sets of statistics, performs calculation to form exclusion ranges in one or more characteristics based on histograms therein, and outputs to a memory-2 908, which may store these exclusion ranges under an index value provided on input control signal 'index' upon a write command on the input control signal 'R/W'.

Figure 18 is a block diagram of an alternate embodiment of an exclusion calibrator. This embodiment adds an exclusion filter 910 to the structure of Figure 17. The exclusion filter 910 filters by a chain of sets of exclusion ranges, each set corresponding to a different characteristic. Edges are filtered by one set after another in the chain. At each iteration, the set of exclusion ranges calculated for the characteristic analyzed at the prior iteration is appended to the chain of sets of exclusion ranges. The resultant edges and edge widths (and exclusion weights, if the exclusion filter 910 follows the aforementioned alternate embodiment of exclusion filter) output by the exclusion filter 910 and further filtered by the newly added set are analyzed by Edge Statistics unit 902 to generate a new set of all-edge statistics and sharp-edge statistics (and exclusion weights, ditto). The exclusion calculator 906 analyzes the new set of all-edge statistics and sharp-edge statistics (and exclusion weights, ditto) and selects the next characteristic and its sets of exclusion ranges. A characteristic not used in prior iterations is chosen.

The flowchart in Figure 20 illustrates this process. At step 1010, the chain of sets of exclusion ranges is initialized to empty. At step 1012, edge statistics unit 902 generates all-edge statistics and sharp-edge statistics for a number of characteristics for edges and associated edge widths received from exclusion filter 910. At step 1014, exclusion calculator 906 calculates exclusion ranges for a number of characteristics not used in prior iterations. At step 1016, a next characteristic is chosen from the abovementioned characteristics and its associated set of exclusion ranges is appended to the chain of exclusion range sets. At step 1018, a query on "good enough" (described below) is made. If answer is yes, the iterative process is done, and the chain of sets of exclusion ranges may be stored to the memory-2 908. If not, at step 1020, the exclusion filter 910 further filters those edges and their associated edge widths previously input to step 1012 with the latest added exclusion ranges, and subsequently a new iteration starts at step 1012 to re-calculate edge statistics.

Each iteration in Figure 20 may choose a different characteristic that is not used in prior iterations in one of several ways. In a first way, the sequence of all characteristics may be predetermined, such that each next iteration uses the next characteristic down the sequence. In a second way, to choose between a first characteristic and a second characteristic to become a next characteristic, the characteristic that generates exclusion ranges that de-emphasize or even exclude more edges that survive into the current iteration may be preferred over the other characteristic. This preference may be reversed if the characteristic de-emphasizes or removes more than a

certain fraction, e.g. 10%~50%, preferably 20%, of sharp edges. This selection procedure for a next characteristic is applicable to the embodiment of Figure 17 as well as the embodiment of Figure 18.

In general, a first characteristic may be preferred over a second characteristic if the former results in a greater increase in a ratio of sharp-enough edges to all edges among the surviving edges after a re-filtering using a corresponding set of exclusion ranges.

Exclusion ranges corresponding to a number of different indices may be combined to form new exclusion ranges that are stored under a new index. For each characteristic present under one or more of said different indices, the exclusion ranges of said characteristic under said different indices may be logically ANDed across said indices followed by an inversion to form new exclusion ranges such that a value is within such new exclusion ranges if and only if said value is not within an exclusion range for said characteristic for at least an index that has said characteristic in its exclusion chain. Effectively, such new exclusion ranges for said characteristic tries to exclude sharp-enough edges from all of said different indices. One or more characteristics may be operated upon in this manner to generate new exclusion ranges. Such characteristics may form an exclusion chain. An exclusion calibrator may receive a command input that specifies a set of different indices along with the new index to store the resultant exclusion chain under. A new exclusion chain thus formed under a new index may be retrieved to apply on the exclusion filter 207 to exclude

edge contributions from a number of objects already calibrated for to discover remaining objects in the scene.

The exclusion calibration works in iteration from the start of the calibrate command until either a certain "good enough" condition is met or no more characteristics remain. Then the entire chain of set of exclusion ranges may be stored in the memory-2 808 along with the index value from the 'index' input control signal or transmitted to the processor 112, 112', 112" or both. The "good enough" condition can be met in one of several ways. In one, the condition is met if the chain of exclusion ranges has a predetermined number of characteristics, for example three. In a second, the condition is met if, for example, 75% or some other percentage between 50% to 100% of edges that are not sharp-enough edges are eliminated after exclusion filtering. In a third, the condition is met if the number of sharp-enough edges outnumber the rest by three to one or some other ratio not less than two to one after exclusion filtering. "Good enough" condition may be anyone of the above, or combination thereof, or other reasonable condition that indicates that what remains after exclusion filtering are not dominated by edges other than sharp-enough edges.

Figure 19 is a flowchart for the exclusion calculator 906 shown in Figures 17 and 18 to generate exclusion ranges for each characteristic. The characteristic's range may be divided into bins, each bin covering a fraction of the range, and all bins together cover the entire range, and adjacent bins do not overlap except sharing the common boundary. Starting with the first bin at step 1002, the exclusion range is emptied. At step 1004, the count of

sharp-enough edges is compared with the count of all edges. If the count of sharp-enough edges in this bin is either zero or less than a given fraction, e.g. three quarters, of the count of all edges in this bin, include this bin in the exclusion range. Repeat steps 1004 and 1006 until all bins are done.

An exclusion calibrator may create a separate set of exclusion ranges ("pointed exclusion ranges") by further limiting sharp-enough edges to be within a given region in the image. To do so, sharp-edge statistics is further tightened to exclude edges that lie outside the given region. The given region may be formed, for example, in Figure 16, from a selection region 1920 shown overlapping the displayed image in the display 114. The selection region 1920 indicates an object desired to be in sharp focus. Thus if there were a different object outside the selection region 1920 but at the same focus distance as the object within the selection region 1920, the different object does not interfere with the formation of exclusion ranges to reject edges not pertaining to the desired object. The exclusion calibrator may create and memorize a separate set of exclusion ranges corresponding to further limiting sharp-enough edges within the selection region. The given region may be formed, alternately, as a predetermined focusing region (not shown) in the center of the display of digital cameras and the viewfinder of cameras in general, often in rectangular shape or circular shape. The given region may be formed, alternately, by a touch-screen sensor overlapping the display 114. The touch-screen sensor may sense one or more strokes of touching by one or more of a stylus and fingers, for example, and provide such information as the positions of

the touching to a processor to determine the corresponding selection region.

Although shown to reside together in the focus signal generator 120, one or more components of the exclusion calibrator 205 may reside instead in the processor 112, 112′, 112″. For example, the exclusion calculator 906 and the memory 908 may reside in the processor 112, 112′, 112″. In this configuration, the processor 112, 112′, 112″ receives all-edge and sharp-edge statistics (shown in Figure 17 and 18) via signals 134 for use in the exclusion calculator 906. The processor 112, 112′, 112″ may perform the process of the flowchart in Figure 19 and/or 20 entirely within itself or in conjunction with the focus signal generator 120, 120′.

Use with Exclusion

Exclusion calibrator 205 and exclusion filter 207 together may be used to form a chain of exclusion ranges to eliminate edges that do not belong to the object in sharp focus in one image captured at a time. The same chain of exclusion ranges may subsequently be used to eliminate those other edges even though the object has moved relative to the background objects. Doing so allows the edges of the object to continue to dominate the focus signal. Exclusion filtering may be operated whether or not the width filter 209 is bypassed by the fine switch 220 in Figure 3. If the width filter 209 is bypassed, i.e. the focus signal is a gross focus signal, those two outlier peaks in Figure 11 at edge widths of 4.0 and 5.0 may be eliminated so that even if the previously in-focus object has moved out of focus so much that the associated peak 820 moves outside of the narrow-edge range, the gross focus

signal can still provide a good feedback signal to the focus control system to estimate how much to adjust the focus position to bring the object of interest back into the narrow-edge range where the fine focus signal can provide a more accurate feedback control signal to finally bring the object into a sharp focus.

Re-calibration may be performed at any time, for example during tracking of an object of interest, by issuing a "calibrate" command to the exclusion calibrator 205. The processor 112, 112', 112" may provide the same index to the exclusion calibrator 205 as the index under which the existing calibrated exclusion ranges for the object of interest is stored. The index may be the index used to retrieve the chain of sets of exclusion ranges currently in use in the calibration filter 207. Issuing the same index as an existing index will replace the previous calibrated exclusion ranges and chain that correspond to the existing index with a new chain of sets of exclusion ranges.

A re-calibration may be performed when a selection region is created on and/or around the object of interest to limit sharp-enough edges to within the selection region only, as discussed above. The "pointed exclusion ranges" or "pointed exclusion chain" may be sent to and be used at the exclusion filter 207 instead of non-pointed exclusion ranges or chain, e.g. when the processor 112 receives a user command providing a given region in one of the abovementioned manners.

Re-calibration may be performed during movement of the object of interest within the scene causing one or more image characteristics pertaining to the object to change.

For example, the user may command a given region on and/or around the object of interest as soon as the object of interest is no longer highlighted or is losing more and more of the highlight that indicates sharp edges.

For re-calibration, instead of providing the same index, the processor 112 may provide a new index to store a new chain of sets of exclusion ranges. The re-calibrated chain of sets of exclusion ranges may be stored under a new index and not over-write the existing index and its associated chain of sets of exclusion ranges. The chain of sets of exclusion ranges from the new and the existing indices may be compared to identify which characteristic(s) change, and which do not. The characteristics that do not change from the existing index to the new index may be promoted to become earlier in the new chain. The characteristics that change may be eliminated from the chain. Thus characteristics that remain unchanged over time are retained for tracking the same object over time. A characteristic may be considered having changed if replacing the characteristic's exclusion ranges in the new chain with that of the existing chain would result in a significant change in a ratio of sharp-enough edges to all edges after a re-filtering with the characteristic. A significant change in the ratio may be predetermined in terms of a percentage, for example being larger than 50%. The predetermined percentage may be specified as a function of the image or a sequence of images.

For an object of interest nearly in sharp focus such that it produces edges within the sharp-edge range, exclusion calibrator 205 and exclusion filter 207 help to eliminate edges contributed by out-of-focus objects so that

contribution to the fine focus signal (for which width filter is not bypassed) is dominated by edges contributed by the object of interest to give an improvement in the accuracy of fine focus signal as an indication of focus sharpness.

When a selection region 1920 is created on and/or around the object of interest, the focus signal generator 120 may give preference in the calculation of the focus signal to edges that correspond to only the selection region 1920 ("preferred edges") under a control (not shown) of the processor 112. Preference to preferred edges may be given in one of several ways. The image provided to the focus signal generator 120 on bus 130 may be limited to within the selection region 1920. Or a weight may be applied on edges that enter the focus signal calculation such that edges outside and/or farther from the selection region 1920 have lesser weights than the preferred edges, or even zero (i.e. equivalent to being excluded from focus signal calculation altogether). Or edges that are not preferred edges may be eliminated at any one of the units within the focus signal generator 120, such as the edge detection & width measurement unit 206, the width filter 209, and the exclusion filter 207. Ways to give preferences to intra-region edges are not limited to the above. Nor is there a need for a rigid or sharp distinction between inside and outside of the selection region 1920. One skilled in the art can readily appreciate that it suffices as long as a plurality of edges are selected to correspond to the selection region and to receive such preference against a plurality of edges outside the selection region.

When a selection region 1920 is created on or around an object of interest, the processor 112 may control the focus signal generator to generate a gross focus signal that applies a preference to the preferred edges. Doing so can eliminate edges not pertaining to the object of interest. For example, in Figure 14 is shown a gross focus signal across a sweep of focus position from far to near without applying such preference. The gross focus signal exhibits multiple minima but only one minimum, at position FB, is due to the car. By applying such preference for the car, such as by using the selection region 1920 shown in Figure 16, the minima corresponding to the foreground "person", at position FC, and the background "mountains, sun & horizon", at position FA, can be eliminated. In addition, the gross focus signal level at position FB, corresponding to the "car", will have a value closer to the sharp-edge width. The focus control system 102 may control the focus position of the focus lens 104 to reduce the difference between the focus position FB to the current focus position by evaluating a difference between the current gross focus signal level and the sharp_edge_width by applying one of the known control methods, PI-controller. The focus control system 102 may switch to use the fine focus signal when the current focus signal level falls within a range close enough to the sharp_edge_width, such as the narrow-edge range.

Control – Scanning

Figure 25 is a flowchart for a focus system controller such as processor 112 of Figures 1 and 2 to adjust the focus position and measure focus signal when moving the focus position across its range from one end to the other

in search of focus positions that render sharp images of objects in the scene. At step 1400, the focus position is set to the far end. All indices for the exclusion calibrator 205 of Figure 3 may be cleared, along with the exclusion range data in memory-2 908 of Figures 17 and 18. At step 1402, the focus position is moved one step closer. At step 1404, if the focus position is the near end, scanning is completed. If not, at step 1406, check to see if the narrow-edge count peaks. If not, go to the next iteration, starting back at step 1402. If yes, create a new index for this focus position, record the focus position, send a calibrate command to the exclusion calibrator 205 to gather edge statistics, form a chain of sets of exclusion ranges, and send the index and a write command to store the chain of exclusion ranges, then proceed to the next iteration, starting back at step 1402.

A chain of sets of exclusion ranges may be formed during the scanning process for each focus position where sharp images are found. In a subsequent search for any of these objects, the exclusion ranges may be applied to the focus signal generator to help de-emphasize and discriminate against edges contributed by the other objects so that the gross focus signal may exhibit a single trough and further the trough has a minimum value that is close to the sharp_edge_width, and so that the fine focus signal also has less interference from out-of-focus objects that its departure from the sharp_edge_width gives an accurate estimate of how much to adjust the focus position to bring the object into sharp focus. Both remain useful and reliable even if the object of interest moves relative to the other objects.

As an illustration, Figure 13 is a graph of narrow-edge count plotted against time when scanning the scene illustrated in Figure 12. The narrow-edge count peaks whenever the focus position is such that an object projects a sharp image on the pixel array 108 in Figures 1 or 2, thus its peaking signifies a presence of sharp-enough edges. Figures 26, 27, and 28 illustrate the images captured when the focus lens is at each of those focus positions where the narrow-edge count peaks.

Figure 14 shows the gross focus signal output by the focus signal generator 120 during the scan, where the exclusion filter 207 is bypassed by the 'exclude' signal being OFF. The gross focus signal correctly exhibits a minimum corresponding to the times when the focus position is near each of the three focus positions that brings an object into sharp focus. However, the gross focus signal's minimum is not at the sharp_edge_width level, which is 2.0 in this example, due to the interference from blurred edges contributed by the other objects that are out-of-focus. As aforementioned, turning on 'exclude' signal after having calibrated the exclusion calibrator 205 will subsequently allow the gross focus signal to exhibit a single global minimum for each of the 3 groups of objects by retrieving exclusion ranges using the index for each group of object, even if they have moved from where they were during scanning. Figures 29, and 30A-30C illustrate how exclusion ranges for hue for each of those three groups of objects may be formed.

Search – Display & User Direction

Figure 31-33 illustrate how edges may be highlighted on the display 114 of Figure 1 or 2 when the focus position

bring them into sharp focus. Highlighting sharp edges or sharp-enough edges is especially helpful to the user when the image capture resolution is far higher than the display resolution such that an insufficiently sharply focus edge still appears to be sharp on the display. It also solves a common problem wherein the user is not able to tell which object among several objects in the scene is in sharp focus. Having been thus informed of which objects are in sharp focus, the user can then press either the outward button 1912 of the image capture apparatus 102 of Figure 16 to focus on a farther object, or inward button 1910 to focus on a nearer object or use any one of user input device and method available to input such user commands. The image capture apparatus 102 may also display a blinking outline 2100 overlapping the object whose edges are to be focused on, as shown in Figure 33. In general, any display method to indicate one or more sharp-enough edges may be used, as one skilled in the art would readily recognize.

A Search Mode

Figure 34 is a flowchart for seeking to the Nth object in a given direction. At step 2200, the focus lens 104 moves until N-1 peaks are skipped. Peak skipping can be detected using one of several signals for peak detection ("peak-detection signal"). One candidate peak-detection signal is gross focus signal, which as Figure 36 shows attains a local minimum at each position where there are objects producing sharp edges in the captured image. For the scene of Figure 12, to bring the car into sharp focus, the focus lens will move outwards from the innermost position to skip focus position FC where the person is in sharp focus, past the focus position where the gross focus

signal reaches a local minimum (that nearly reaches the sharp_edge_width value of 2.0). Another candidate peak-detection signal is the narrow-edge count. Figure 35 shows narrow-edge count as focus position moves outward from the innermost position past the position where the person produces a sharp image in the captured image.

At step 2202 of the flowchart in Figure 34, unless having found the Nth peak, continue to move focus lens in the same direction, at step 2206, and return to the same query at 2202. If found, move to step 2204 to turn on tracking mode. Detection of the Nth peak can use one of several peak-detection signals. One candidate peak-detection signal is the gross focus signal. Another candidate is the narrow-edge count. A different peak-detection signal may be used for step 2202 than step 2200. Tracking may be turned on after the peak is detected, as shown in Figure 35 and 36 following the flowchart of Figure 34, or when approaching and near enough to the peak value, as shown in Figure 37, following flowchart of Figure 38. ("Near enough" may be exceeding a predetermined fraction of the prior detected peak value, e.g. from a prior scan.)

User Control on Search

The number N to associate with the focus position to seek to may be established in one of several ways.

In a first method, the apparatus 102 may provide a user control, such as buttons 1912 and 1910, shown in Figure 16, or any other form of user input method/apparatus mentioned in this description, to navigate outward or inward among sharp focus positions. For example, each pressing of the button 1912 may select the next farther sharp focus

position, whereas each pressing of the button 1910 may select the next nearer sharp focus position. The apparatus 102 may display a highlight such as a highlight 2000 shown in Figure 31 on a sharp edge or a sharp object. The sharp focus positions may be memorized during a scan. The highlight 2000, or the corresponding sharp edges, or both, at each sharp focus position found during the scan may be formed and memorized in a memory, such as within the processor 112, 112', 112", during the scan. The displayed image at each sharp focus position may be memorized along. During a navigation to a target focus position, such as by using buttons 1912 and 1910 to jump farther and nearer among sharp focus positions, the highlight that corresponds to the selected sharp focus position may be retrieved from the memory and displayed on the display 1902. Along with the highlight 2000, the previously memorized displayed image that corresponds to the selected sharp focus position may be displayed as well to show what object in the memorized display image gave rise to the sharp edges at the selected sharp focus position. With this aid, the user may decide whether the selected sharp focus position corresponds to his or her intended target sharp, or he or she needs to navigate farther or nearer. Thus, even with several different objects at different focus distances giving rise to edges overlapping within the image in the display 1902 in Figure 16, for example the head of the person and the left end of the car, the user is able to select the target object. The processor 112 thus determines the user's selection of the target sharp focus position and its associated memorized sharp focus position or exclusion chain or index or any combination thereof. If the target sharp focus position is the nearest, found from

the scan, N is 1. If it is the one immediately after, N is 2; and so on. The associated chain of exclusion ranges may be retrieved and applied to the exclusion filter 207, the associated chain having been calibrated, created and stored under an index previously.

