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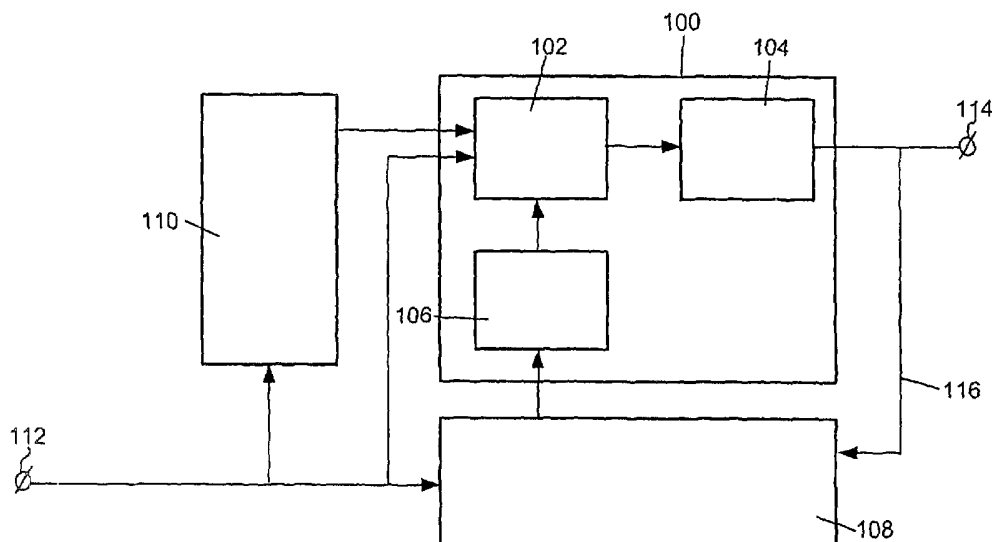
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(54) Title: UNIT FOR AND METHOD OF ESTIMATING A CURRENT MOTION VECTOR



(57) Abstract: The motion estimation unit (100) being arranged to estimate a current motion vector for a first group (212) of pixels, comprises: a generating unit (106) for generating a set of candidate motion vectors for the first group (212) of pixels, with the candidate motion vectors being extracted from a set of previously estimated motion vectors; a match error unit (102) for calculating match errors of respective candidate motion vectors; and a selection unit (104) for selecting the current motion vector from the candidate motion vectors. The motion estimation unit (100) is arranged to modulate the match error on basis of a result of segmentation for the first image, into segments of pixels, whereby the result of segmentation is related to a probability that the first group of pixels and a second group of pixels, on basis of which the candidate motion vector is determined, both correspond to the same segment.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Unit for and method of estimating a current motion vector

The invention relates to a motion estimation unit for estimating a current motion vector for a group of pixels of an image, comprising:

- generating means for generating a set of candidate motion vectors for the first group of pixels, the candidate motion vectors being extracted from a set of previously estimated motion vectors;
- a match error unit for calculating match errors of respective candidate motion vectors, the match error of a first one of the candidate motion vectors being based on a first component and a second component, the first component corresponding to a comparison of values of pixels of the first group of pixels with values of pixels of a second group of pixels of a second image, and the second component depending on a relation between the first group of pixels and a third group of pixels for which a first one of the previously estimated motion vectors has been estimated, the first one of the candidate motion vectors being based on the first one of the previously estimated motion vectors; and
- a selection unit for selecting the current motion vector from the candidate motion vectors by means of comparing the match errors of the respective candidate motion vectors.

The invention further relates to a method of estimating a current motion vector for a group of pixels of an image, comprising:

- generating a set of candidate motion vectors for the first group of pixels, the candidate motion vectors being extracted from a set of previously estimated motion vectors;
- calculating match errors of respective candidate motion vectors, the match error of a first one of the candidate motion vectors being based on a first component and a second component, the first component corresponding to a comparison of values of pixels of the first group of pixels with values of pixels of a second group of pixels of a second image, and the second component depending on a relation between the first group of pixels and a third group of pixels for which a first one of the previously estimated motion vectors has been estimated, the first one of the candidate motion vectors being based on the first one of the previously estimated motion vectors; and

- selecting the current motion vector from the candidate motion vectors by means of comparing the match errors of the respective candidate motion vectors.

The invention further relates to an image processing apparatus comprising:

- receiving means for receiving a signal representing a series of images;
- 5 - such a motion estimation unit; and
- a motion compensated image processing unit for determining processed images on basis of the images and the current motion vector.

10 An embodiment of the motion estimation unit of the kind described in the opening paragraph is known from the article "True-Motion Estimation with 3-D Recursive Search Block Matching" by G. de Haan et. al. in IEEE Transactions on circuits and systems for video technology, vol.3, no.5, October 1993, pages 368-379.