In a second method, a prior scan is not assumed. Using the user interface as described in the previous paragraph, the user may navigate farther or nearer by N number of steps. For example, the user may press button 1912 three times to demand an outward search from the current focus position past a first sharp focus position followed by a second sharp focus position to stop at a third sharp focus position. The focus system controller 112 commands the focus lens 104 to move outwards to the third sharp focus position by following the flowchart in Figure 34, having N initialized to 3. If the user subsequently demands to change the target sharp focus position to the second sharp focus position by pressing button 1910 once, the focus system controller 112 commands the focus lens 104 to move to the second sharp focus position by following the flowchart in Figure 34, but moving the focus position in the inward direction this time, having N initialized to 1. The apparatus 102 may display a highlight 2000 on sharp edges each time a sharp focus position is found at the final destination or in passing.

Either of the above methods is useful to deal with difficult focusing situations in which edges from objects at different focus distances overlap. One example of such situation is a chicken wire and a chicken behind the chicken wire. If the focus position has the chicken wire in sharp focus whereas the chicken is the desired object,

the user can navigate outwards one step using the user interface, for example by pressing the outward button 1912 once. In response, the focus system controller 112 commands the focus lens 104 to move outwards until the next sharp focus is detected, which is the sharp focus position for the chicken. On the other hand, if the focus position has the chicken in sharp focus whereas the chicken wire is the desired object, the user can navigate inwards one step using the user interface, for example by pressing the inward button 1910 once. In response, the focus system controller 112 commands the focus lens 104 to move inwards until the next sharp focus is detected, which is the sharp focus position for the chicken wire. In either case, the sharp object or its edges may be highlighted on the display 1902 each time an object is brought into sharp focus to help the user determine which object is in sharp focus.

Highlighting on a display an object or its edges in sharp focus, providing a user interface that accepts a user's command to initiate and/or request a direction to seek to a next focus position to bring a farther or nearer object into sharp focus, seeking to said next sharp focus position upon a user entering a corresponding command via said user interface, and highlighting objects or their edges brought into sharp focus during transiting to the final focus position are steps useful to a user of an apparatus 102 regardless of how the focus signal is formed or how the object or its edges in sharp focus is determined. The focus signal may be generated by measuring widths of edges in an image as in this application. Alternately, the apparatus 102 may measure a contrast across an edge and detecting sharp focus of the edge by detecting a peaking in said contrast when focus position of

the focus lens 104 is changed. Alternately, the apparatus 102 may generate a focus signal by dividing the image into groups of adjacent pixels, e.g. each group having 16-by-16 pixels, a contrast measured within each group as a difference between a maximum value and a minimum value of a signal that represents visible light reflecting from the scene, e.g. luminance, and detecting sharp focus within said group of pixels by detecting a peaking in said contrast when focus position of the focus lens 104 is changed, and highlighting a portion of the image displayed in display 1902 corresponding to said group of pixels. Alternately, the apparatus 102 may generate a focus signal using any conventional method.

A Tracking Mode

The focus system controller, such as processor 112 in Figure 1 or 2, may turn on the 'fine' control signal to the focus signal generator 120 to receive a fine focus signal when tracking mode starts. It may also turn on the 'exclude' control signal and provide the corresponding index to an exclusion calibration 205 within the focus signal generator 120 to retrieve the corresponding exclusion ranges, if the object nearly in-focus has been previously calibrated. If not, it can issue a calibrate command to the exclusion calibration 205 to perform a calibration and provide a new index to store the calibrated exclusion ranges, and subsequently retrieve them for use by the exclusion filter 207. Doing so improves an accuracy of the fine focus signal by greatly attenuating the interference from unintended objects.

The focus system controller may adjust the focus position to keep the fine focus signal nearest possible to

the minimum, as shown in Figure 39, or it can pursue an alternate strategy of controlling the focus position to keep the fine focus signal an offset away from the sharp_edge_width and above the minimum, as shown in Figure 40 and 41. (sharp_edge_width is labeled as h_{FB} in Figures 40-41.) Maintaining fine focus signal at an offset above sharp_edge_width and the minimum has a benefit in that a slight change in the fine focus signal due to any movement in the object gives off clue as to whether the object is moving closer or farther. If the focus position is farther than the ideal focus position that would have brought the fine focus signal to the minimum (hence the fine focus signal level is higher than the minimum), a movement in the object that reduces the fine focus signal must be directed outwards, i.e. closer to the scene location where the current focus position would make sharp image. On the other hand, if a movement in the object increases the fine focus signal, the object must be moving inwards, i.e. away from that scene location. On the other hand, if the focus position is nearer than the ideal focus position, the opposite would be true. The focus system controller then can immediately move the focus lens in the direction thus determined. This is shown in Figure 41 where the fine focus signal is shown to always return to the same level after a small departure, whereas in Figure 39 where the focus system controller targets the fine focus signal to the minimum is unable to immediately determine the direction of movement of the object and may make a mistake when the object starts moving, causing the initial increase in fine focus signal to be more rapid, and only after that to realize the mistaken guess of direction and to correct itself. In Figure 39, the subsequent ripples are

maintained as small as Figure 41 on the assumption that the object continues to move in the same direction, hence the focus system controller does not make a second mistake in the direction. But if the object changes direction, the focus system controller that targets the minimum focus signal level can make a mistake again.

In general, in this alternative strategy, the focus system controller should servo a focus signal to a target level offset from a optimal signal level (of the focus signal) that indicates a sharpest focusing of a plurality of edges whose edge widths contribute towards the focus signal, the target level indicating a less focused state of the plurality of edges than the optimal signal level. This is due to the observation that the effects on the focus signal would be indistinguishable between a forward displacement and a backward displacement of the focus lens, that both would result in the edges becoming wider, if the focus lens were positioned at the sharpest focus position for these edges.

Use with Exclusion Illustrated

Figures 42A-42C illustrate an ability of the focus control system to track an object (the bird) that moves relative to background objects. In Figure 42A, the bird is in sharp focus, and the focus system controller issues a calibrate command to the exclusion calibrator 205 and turns the 'fine' control signal ON to generate a fine focus signal and the 'exclude' control signal ON to exclude the mailbox, which is not sharp in Figure 42A. The exclusion calibrator 205 finds two characteristics, namely the length of concatenated edges and slant angles, whose exclusion

ranges are shown in Figures 43 and 44, respectively, to exclude the mailbox from the bird.

Next, in Figure 42B, the bird flies near and rests on the mailbox. Between Figure 42A and 42B, the focus control system continues to track the bird to keep it in sharp focus. When the bird comes to rest on the mailbox, edges contributed by the mailbox are also sharp-enough edges, but they are excluded by the exclusion filter 207 by using two characteristics, namely the length of concatenated edges and slant angles, whose exclusion ranges are shown in Figures 43 and 44, respectively. The fine focus signal continues to indicate the sharpness of edges contributed by only the bird, not the mailbox. Finally, when the bird flies away, the focus control system continues to track the bird to maintain its image in sharp focus and not getting falsely-locked onto the mailbox, which by the sheer larger number of edges would have otherwise dominated the fine focus signal and falsely tell the focus control signal that the object of interest remains at the same focus distance.

Certain Advantages

One advantage of the focus signal generator is that the minimum focus signal of different images are at approximately the same values. This ensures that the lens will remain in the same position even if the camera is shaking but the image still remains sharp. Another advantage is that the range between the largest and smallest focus signal for a scene with different focal distances are wide enough to ensure that the optimum focus can be obtained.

A further advantage is that the focus signal value is not dependent on illumination nor on color or reflectivity of objects in the scene. Conventional contrast method of generating a focus signal produces contrast signal which is strongly dependent on all said factors, such that when a new object enters the scene even though at the sharp focus distance, the focus signal produced by the contrast method usually changes.

Alternate Embodiments

Figure 45 shows an alternate embodiment of a focus signal generator 120′. Focus signal generator 120′ outputs statistics of edges and edge widths. Among the edge-width statistics that controller 120′ outputs may be one or more of the following: an edge-width histogram comprising edge counts at different edge widths; an edge width where edge width count reaches maximum; a set of coefficients representing a spline function that approximates edge counts at different edge widths; and any data that can represent a function of edge width. Census Unit 240 may receive data computed in one or more of the other units with the focus signal generator 120′ to calculate statistics of edge widths. In general, the focus signal generator 120′ may output a signal that has an indication of a distribution of edge widths.

Referring to Figure 46, the edge-width statistics thus provided in signals 134 to an alternate embodiment of processor 112′ in an alternate auto-focus image pickup apparatus 102′ may be used by the processor 112′ to compute a gross and/or fine focus signal and a narrow-edge count in accordance with methods discussed above or equivalent thereof. In addition, any data computed in the focus

signal generator 120′ may be output to the processor 112′ as part of the output signals 134. For example, the exclusion ranges and chains, along with statistics of edges, such as statistics of edge characteristics used for calculating the exclusion ranges and chains according to the flowcharts of Figure 19 or Figure 20, may be sent to the processor 112′.

The processor 112′ may internally generate a focus signal and/or a narrow-edge count in addition to the functions included in the processor 112 of Figure 1.

The pixel array 108, A/D Converter 110, color interpolator 148, and generator 120′ may reside within a package 142, together comprising an image sensor 150′, separate from the processor 112′.

Yet another embodiment of a focus signal generator may add a census unit 240 to the generator 102 of Figure 1 and output one or more statistics calculated in such a generator to the processor 112.

Auxiliary Pixel Array

Figure 47 shows an alternate embodiment of an auto-focus image pickup system 103. In addition to elements included in a system 102, the system 103 may include a partial mirror 2850, a full mirror 2852, an optical lowpass filter 2840, a main pixel array 2808, and a main A/D Converter 2810. The partial mirror 2850 may split the incoming light beam into a first split beam and a second split beam, one transmitted, the other reflected. The first split beam may further pass through the optical lowpass filter 2840 before finally reaching the main pixel array 2808, which detects the first split beam and converts

to analog signals. The second split beam may be reflected by the full mirror 2852 before finally reaching the auxiliary pixel array 108", which corresponds to the pixel array 108 in system 102 shown in Figure 1. Upon splitting at the partial mirror 2850, the ratio of light intensity (in unit of Joule per second) of the first beam to the second beam may be greater than 1-to-1, preferably greater than 2-to-1. For example, the ratio may be 4-to-1.

The main pixel array 2808 may be covered by a color filter array of a color mosaic pattern, e.g. the Bayer pattern. The optical lowpass filter 2808 prevents the smallest light spot focused on the pixel array 2808 from being too small as to cause aliasing. Where a color filter of a mosaic pattern covers the pixel array 2808, aliasing can give rise to color moiré artifacts after a color interpolation,. For example, the smallest diameter of a circle encircling 84% of the visible light power of a light spot on the main pixel array 2808 ("smallest main diameter") may be kept larger than one and a half pixel width but less than two pixel widths by use of the optical lowpass filter. For example, if the main pixel array 2808 has a pixel width of 4.5um, whereas the smallest diameter is 2.0um without optical lowpass filtering, the optical lowpass filter 2840 may be selected to make the light spot 6.7um or larger in diameter.

The auxiliary pixel array 108" may comprise one or more arrays of photodetectors. Each of the arrays may or may not be covered by a color filter array of a color mosaic pattern. The array(s) in auxiliary pixel array 108" outputs image(s) in analog signals that are converted to digital signals 130 by A/D Converter 110. The images are

sent to the focus signal generator 120. A color interpolator 148 may generate the missing colors for images generated from pixels covered by color filters. If auxiliary pixel array 108" comprises multiple arrays of photodetectors, each array may capture a sub-image that corresponds to a portion of the image captured by the main pixel array 2808. The multiple arrays may be physically apart by more than a hundred pixel widths, and may or may not share a semiconductor substrate. Where the pixel arrays within auxiliary pixel array 108" do not share a semiconductor substrate, they may be housed together in a package (not shown).

Main A/D Converter 2810 converts analog signals from the Main Pixel Array 2808 into digital main image data signal 2830, which is sent to the processor 112, where the image captured on the Main Pixel Array 2808 may receive image processing such as color interpolation, color correction, and image compression/decompression and finally be stored in memory card 116.

An array of photodetectors in the auxiliary pixel array 108" may have a pixel width ("auxiliary pixel width") that is smaller than a pixel width of the main pixel array 2808 ("main pixel width"). The auxiliary pixel width may be as small as half of the main pixel width. If an auxiliary pixel is covered by a color filter and the auxiliary pixel width is less than 1.3 times the smallest spot of visible light without optical lowpass filtering, a second optical lowpass filter may be inserted in front of the auxiliary array 108" to increase the smallest diameter on the auxiliary pixel array 108" ("smallest auxiliary diameter") to between 1.3 to 2 times as large but still smaller than

the smallest main diameter, preferably 1.5. The slight moiré in the auxiliary image is not an issue as the auxiliary image is not presented to the user as the final captured image.

Figure 50 illustrates how edge widths may vary about a sharp focus position for main images from the main pixel array 2808 (solid curve) and auxiliary images from the auxiliary pixel array 108" (dashed curve). The auxiliary images give sharper slopes even as the main images reach the targeted sharp edge width of 2. The auxiliary image is permitted to reach below the targeted sharp edge width, since moiré due to aliasing is not as critical in the auxiliary image, as it is not presented to the user as a final image. This helps to sharpen the slope below and above the sharp edge width. The sharper slope is also helped by the auxiliary pixel width being smaller than the main pixel width.

The shaded region in Figure 50 indicates a good region within which to control the focus position to keep the main image in sharp focus. A change in focus position outwards will cause the edge width to increase in the auxiliary image, whereas a change inwards will cause the it to decrease. To maintain the main image's edge widths near the sharp edge width, a linear feedback control system may be employed to target the middle auxiliary edge width value within the shade region and to use as feedback signal the edge widths generated from the auxiliary images. This is in accordance with the alternate strategy described in the above section on Tracking Mode, where the focus system controller should servo a focus signal to a target level offset from a optimal signal level (of the focus signal)

that indicates a sharpest focusing of a plurality of edges whose edge widths contribute towards the focus signal, the target level indicating a less focused state of the plurality of edges than the optimal signal level. With reference to Figure 50, the focus control system servoes the edge width from the auxiliary array to a width somewhat larger than the smallest possible edge width achievable on the auxiliary array.

The auxiliary pixel array 108", A/D Converter 110, focus signal generator 120 together may be housed in a package 142 and constitute an auxiliary sensor 150. The auxiliary sensor 150 may further comprise a color interpolator 148.

Figure 48 shows an alternate embodiment of auto-focus image pickup apparatus 103' similar to apparatus 103 except focus signal generator 120' replaces focus signal generator 120. The auxiliary pixel array 108", A/D Converter 110, focus signal generator 120' together may be housed in a package 142 and constitute an auxiliary sensor 150'. The auxiliary sensor 150 may further comprise a color interpolator 148.

Figure 49 shows an alternate embodiment of auto-focus image pickup apparatus 103". The focus signal generator 120 and the processor 112" may be housed in a package 144 as a camera controller, separate from the auxiliary pixel array 108". The processor 112" is similar to processor 112 except that processor 112" receives images from the main pixel array 2808 as well as the auxiliary pixel array 108". The processor 112" may perform a color interpolation, a color correction, a compression/decompression, and a storing to memory card 116 for the images received on

signal 2830 similar to the processing that the processor 112 may perform on signal 130 in Figure 2. Unlike in Figure 2, here the images received on signal 130 need not receive compression/decompression and storing to memory card 116. The processor 112" may perform color interpolation on images received on signal 130 for pixels that are covered by color filters in the auxiliary pixel array 108" and send the color interpolated images to the focus signal generator 120 on signal 146.

The auto-focus image pickup system 102, 102', 103, 103', 103" may include a computer program storage medium (not shown) that comprises instructions that causes the processor 112, 112', 112" respectively, and/or the focus signal generator 120, 120' to perform one or more of the functions described herein. By way of example, the instructions may cause the processor 112 or the generator 120' to perform a slant correction for an edge width in accordance with the flowchart of Figure 7. As another example, the instructions may cause the processor 112' or the generator 120 to perform an edge width filtering in accordance with the above description for Width Filter 209. Alternately, the processor 112, 112' or the generator 120, 120' may be configured to have a combination of firmware and hardware, or a pure hardware implementation for one or more of the functions contained therein. For example, in generator 120, a slant correction may be performed in pure hardware and a length filter 212 performed according to instructions in a firmware.

While a memory card 116 is shown as part of system 102, any nonvolatile storage medium may be used instead, e.g. hard disk drive, wherein images stored therein are

accessible by a user and may be copied to a different location outside and away from the system 102.

One or more parameters for use in the system, for instance the sharp_edge_width, may be stored in a non-volatile memory in a device within the system. The device may be a flash memory device, the processor, or the image sensor, or the focus signal generator as a separate device from those. One or more formulae for use in the system, for example for calculating the concatenated length threshold, or for calculating beta may likewise be stored as parameters or as computer-executable instructions in a non-volatile memory in one or more of those devices.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

CLAIMS

What is claimed is:

1. A method for controlling sharpness of objects in images in an auto-focus image system, comprising:

providing a user interface to accept a user's command to initiate a seek to a next nearer/farther sharp focus position and/or request a forward/backward direction to seek to a next sharp focus position.

2. The method of claim 1, wherein the user interface accepts a user command to request skipping (N-1)-th sharp focus positions to reach and lock onto the N-th sharp focus position and causes a focus lens of the auto-focus image system to perform according to the user command.

3. The method of claim 2, further comprising:

seeking to the N-th sharp focus position upon said user command.

4. A method for generating a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

discriminating against a plurality of sharp-enough edges found at a plurality of sharp-focus positions.

5. The method of claim 4, further comprising:

finding an exclusion range that discriminates against said plurality of sharp-enough edges; and

filtering the plurality of edge widths using the exclusion range.

6. The method of claim 5, further comprising:

using the focus signal having the plurality of edge widths filtered by said filtering step to control a search for a sharp-focus position that is not among the plurality of sharp-focus positions.

7. A method for generating a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

forming from a first image an exclusion range from only sharp-enough edges in a given region; and

discriminating in a second image against edges by filtering edge widths using the exclusion range.

8. A method for generating a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

selecting a first characteristic from a plurality of characteristics;

forming exclusion range(s) of the first characteristic to discriminate against a plurality of not sharp-enough edges in the image.

9. The method of claim 8, further comprising:

selecting a second characteristic different from the first characteristic, the second characteristic excluding more edges that are not sharp-enough edges and that are not excluded by the exclusion ranges of the first characteristic than a third characteristic that is not selected.

10. A method for generating a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

finding a first set of exclusion ranges for a first characteristic from a first image;

finding a second set of exclusion range for the first characteristic from a second image;

filtering the second image using the first set of exclusion ranges to find a first population of sharp-enough edges and a second population of sharp-enough and not sharp-enough edges;

filtering the second image using the second set of exclusion ranges to find a third population of sharp-enough edges and a fourth population of sharp-enough and not sharp-enough edges;

finding a first ratio between the first population and the second population;

finding a second ratio between the third population and the fourth population;

comparing the first ratio with the second ratio; and

rejecting the first characteristic if there is a significant change from the first ratio to the second ratio.

11. A method of automatic focus control for an image system employing a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

servoing the focus signal to a target level that is offset from a optimal signal level that indicates a sharpest focusing of the plurality of edges whose edge widths contribute towards the focus signal, the target level indicating a less focused state of the plurality of edges than the optimal signal level.

12. A method for generating a focus signal that is a function of a plurality of edge widths each associated with one of a plurality of edges in an image, comprising:

correcting an edge width of an edge for a slant of a boundary, the edge width being measured along a first prescribed direction, the correcting being from the first prescribed direction to a direction perpendicular to the boundary.

13. The method of claim 12, wherein a correction for the slant is calculated from a first maximal gradient and a second maximal gradient, the first maximal gradient being a peak gradient of the edge and is in the first prescribed direction, the second maximal gradient being a largest gradient of two

pixels from the edge and in a second prescribed direction that is perpendicular to the first prescribed direction.

14. The method of claim 12, wherein the edge width is corrected to a corrected edge width that is a projection of the edge width to the direction perpendicular to the boundary.

15. A method for generating a focus signal that is a function of a plurality of edge widths each of one of a plurality of edges in an image, comprising:

reducing or eliminating a contribution to the focus signal from an edge width of a narrower edge adjacent to a wider edge, a peak gradient of the narrower edge having being smaller than a predetermined fraction of a peak gradient of the wider edge.

16. The method of claim 15, wherein the fraction is 80% or less.

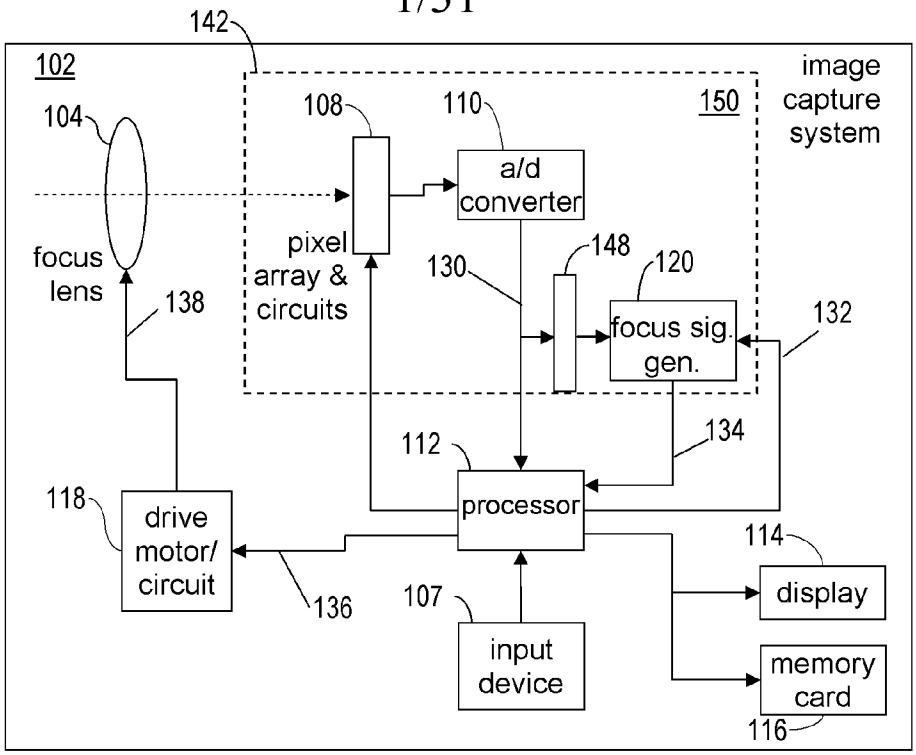
142
102
image capture system
104
108
110
150
a/d converter
pixel array & circuits
focus lens
138
130
148
120
focus sig. gen.
132
112
134
processor
118
drive motor/ circuit
114
display
136
107
input device
memory card
116

FIG. 1

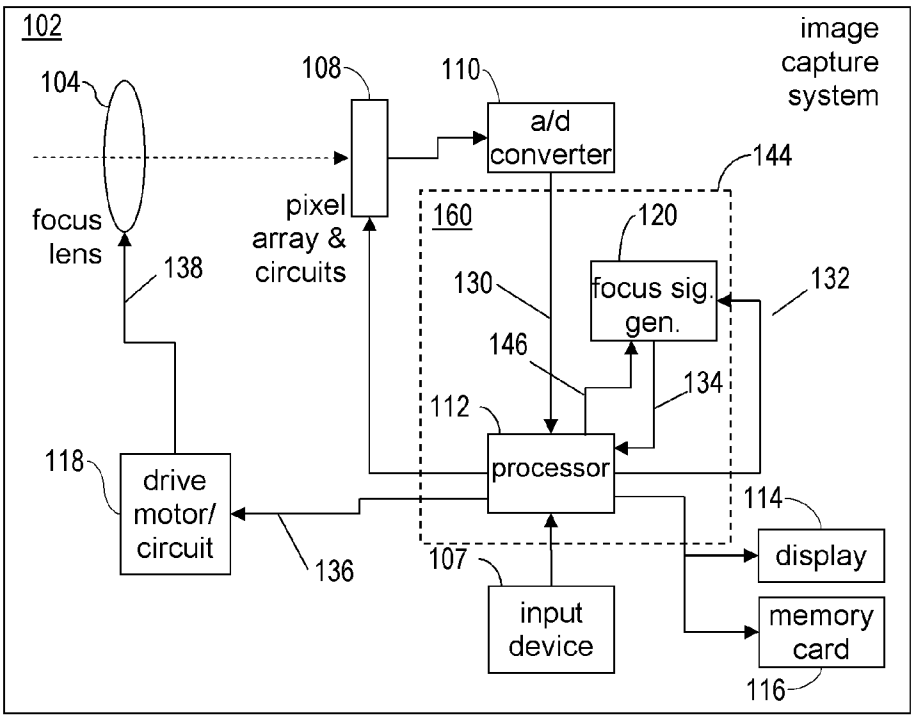
102
image capture system
104
108
110
a/d converter
144
pixel array & circuits
160
120
focus lens
138
130
focus sig. gen.
132
146
134
112
processor
118
drive motor/ circuit
114
display
136
107
input device
memory card
116

FIG. 2

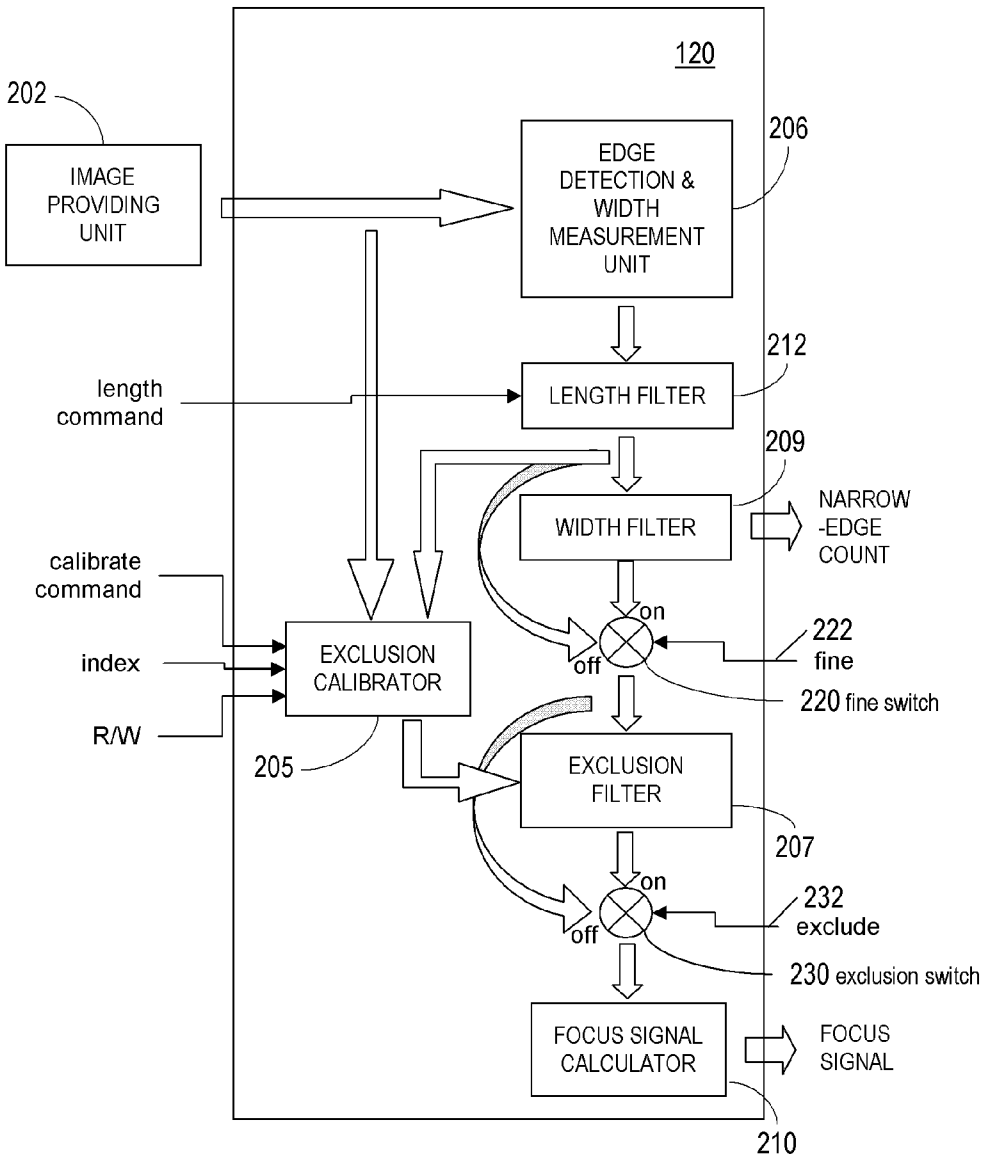
120
202
IMAGE PROVIDING UNIT
206
EDGE DETECTION & WIDTH MEASUREMENT UNIT
212
length command
LENGTH FILTER
209
WIDTH FILTER
NARROW -EDGE COUNT
calibrate command
index
R/W
EXCLUSION CALIBRATOR
205
on
off
222 fine
220 fine switch
EXCLUSION FILTER
207
on
off
232 exclude
230 exclusion switch
FOCUS SIGNAL CALCULATOR
FOCUS SIGNAL
210

FIG. 3

	C1	C2	C3	C4	C5	C6
R1	**10** **9** **V**	**10** **10** **V**	**10** **9** **V**	2 0	0 0	0 0
R2	3 0	**10** **8** **V**	**10** **11** **V**	**9** **10** **V**	1 0	0 0
R3	1 0	3 1	**8** **8** **V**	**9** **11** **V**	**7** **8** **V**	1 0
R4	0 0	1 0	3 2	**7** **8** **V**	**8** **10** **V**	**7** **8** **V**
R5	0 -2	0 0	1 1	3 3	**7** **12** **H**	**6** **12** **H**
R6	0 -1	0 -1	0 0	1 2	3 0 **V**	**1** **8** **H**

FIG. 4

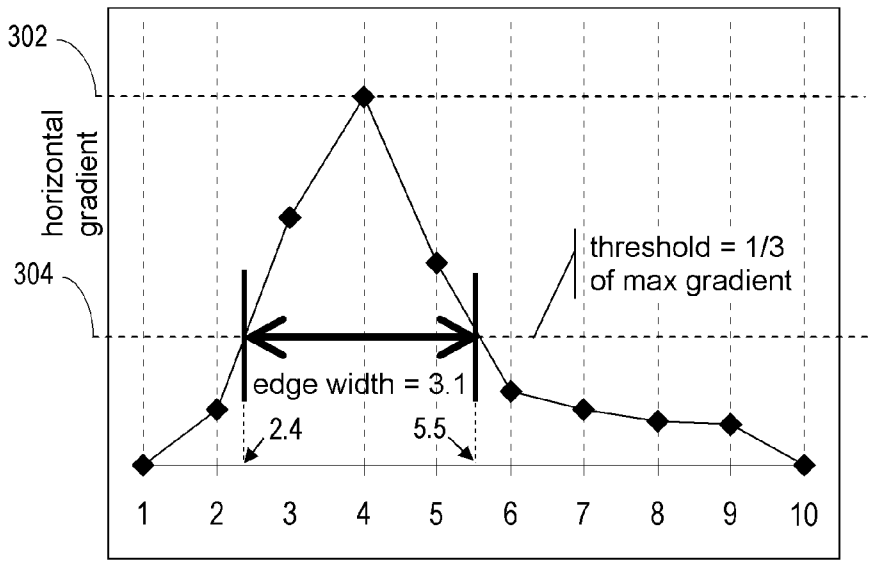

FIG. 5

$b - a\cos\phi$ corrects edge width for slant angle ϕ

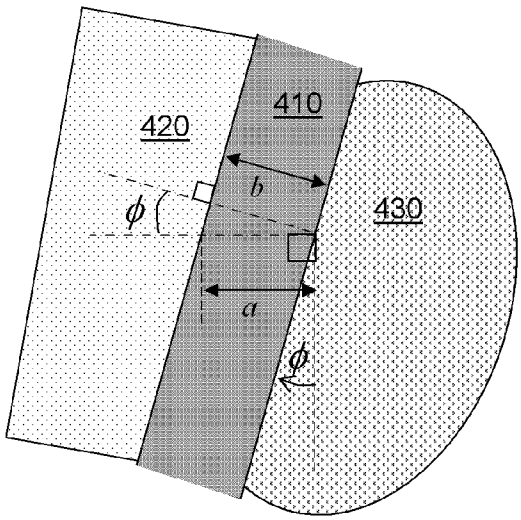

FIG. 6A

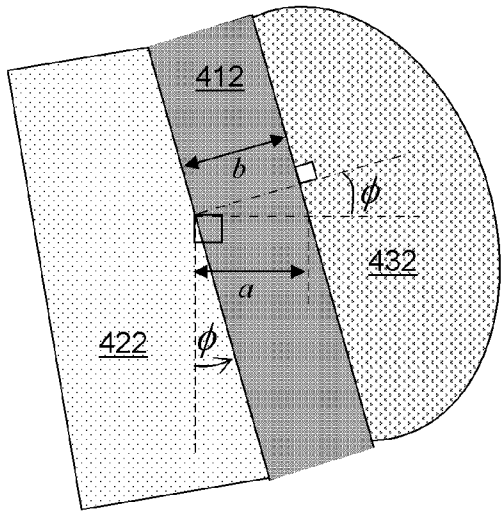

FIG. 6B

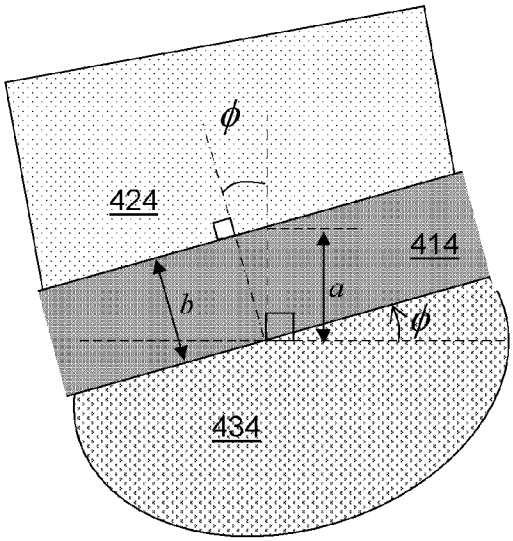

FIG. 6C

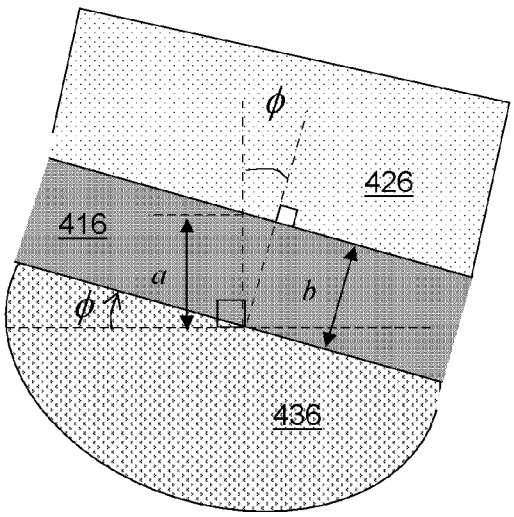

FIG. 6D

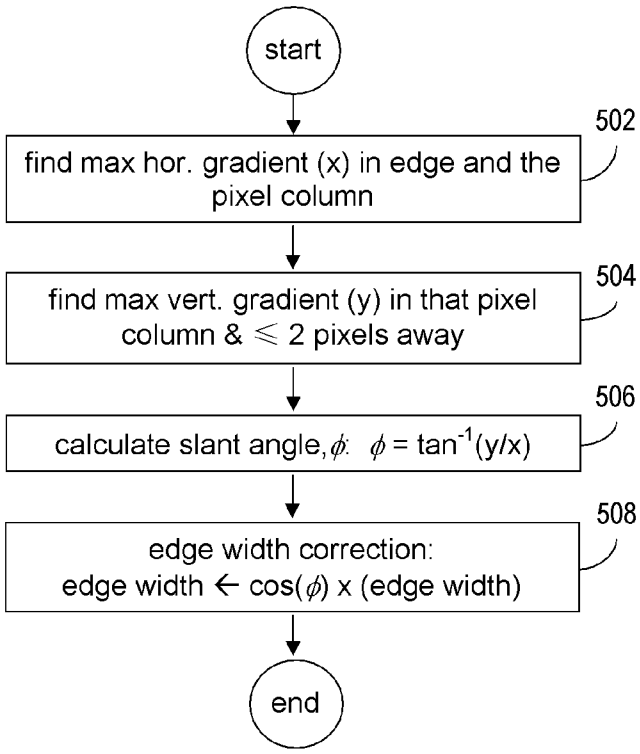

FIG. 7

	C1	C2	C3	C4	C5	C6
R1	**0** **6** **H**	**5** **10** **H**	1 3	2 0	0 0	0 0
R2	3 0	**8** **8** **H**	**15** **11** **V**	**19** **10** **V**	1 0	0 0
R3	1 0	3 1	**18** **8** **V**	**19** **11** **V**	**17** **8** **V**	1 0
R4	0 0	1 0	3 2	**17** **8** **V**	**18** **10** **V**	**7** **3** **H**
R5	0 2	0 0	1 1 V	3 3	**7** **12** **H**	**6** **12** **H**
R6	0 1	0 1	0 0	1 2	3 0	**1** **8** **H**

FIG. 8

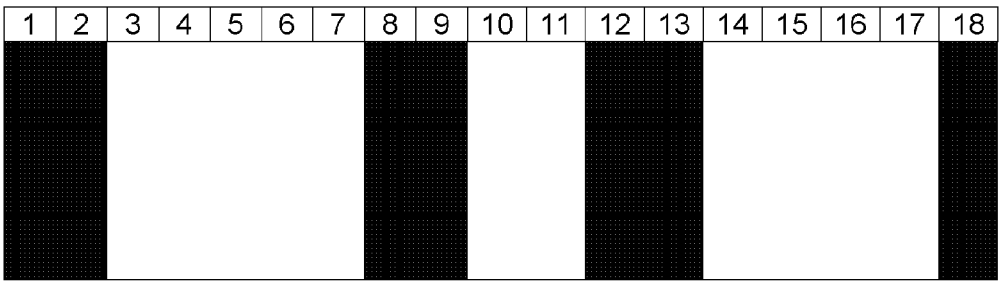

FIG. 9A

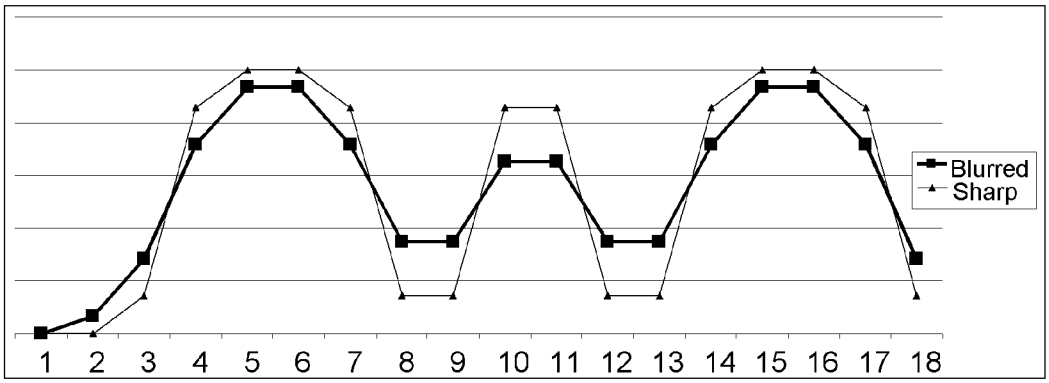

FIG. 9B

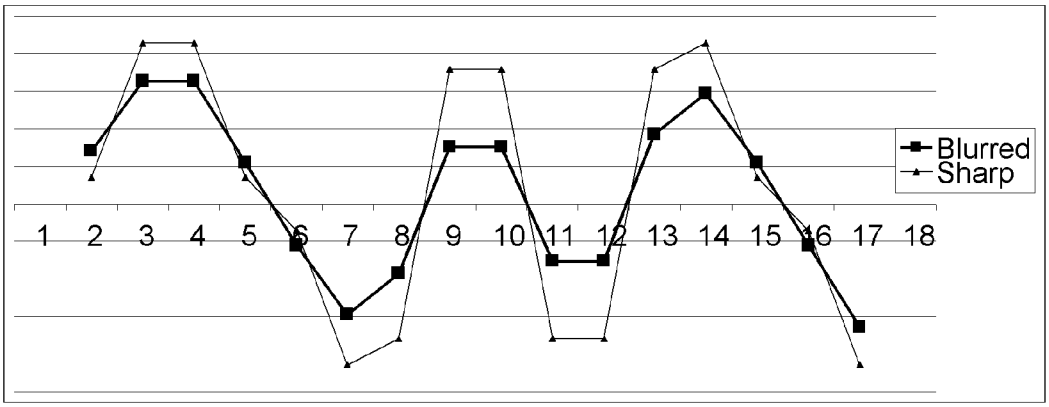

FIG. 9C

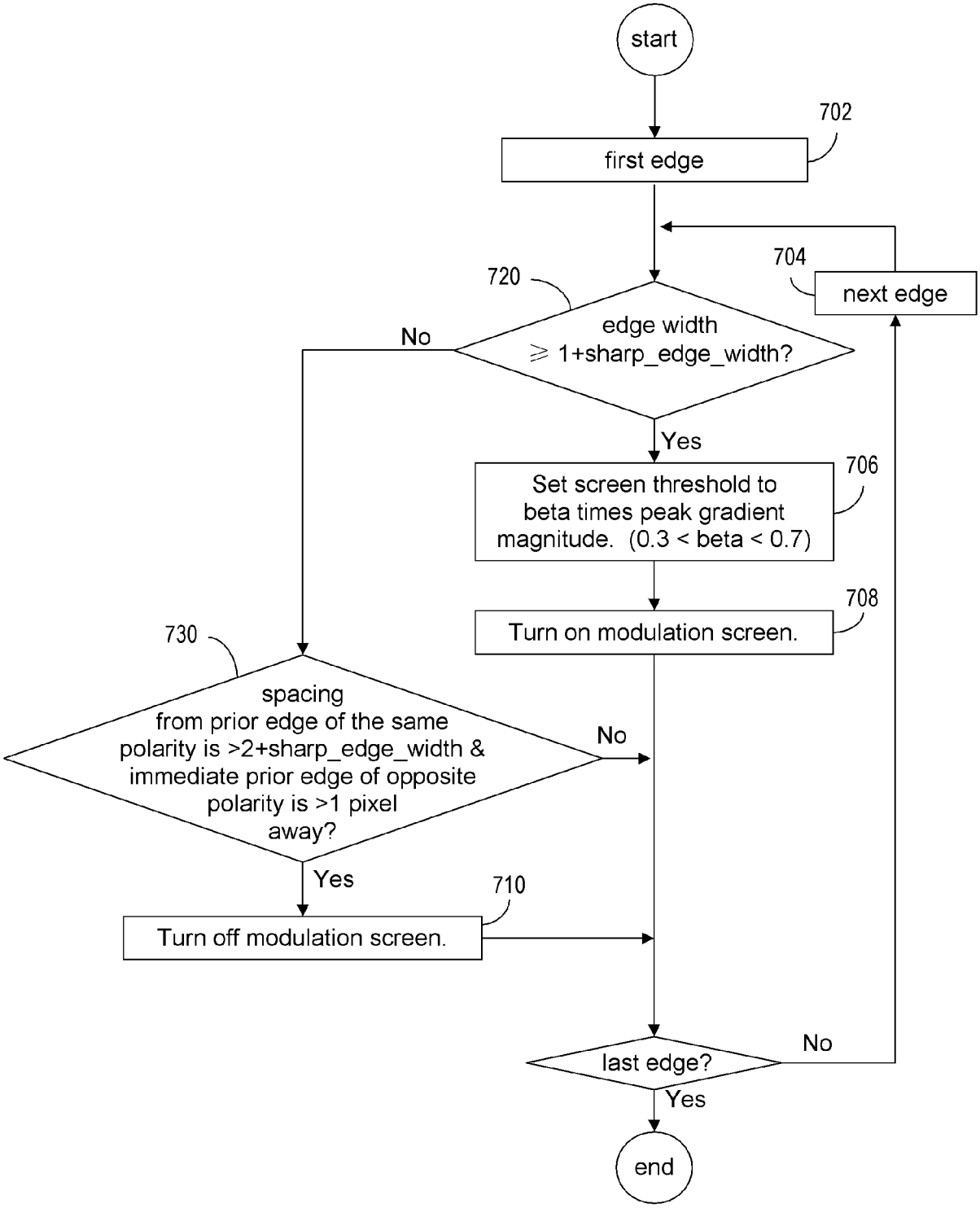
start
702
first edge
704
next edge
720
edge width
≥ 1+sharp_edge_width?
No
Yes
706
Set screen threshold to
beta times peak gradient
magnitude. (0.3 < beta < 0.7)
708
Turn on modulation screen.
730
spacing
from prior edge of the same
polarity is >2+sharp_edge_width &
immediate prior edge of opposite
polarity is >1 pixel
away?
No
Yes
710
Turn off modulation screen.
last edge?
No
Yes
end

FIG. 10

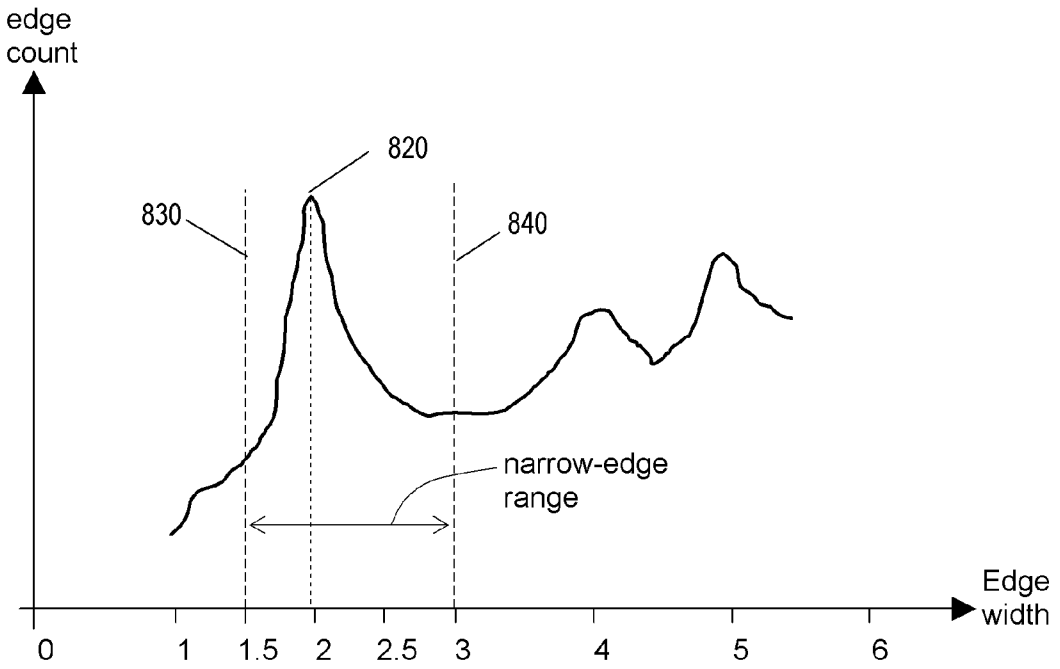
edge
count
820
830
840
narrow-edge
range
Edge
width
0
1
1.5
2
2.5
3
4
5
6

FIG. 11

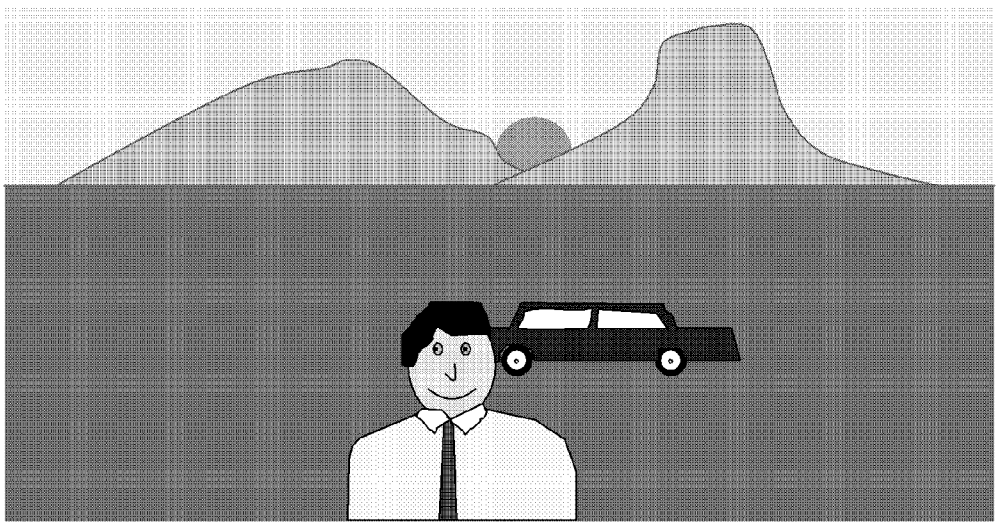

FIG. 12

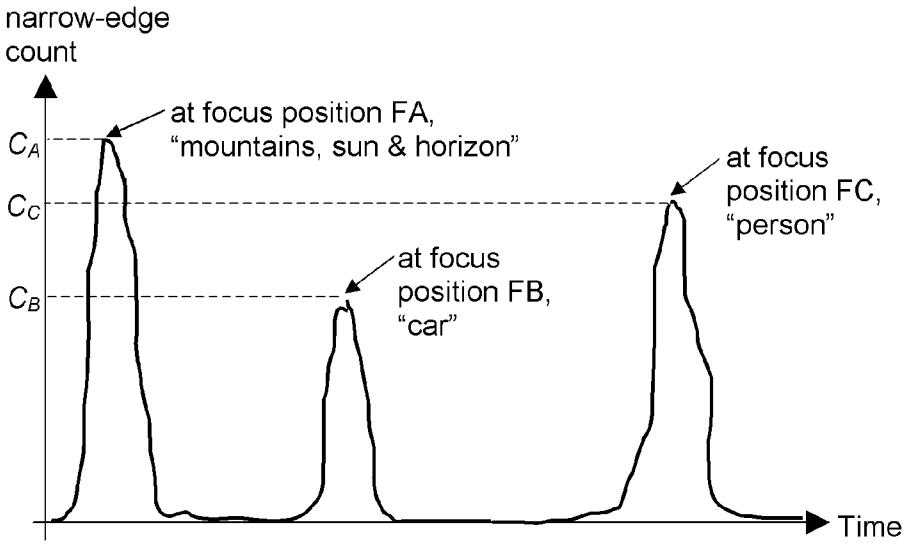
narrow-edge
count
C_A
C_C
C_B
at focus position FA,
"mountains, sun & horizon"
at focus
position FB,
"car"
at focus
position FC,
"person"
Time

FIG. 13

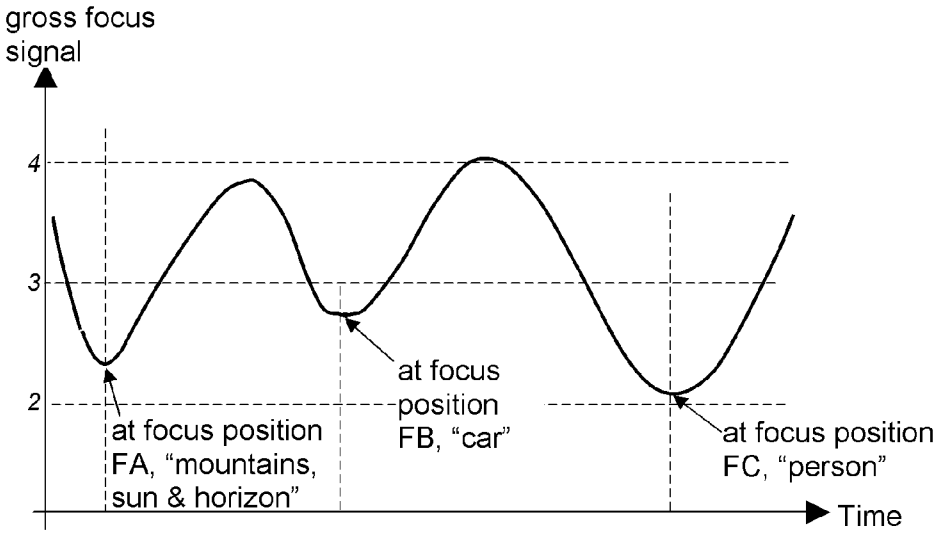
gross focus
signal
4
3
2
at focus position
FA, "mountains,
sun & horizon"
at focus
position
FB, "car"
at focus position
FC, "person"
Time

FIG. 14

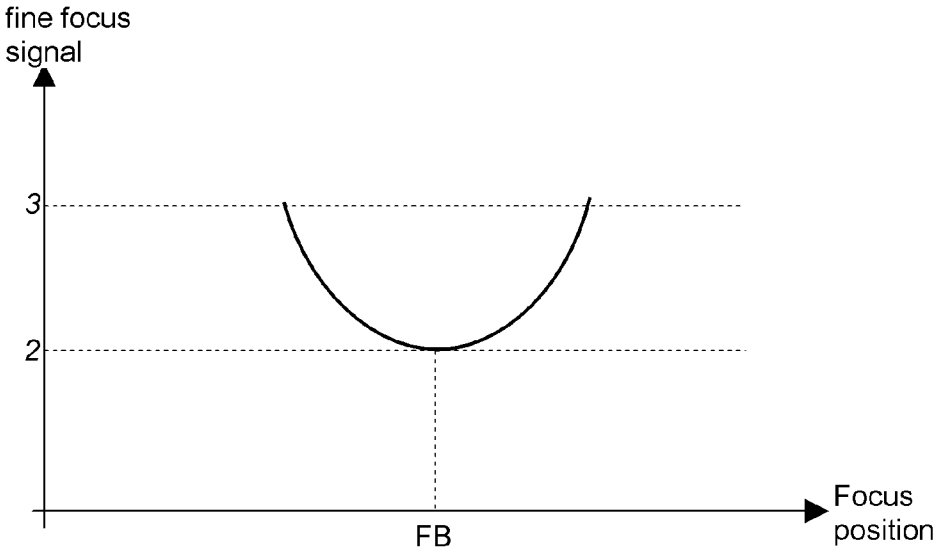
fine focus
signal
3
2
FB
Focus
position

FIG. 15

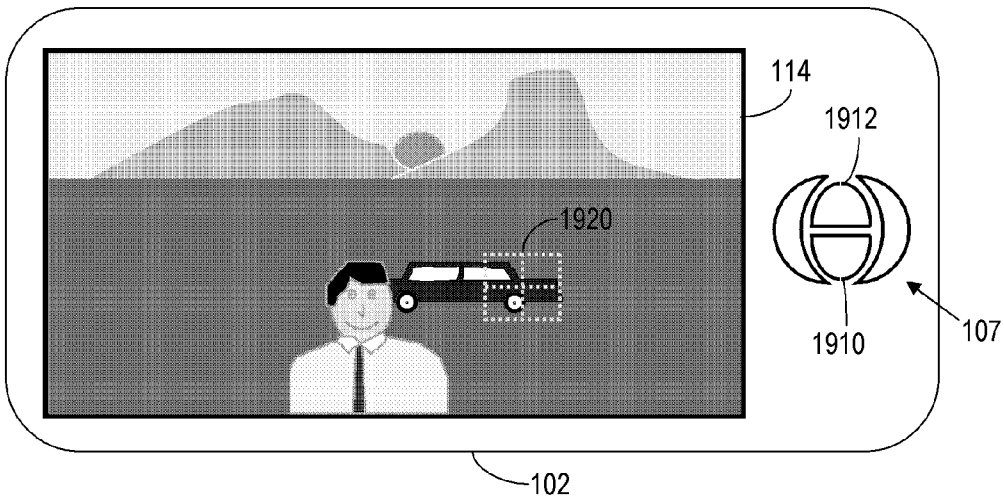
114
1912
1920
1910
107
102

FIG. 16

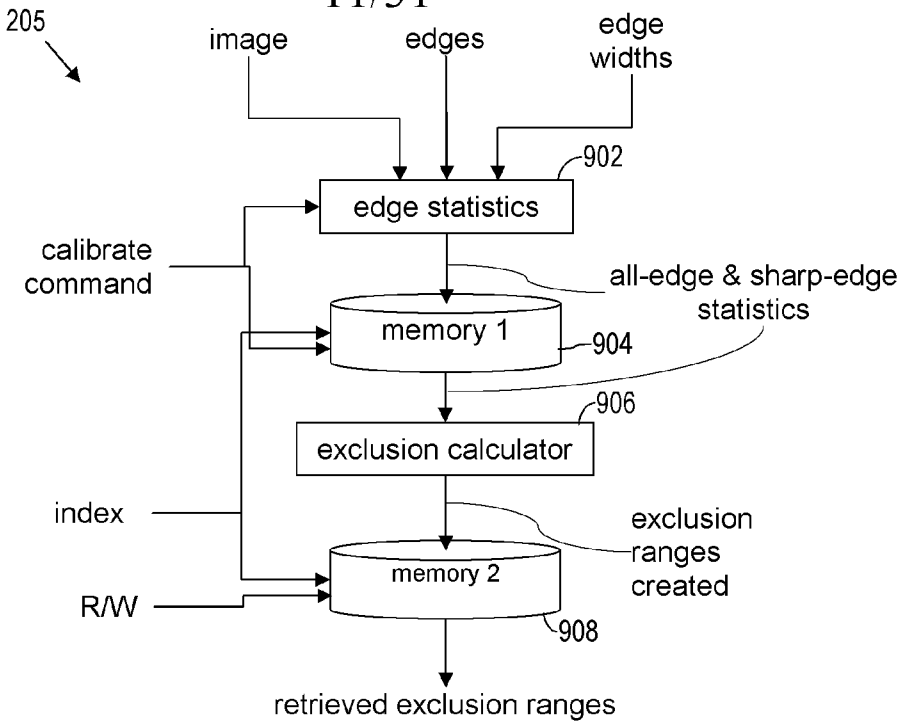
205
image
edges
edge widths
902
edge statistics
calibrate command
all-edge & sharp-edge statistics
memory 1
904
906
exclusion calculator
index
exclusion ranges created
memory 2
R/W
908
retrieved exclusion ranges

FIG. 17

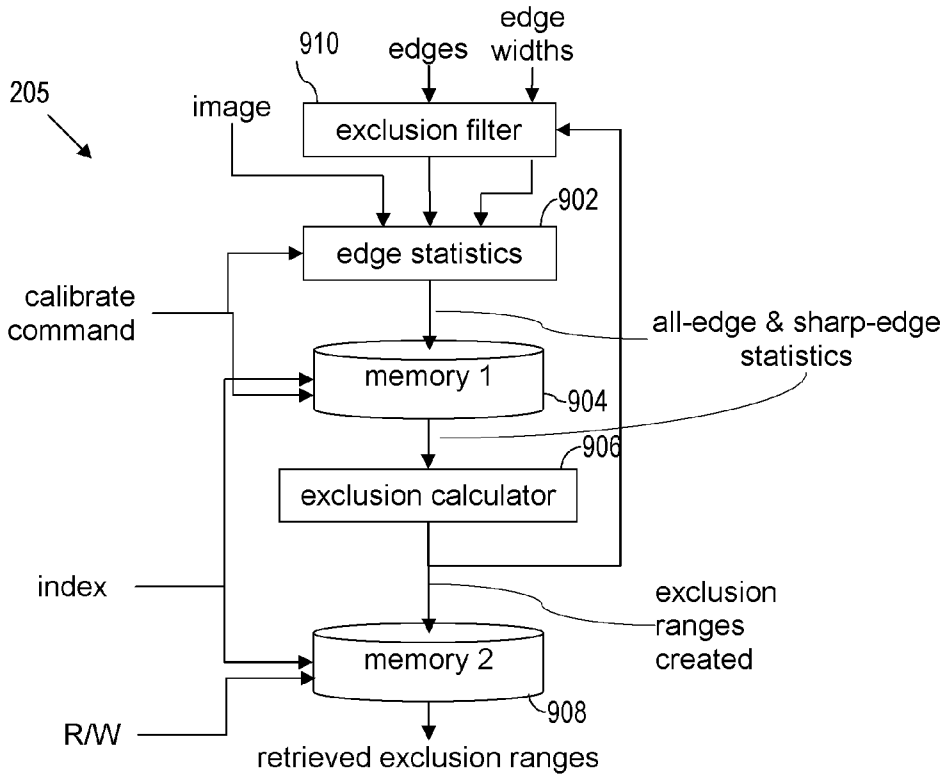
205
910
edges
edge widths
image
exclusion filter
902
edge statistics
calibrate command
all-edge & sharp-edge statistics
memory 1
904
906
exclusion calculator
index
exclusion ranges created
memory 2
R/W
908
retrieved exclusion ranges

FIG. 18

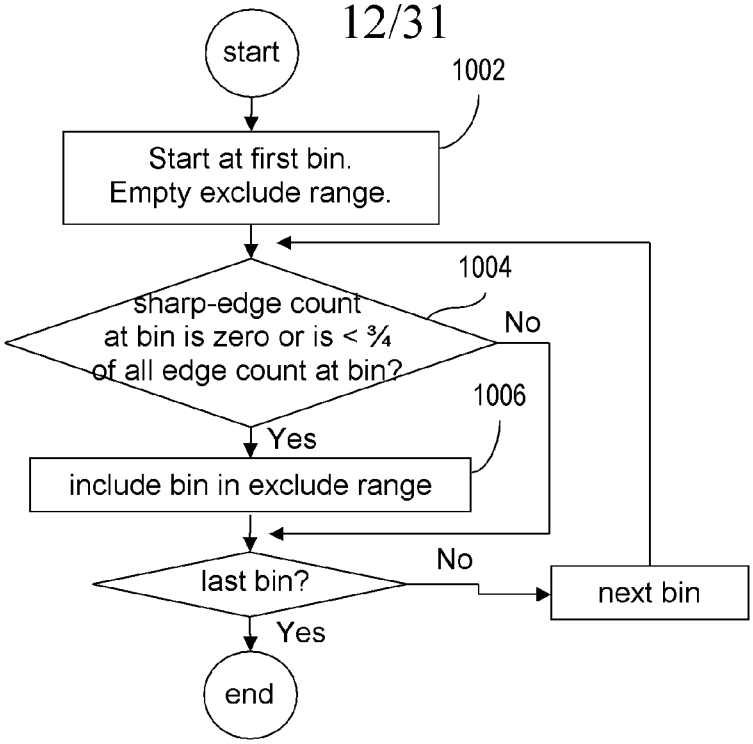
start
1002
Start at first bin.
Empty exclude range.
1004
sharp-edge count
at bin is zero or is < ¾
of all edge count at bin?
No
1006
Yes
include bin in exclude range
last bin?
No
next bin
Yes
end

FIG. 19

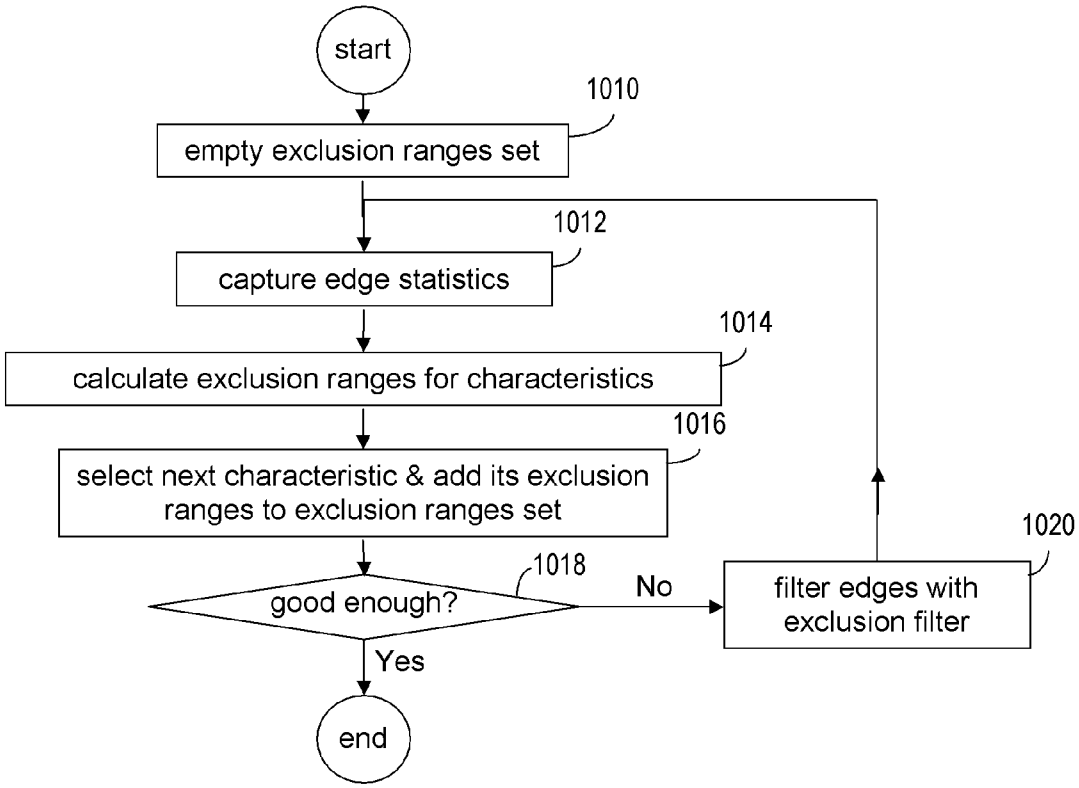
start
1010
empty exclusion ranges set
1012
capture edge statistics
1014
calculate exclusion ranges for characteristics
1016
select next characteristic & add its exclusion
ranges to exclusion ranges set
1020
1018
good enough?
No
filter edges with
exclusion filter
Yes
end

FIG. 20

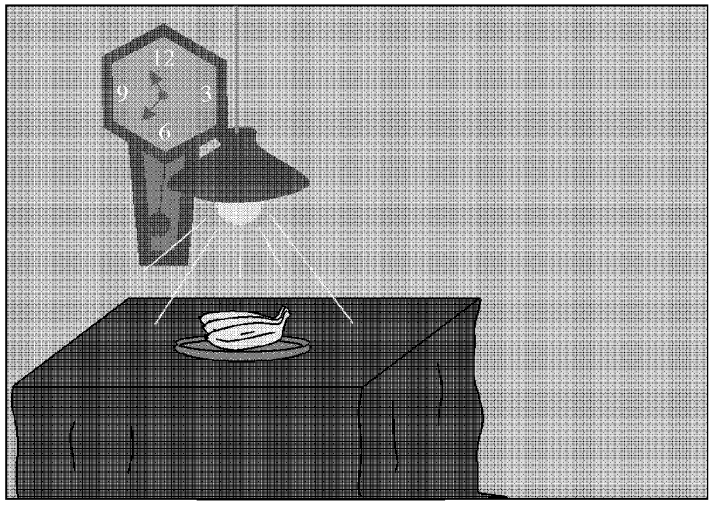

FIG. 21

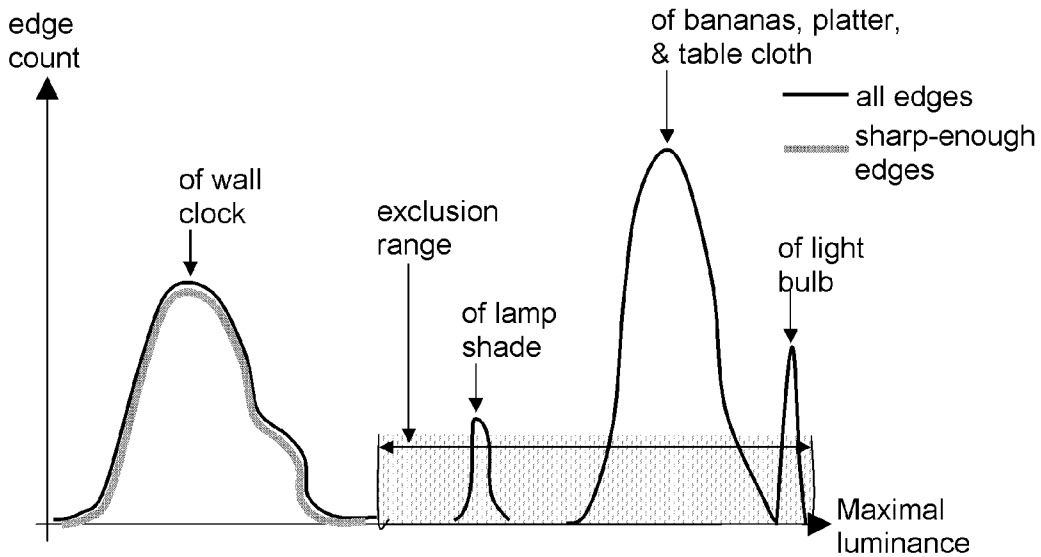
edge
count
of wall
clock
exclusion
range
of lamp
shade
of bananas, platter,
& table cloth
all edges
sharp-enough
edges
of light
bulb
Maximal
luminance

FIG. 22

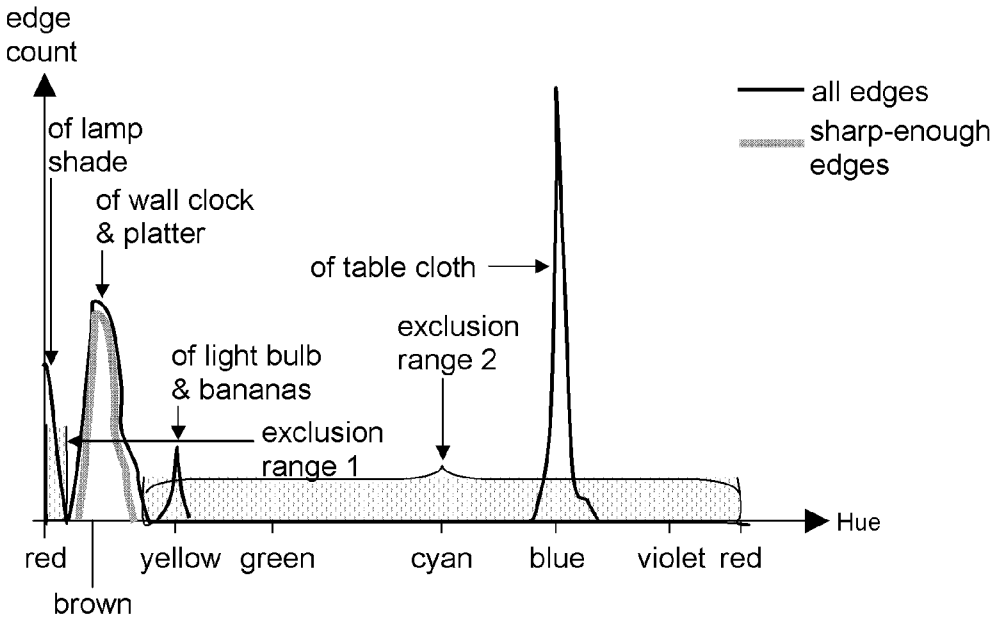
edge
count
all edges
sharp-enough
edges
of lamp
shade
of wall clock
& platter
of table cloth
exclusion
range 2
of light bulb
& bananas
exclusion
range 1
Hue
red
yellow
green
cyan
blue
violet
red
brown

FIG. 23

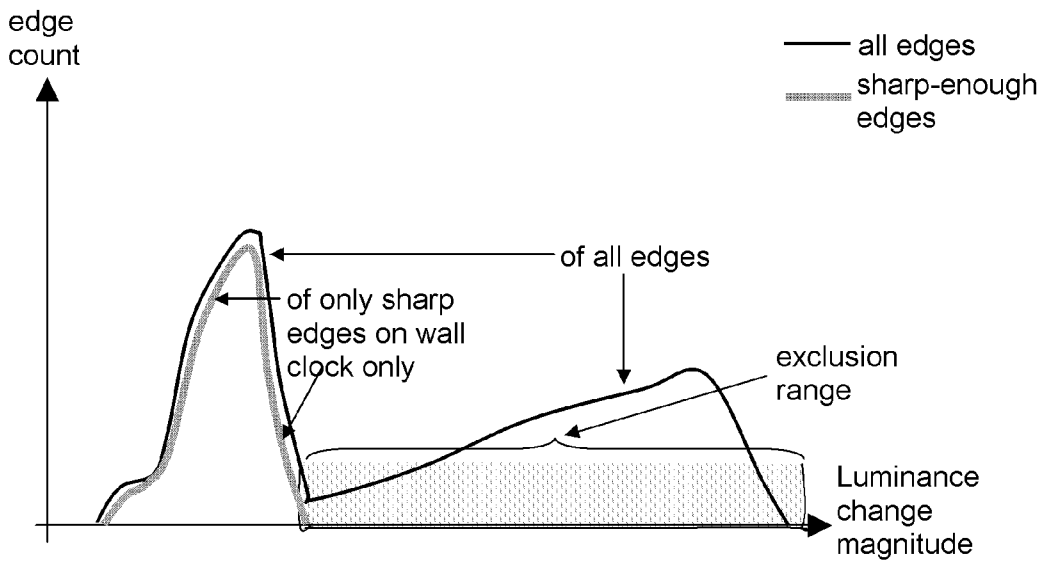
edge
count
all edges
sharp-enough
edges
of all edges
of only sharp
edges on wall
clock only
exclusion
range
Luminance
change
magnitude

FIG. 24

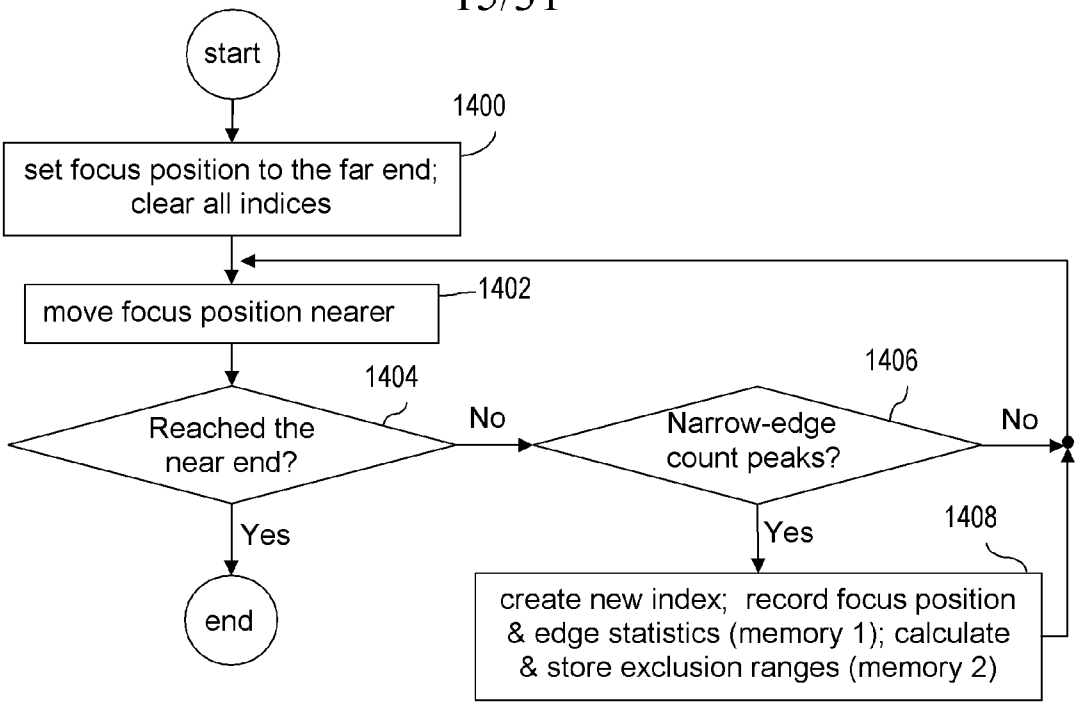
start
1400
set focus position to the far end; clear all indices
move focus position nearer
1402
1404
Reached the near end?
No
1406
Narrow-edge count peaks?
No
Yes
Yes
1408
end
create new index; record focus position & edge statistics (memory 1); calculate & store exclusion ranges (memory 2)

FIG. 25

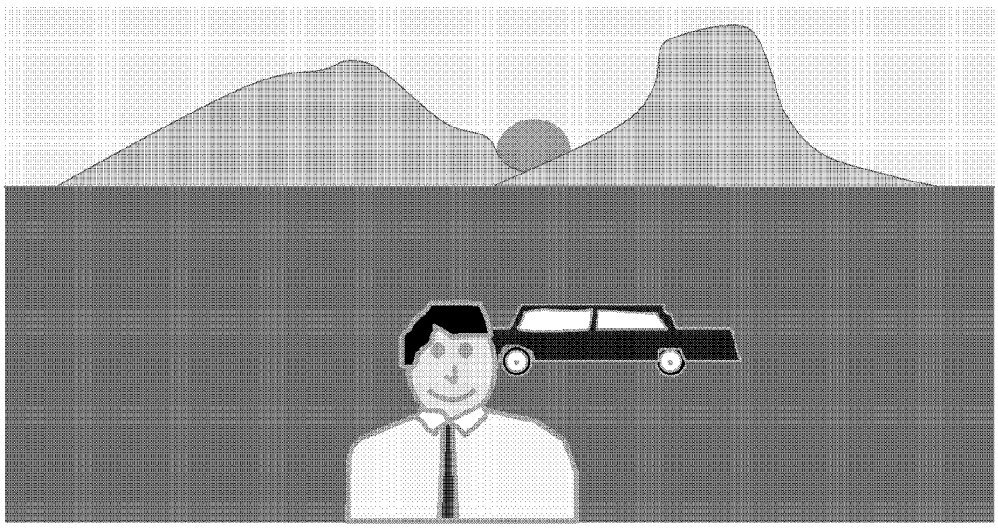

FIG. 26

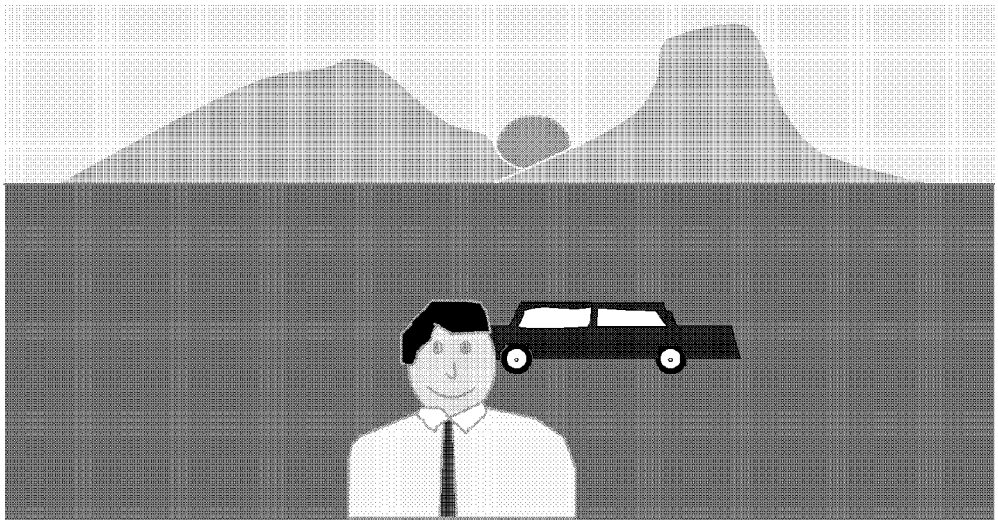

FIG. 27

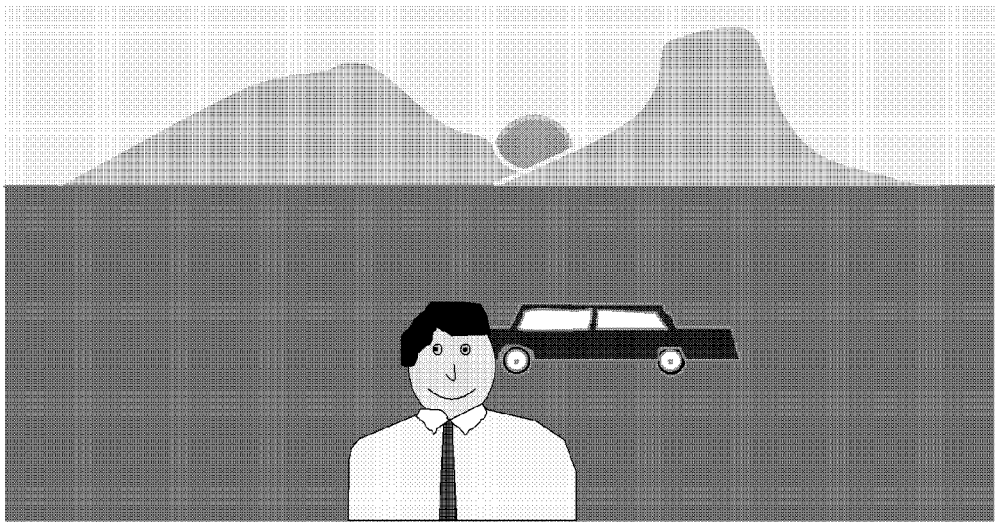

FIG. 28

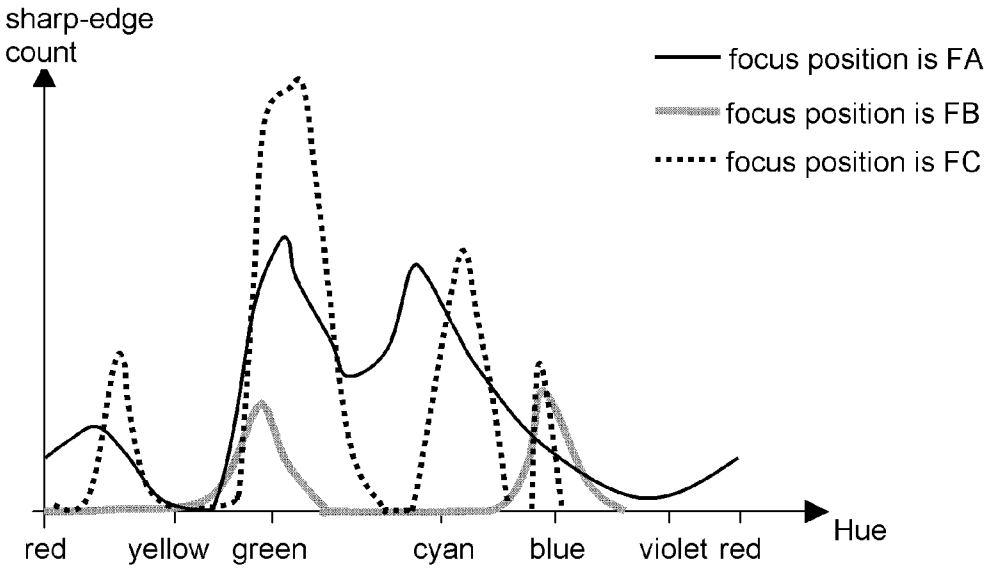

FIG. 29

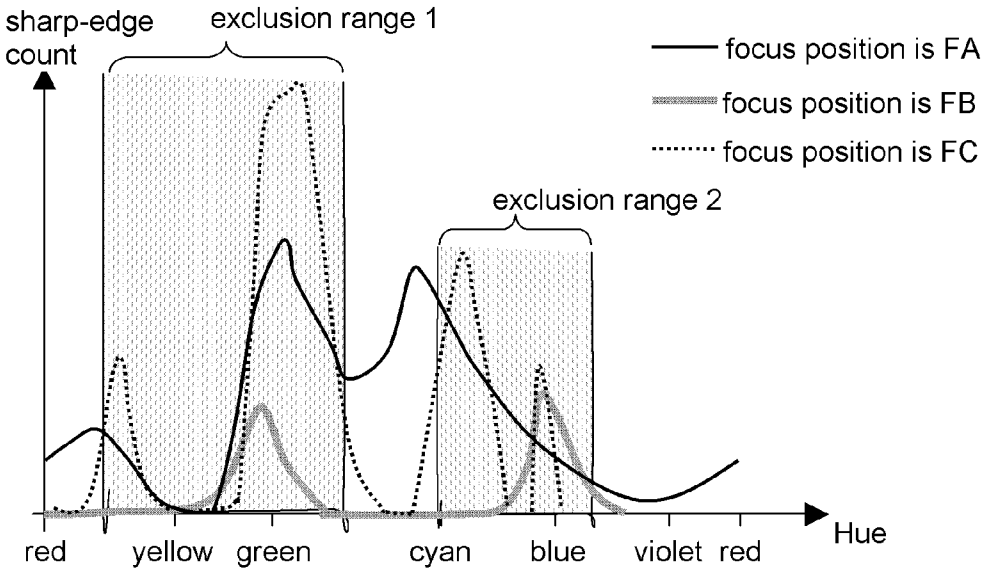

FIG. 30A

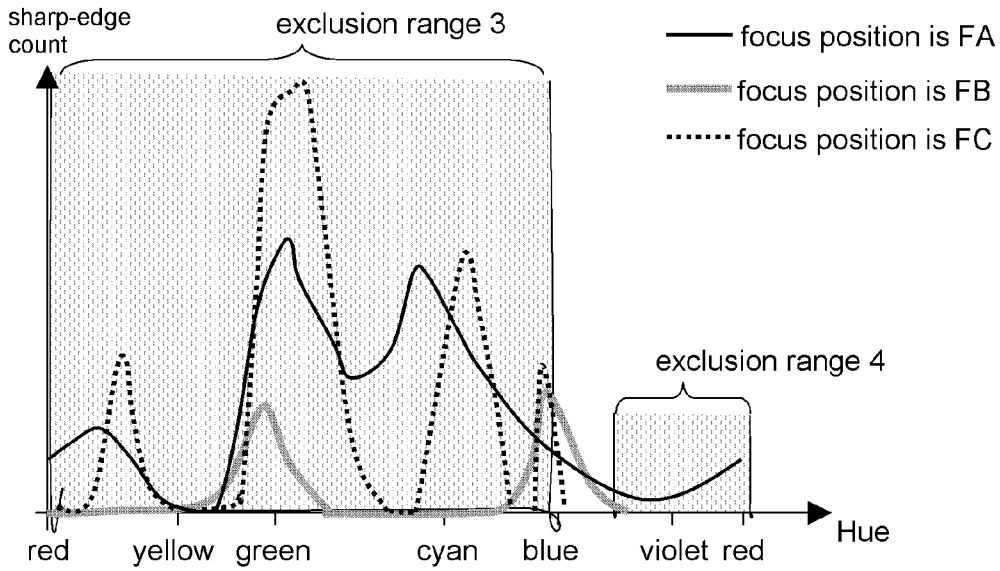

FIG. 30B

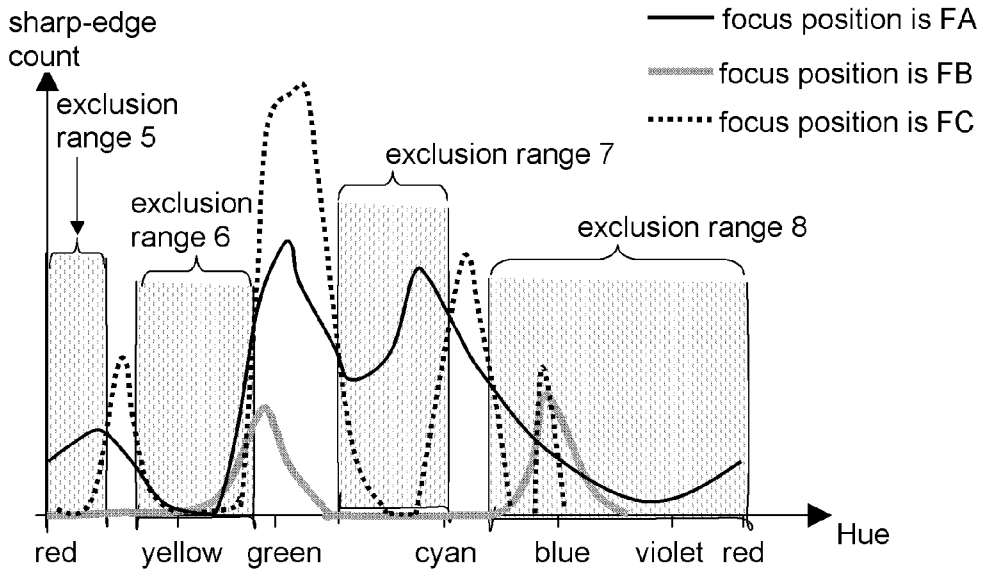

FIG. 30C

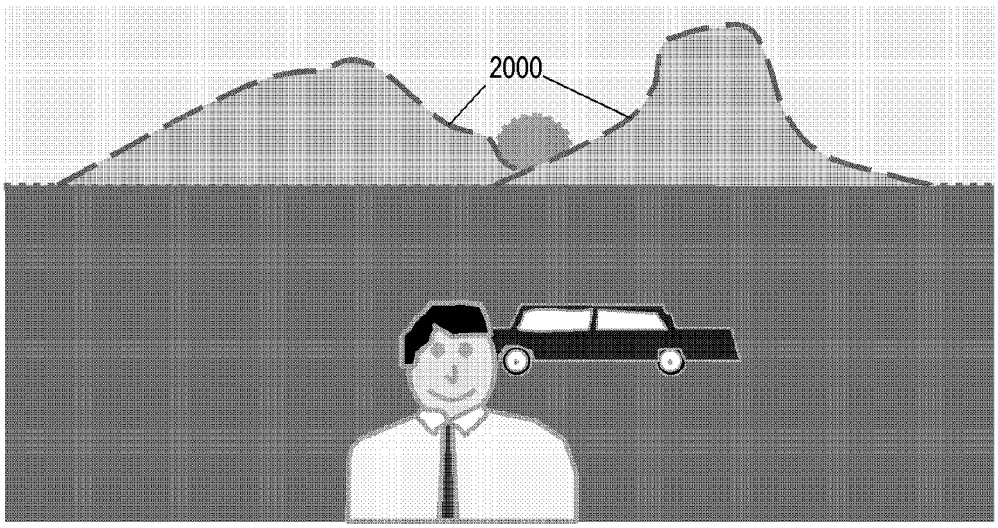

FIG. 31

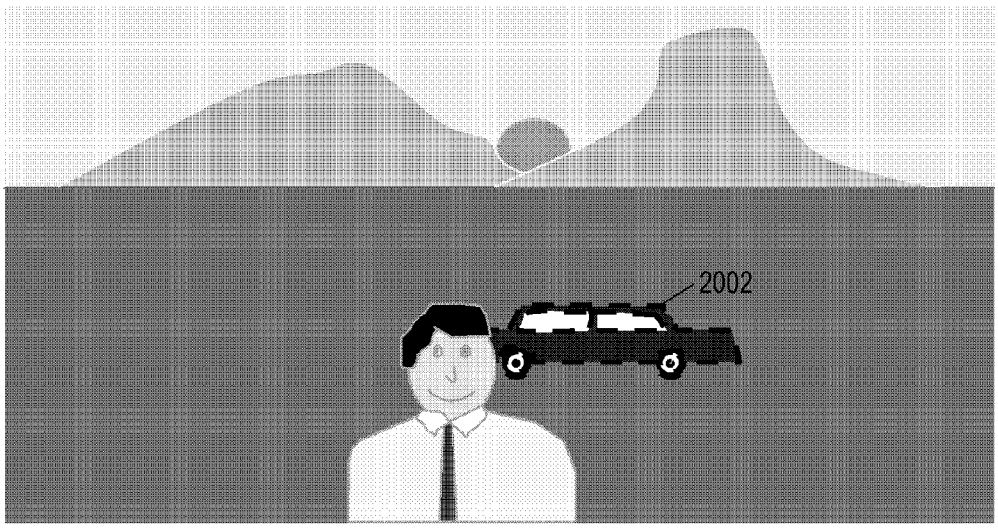

FIG. 32

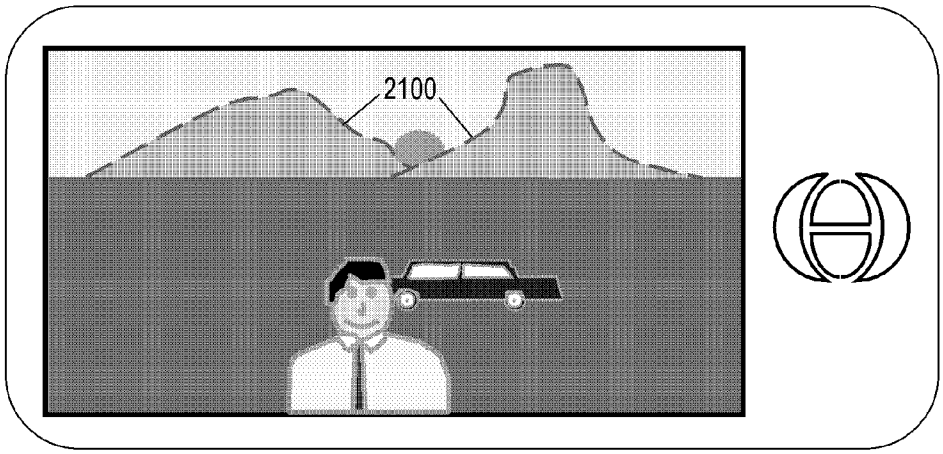
2100

FIG. 33

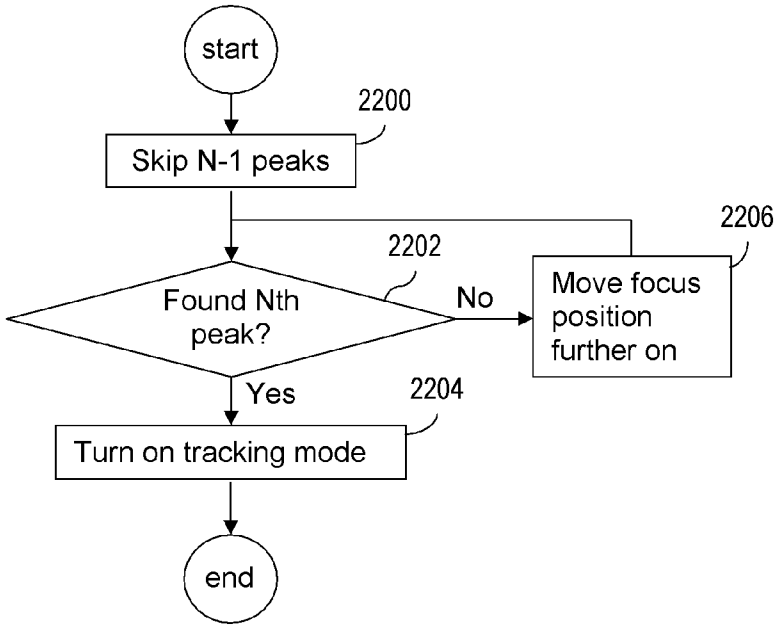
start
2200
Skip N-1 peaks
2206
2202
Found Nth peak?
No
Move focus position further on
Yes
2204
Turn on tracking mode
end

FIG. 34

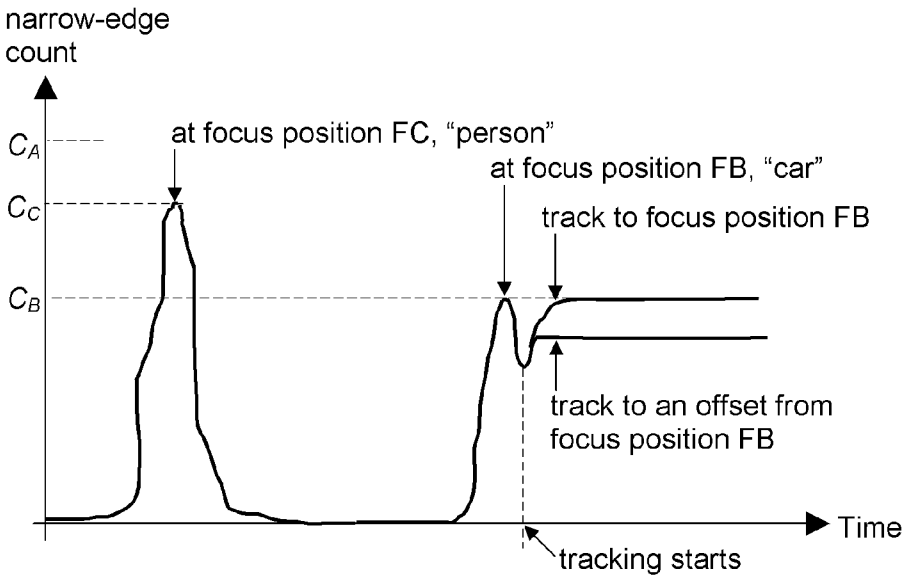
narrow-edge
count
C_A
C_C
C_B
at focus position FC, "person"
at focus position FB, "car"
track to focus position FB
track to an offset from
focus position FB
Time
tracking starts

FIG. 35

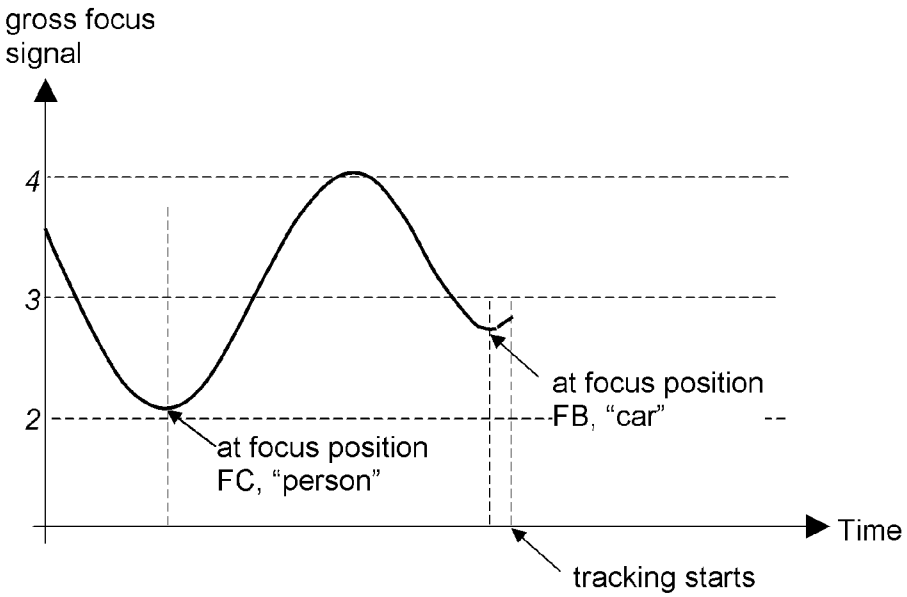
gross focus
signal
4
3
2
at focus position
FB, "car"
at focus position
FC, "person"
Time
tracking starts

FIG. 36

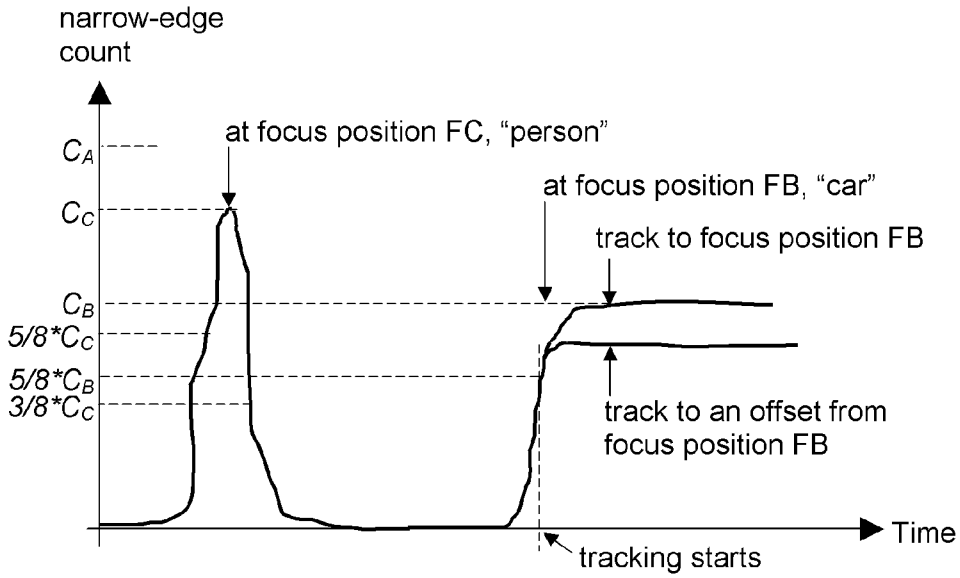
narrow-edge count
C_A
C_C
C_B
5/8*C_C
5/8*C_B
3/8*C_C
at focus position FC, "person"
at focus position FB, "car"
track to focus position FB
track to an offset from focus position FB
Time
tracking starts

FIG. 37

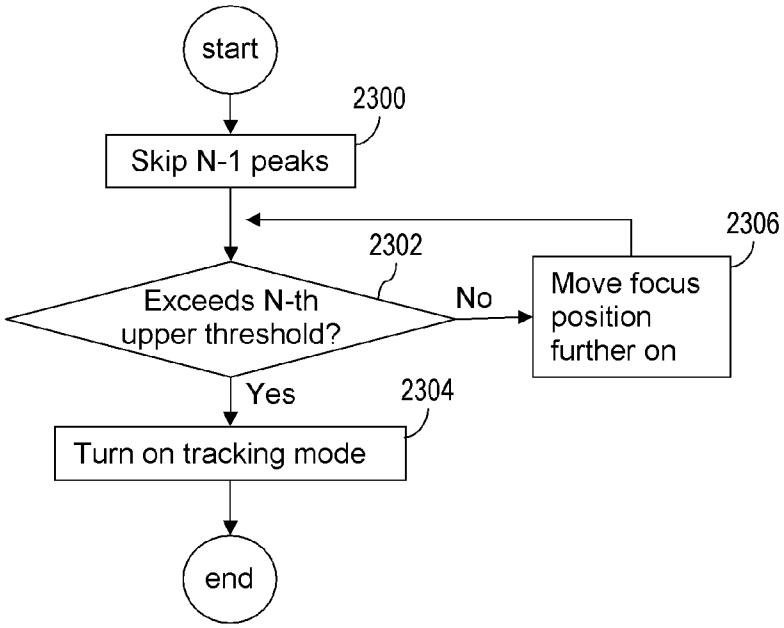
start
2300
Skip N-1 peaks
2302
Exceeds N-th upper threshold?
No
2306
Move focus position further on
Yes
2304
Turn on tracking mode
end

FIG. 38

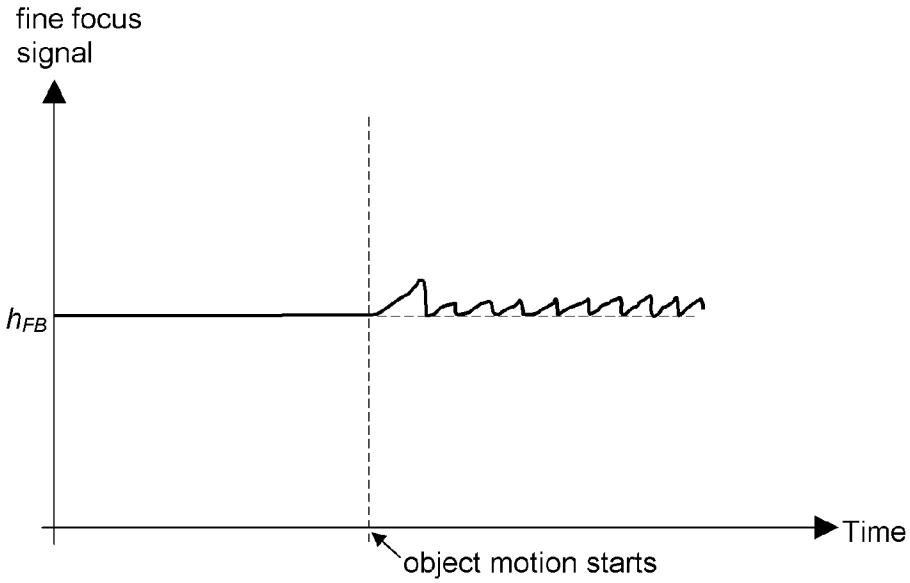
fine focus
signal
h_{FB}
Time
object motion starts

FIG. 39

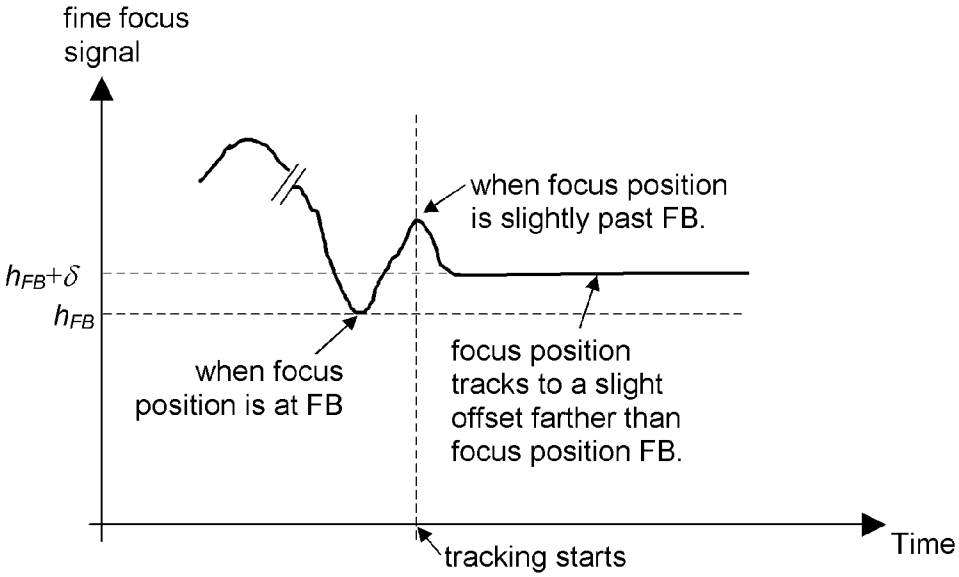
fine focus
signal
when focus position
is slightly past FB.
$h_{FB}+\delta$
h_{FB}
when focus
position is at FB
focus position
tracks to a slight
offset farther than
focus position FB.
Time
tracking starts

FIG. 40

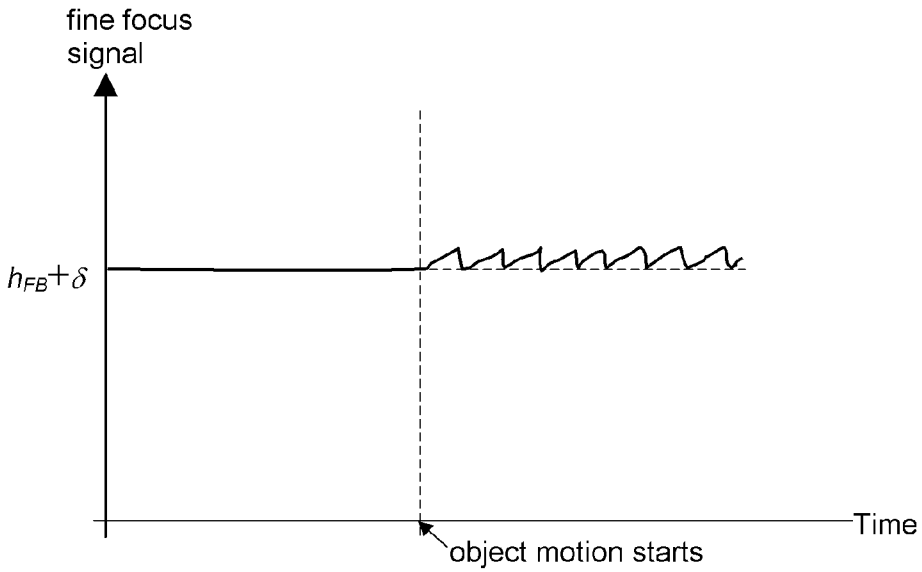

FIG. 41

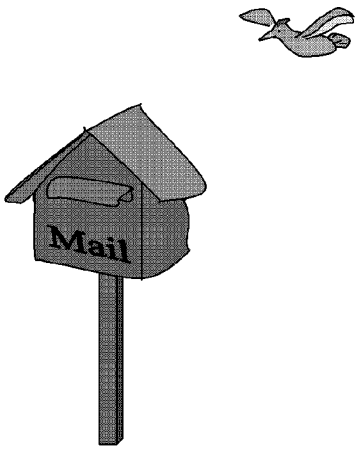

FIG. 42A

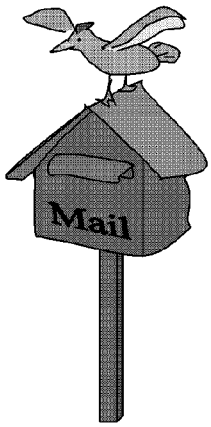

FIG. 42B

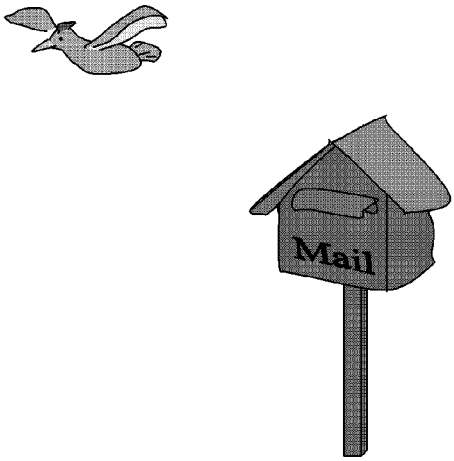

FIG. 42C

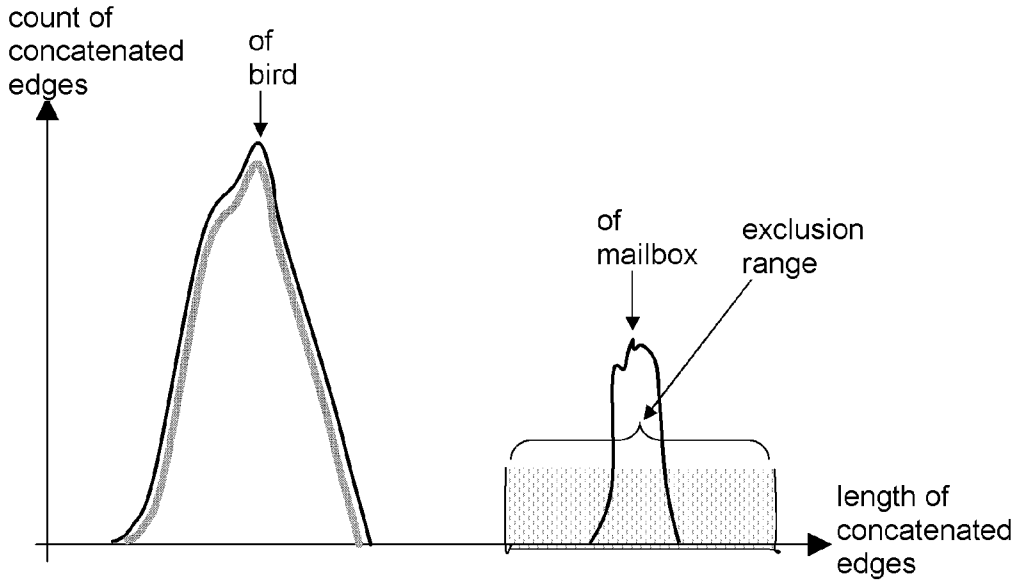
count of concatenated edges
of bird
of mailbox
exclusion range
length of concatenated edges

FIG. 43

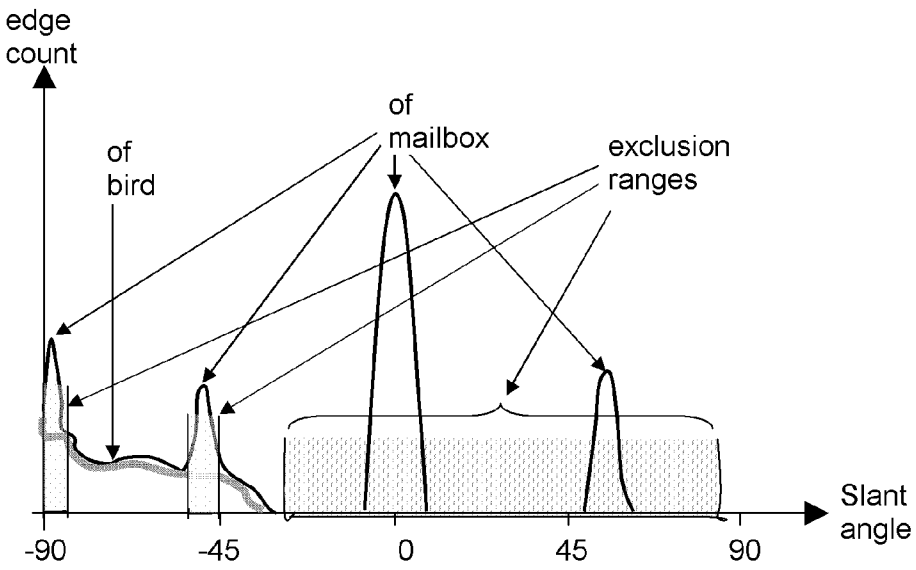
edge count
of bird
of mailbox
exclusion ranges
Slant angle
-90
-45
0
45
90

FIG. 44

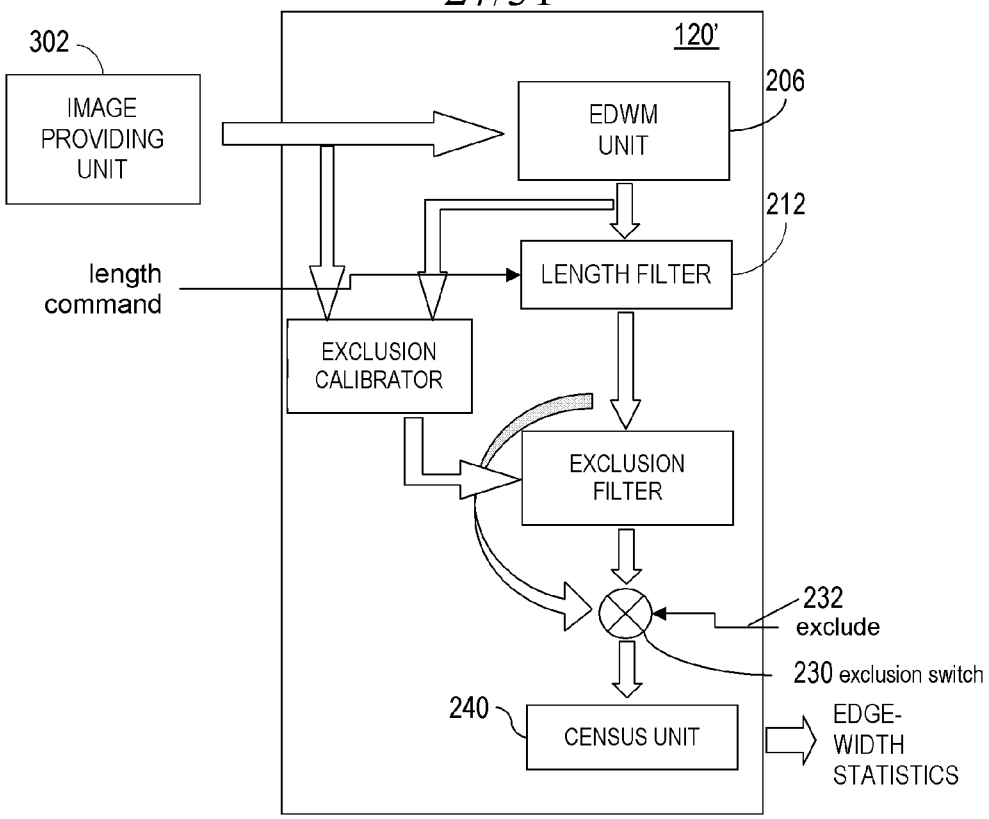
302
IMAGE PROVIDING UNIT
120'
206
EDWM UNIT
212
length command
LENGTH FILTER
EXCLUSION CALIBRATOR
EXCLUSION FILTER
232
exclude
230 exclusion switch
240
CENSUS UNIT
EDGE-WIDTH STATISTICS

FIG. 45

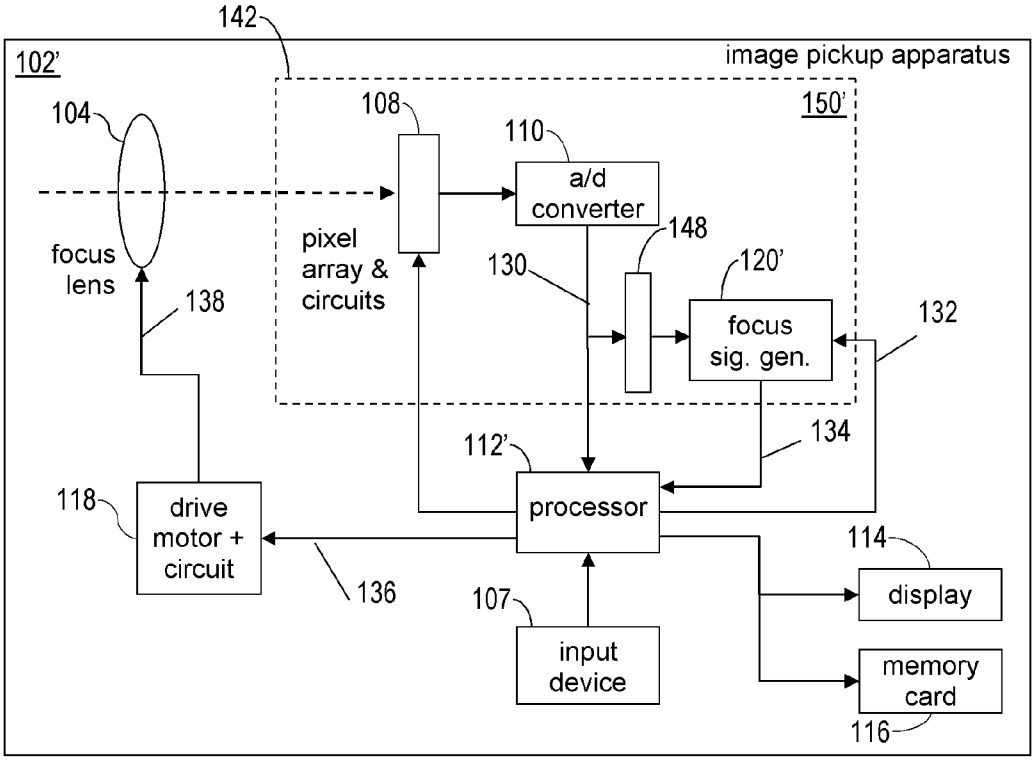
142
102'
image pickup apparatus
150'
104
108
110
a/d converter
148
120'
focus lens
pixel array & circuits
130
138
focus sig. gen.
132
134
112'
processor
118
drive motor + circuit
136
114
display
107
input device
memory card
116

FIG. 46

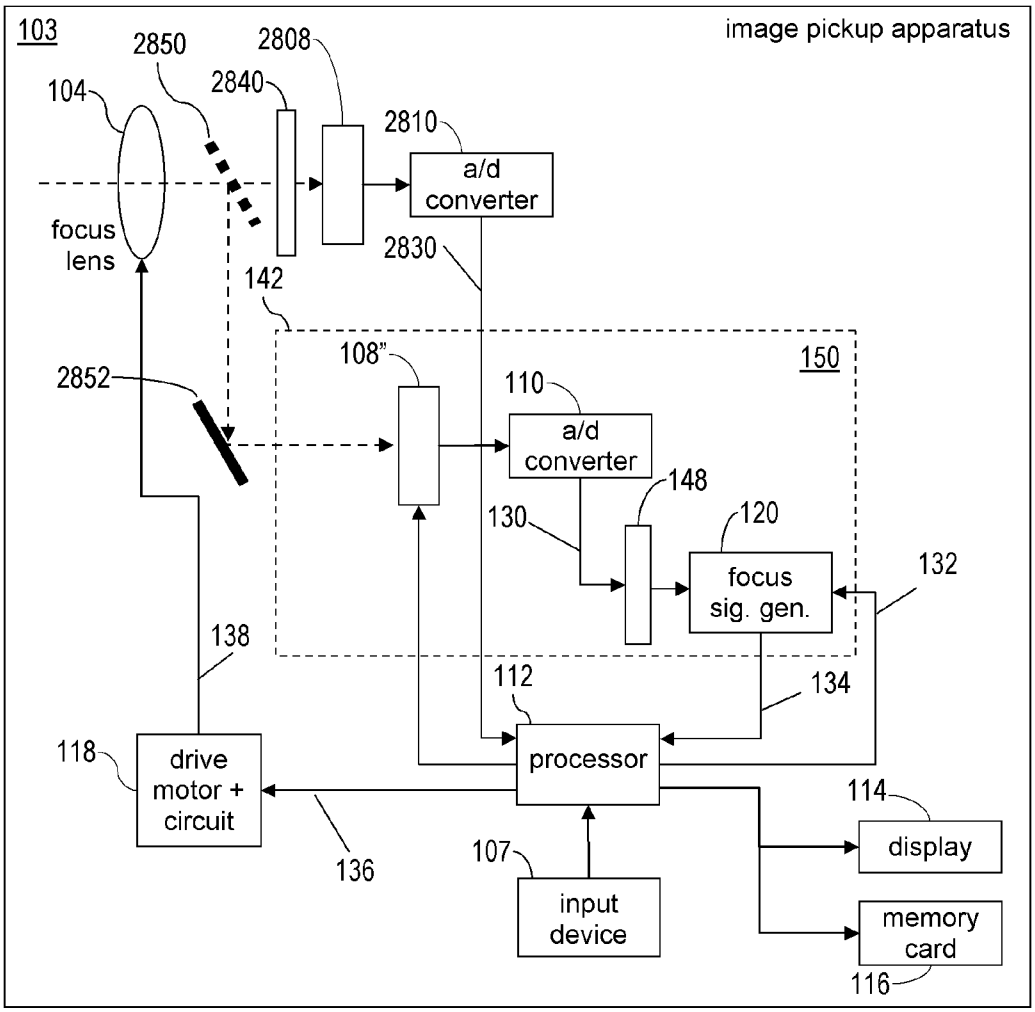
103
image pickup apparatus
2850
2808
2840
104
2810
a/d converter
focus lens
2830
142
150
108"
110
2852
a/d converter
148
130
120
focus sig. gen.
132
138
112
134
118
drive motor + circuit
processor
114
display
107
input device
memory card
136
116

FIG. 47

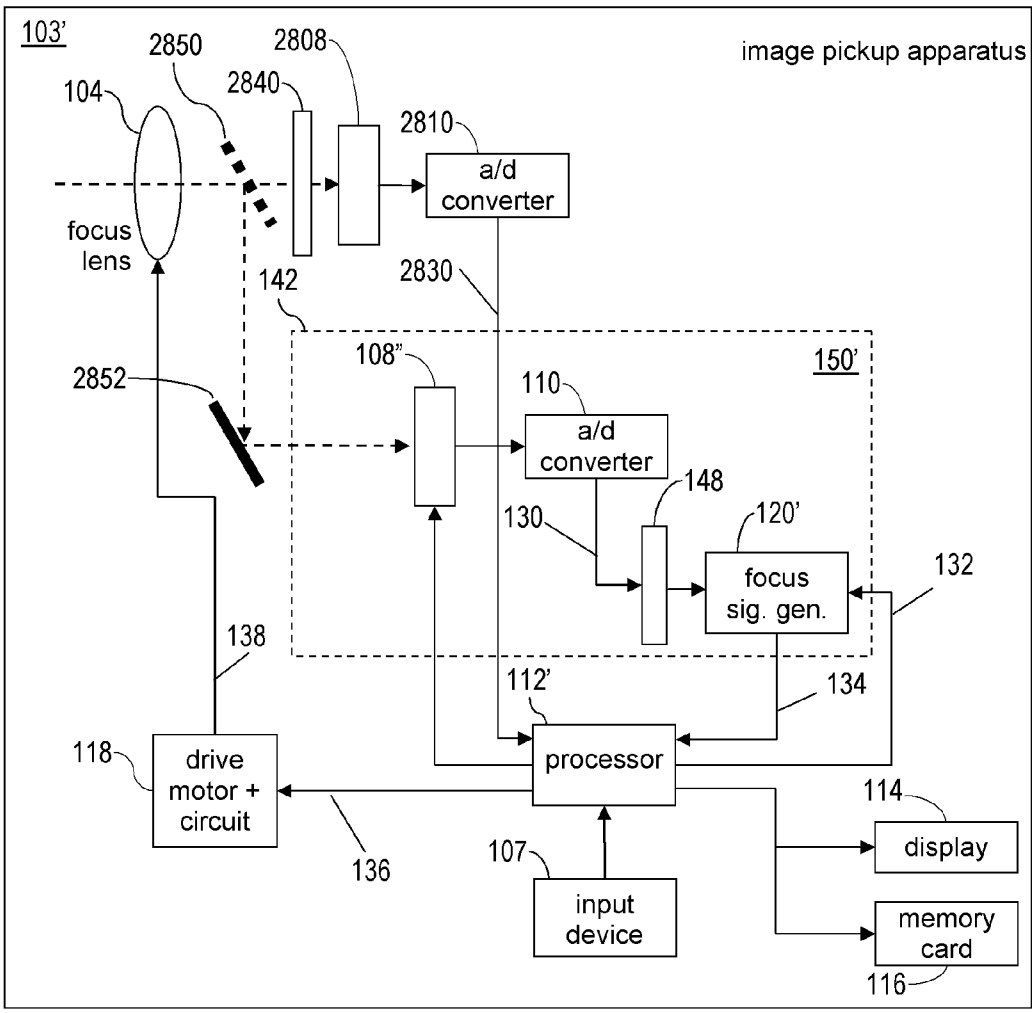
103'
image pickup apparatus
2850
2808
2840
104
2810
a/d converter
focus lens
142
2830
150'
108"
2852
110
a/d converter
148
130
120'
focus sig. gen.
132
138
112'
134
118
drive motor + circuit
processor
114
display
107
input device
memory card
136
116

FIG. 48

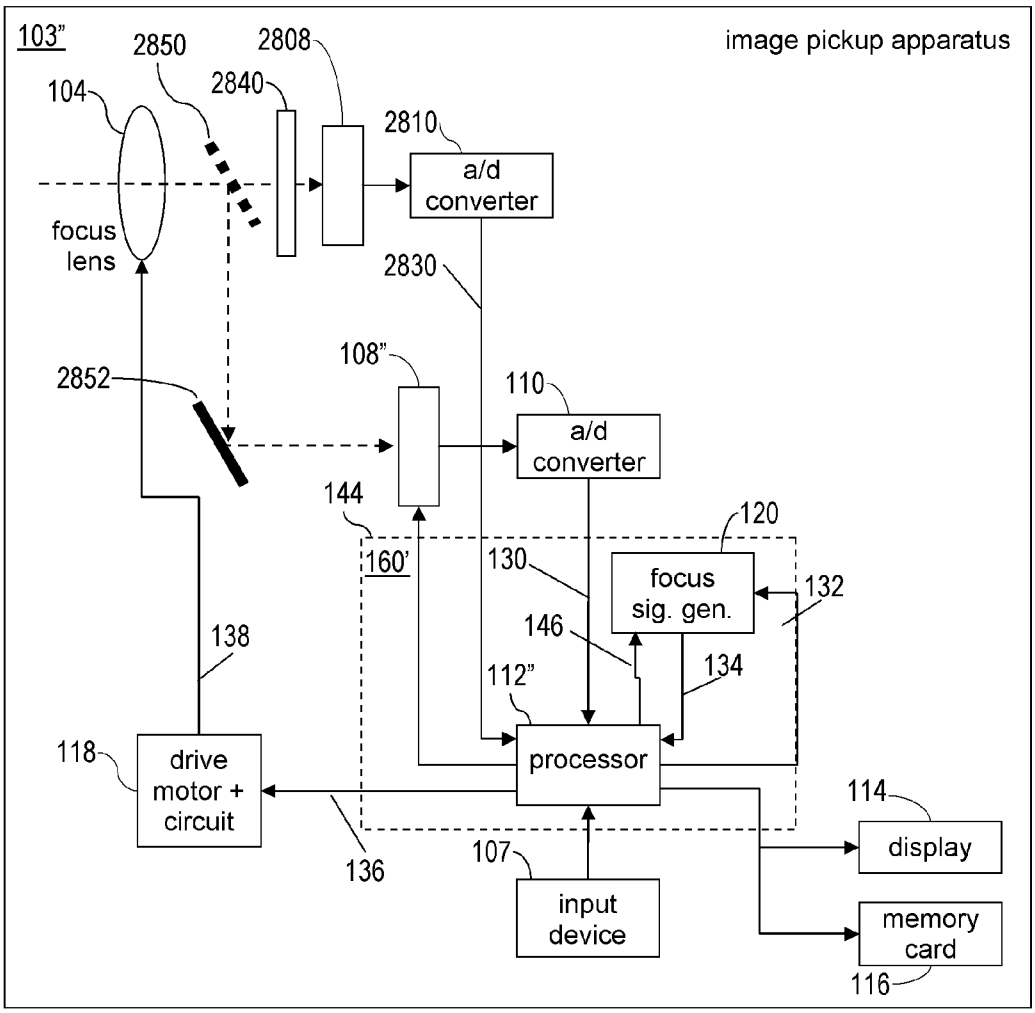
103"
image pickup apparatus
2850
2808
2840
104
2810
a/d converter
focus lens
2830
108"
2852
110
a/d converter
144
120
160'
130
focus sig. gen.
132
146
138
134
112"
118
drive motor + circuit
processor
114
display
107
input device
memory card
136
116

FIG. 49

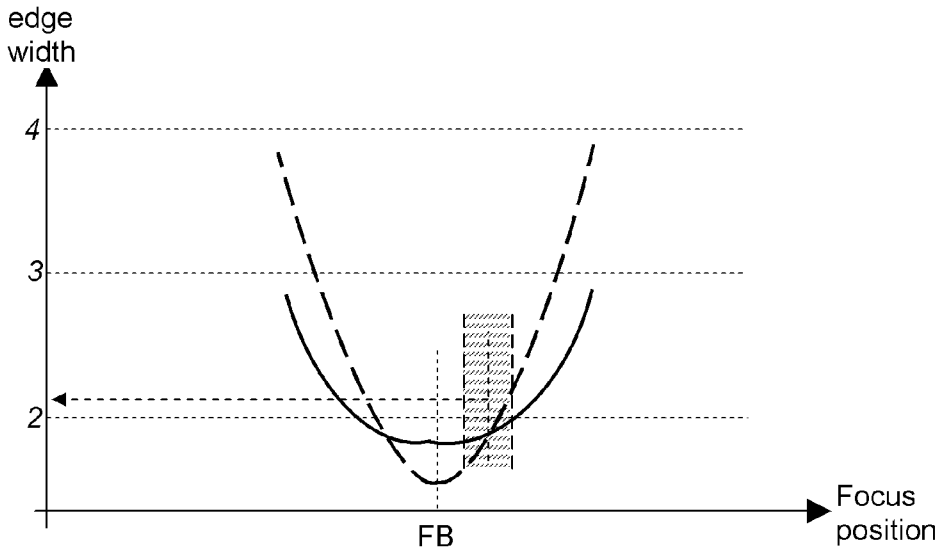

FIG. 50

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/052375

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N5/232 G02B7/36 G03B13/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N G02B G03B

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/102963 A1 (YEO YUNN-EN [SG] ET AL) 23 April 2009 (2009-04-23) claim 1	1-3
X	US 2006/290932 A1 (KAWANAMI NAOTO [JP]) 28 December 2006 (2006-12-28) paragraphs [0005], [0023] - [0036]	1-3
X	EP 0 926 526 A2 (CANON KK [JP]) 30 June 1999 (1999-06-30) paragraphs [0021], [0 90] - [0010]; figure 14	1
X	US 2005/189419 A1 (IGARASHI TAKASHI [JP] ET AL) 1 September 2005 (2005-09-01) paragraphs [0069] - [0085]; figures 5A,5B	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2010	24/11/2010

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2010/052375

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-3

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3

A method for controlling image focus and providing a user interface to change a focus position

---

2. claims: 4-10

A method for generating a focus signal as a function of edge widths wherein edges are discriminated according to their sharpness.

---

3. claim: 11

A method for automatic focus control wherein the focus signal is a function of edge widths and wherein the focus signal is offset from an optimal focus signal level

---

4. claims: 12-14

A method for generating a focus signal as a function of edge widths wherein edge widths are corrected

---

5. claims: 15, 16

A method for generating a focus signal as a function of edge widths wherein contribution of narrower edges depends on the presence of a wider adjacent edge.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2010/052375

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009102963 A1	23-04-2009	CN 101849407 A	29-09-2010
		GB 2467078 A	21-07-2010
		WO 2009063326 A2	22-05-2009
US 2006290932 A1	28-12-2006	CN 1885084 A	27-12-2006
		JP 2007003785 A	11-01-2007
		KR 20060134837 A	28-12-2006
EP 0926526 A2	30-06-1999	DE 69829734 D1	19-05-2005
		DE 69829734 T2	29-09-2005
		JP 4018218 B2	05-12-2007
		JP 11190816 A	13-07-1999
		US 7071985 B1	04-07-2006
US 2005189419 A1	01-09-2005	JP 2005269604 A	29-09-2005