For many applications in video signal processing, it is necessary to know the
15 apparent velocity field of a sequence of images, known as the optical flow. This optical flow is given as a time-varying motion vector field, i.e. one motion vector field per image-pair. Notice that an image can be part of several image-pairs. In the cited article this motion vector field is estimated by dividing the image into blocks. For a set of candidate motion vectors of each block match errors are calculated and used in a minimization procedure to find the most
20 appropriate motion vector from the set of candidate motion vectors of the block.

The cited motion estimation unit relies on two basic assumptions. Firstly, objects are bigger than blocks, this means that a motion vector estimated in the neighborhood of a block will have a high correlation with the actual motion vector of this block and can therefor be used as a so-called spatial prediction, i.e. spatial candidate motion vector, for this
25 motion vector. Secondly, objects have inertia. This means that the motion of the objects does not change erratically from image to image, and the actual motion vector for the current block will have high correlation with motion vectors of corresponding blocks in previous images. Motion vectors from these blocks can be used as so-called temporal predictions, i.e. temporal candidate motion vectors, for the motion vector of the current block. In order to
30 allow updates of motion vectors, extra predictions, called random predictions, i.e. random candidate motion vectors are added which are equal to the spatial candidate motion vectors to which a small noise motion vector is added.

Since some candidate motion vector have a higher correlation to the motion vector of the current block than other candidate motion vectors, penalties are assigned to

candidate motion vectors with a lower correlation. These penalties are added to the match error of the candidate motion vector (usually a sum of absolute differences), making it harder for that candidate motion vector to be chosen as the best matching motion vector. Random candidate motion vectors are given the highest penalty, spatial candidate motion vectors the lowest, the temporal candidate motion vectors have a penalty which is between the penalties of the spatial and random candidate motion vector.

One of the problems with this motion estimation unit is that the assumption under which spatial candidate motion vector can be used, fails on object boundaries. A spatial candidate motion vector which is located in another object will have no correlation with the motion vector of the current block.

It is an object of the invention to provide a motion estimation unit of the kind described in the opening paragraph which provides more accurate motion vector fields.

This object of the invention is achieved in that the motion estimation unit is arranged to modulate the second component on basis of a result of segmentation for the first image, into segments of pixels, the result of segmentation being related to a probability that a first part of the first group of pixels and a first part of the third group of pixels both correspond to a particular one of the segments. Image segmentation is applied as a solution to the issue stated above. Image segmentation aims at dividing an image into segments in which a certain feature is constant or in between predetermined thresholds. For pixels or groups of pixels of the image, values are calculated representing probabilities of belonging to any of the segments. The feature can be anything from a simple grey value to complex texture measures combined with color information. The segmentation method, i.e. the method of extracting the segments, based on the chosen feature, can be anything from simple thresholding to watershed algorithms. Assuming that the edges of the objects in the image are a subset of the segment edges, then the motion estimation is improved in quality by using this information. Since candidate motion vectors from other objects, i.e. previously estimated motion vectors belonging to other objects, have less correlation to the current (first) group of pixels as candidate motion vectors from the same object, the penalty of a candidate motion vector of another segment as the current group of pixels should be raised. Or in other words the second component of a motion vector candidate of another segment as the current group of pixels should be increased.

Applying the result of segmentation for motion compensation is not novel. E.g. in European patent application number 01202615.9 (attorney docket PHNL010445) a hierarchical segmentation method is combined with motion estimation. However it is novel to apply the result of segmentation according to the invention: the second component is modulated on basis of the result of segmentation. The eventual match error is based on the first and second component. Hence, both the comparison of values of pixels of the first group of pixels with values of pixels of the second group of pixels of the second image and the result of segmentation are applied to calculate the match error. The advantage of the motion estimation unit according to the invention is the quality of the match errors.

An embodiment of the motion estimation unit according to the invention is arranged to modulate the second component on basis of the size of the probability. A segmentation might be binary, resulting in a label per pixel indicating whether the pixel belongs or not belongs to a particular segment. However, preferably a segmentation method provides for a pixel, or group of pixels, a probability of belonging to a particular segment. Multiple probabilities for a pixel are possible too: e.g. a first probability of 20% for belonging to segment A and a second probability of 80% for belonging to segment B. This embodiment according to the invention is arranged to apply the actual probability to modulate the second component. For instance, if the probability of not belonging to the same object is relatively high then the second components should be relatively high as well and vice versa. The advantage of this approach is a more accurate second component and thus a more accurate match error.

Another embodiment of the motion estimation unit according to the invention is arranged to modulate the second component on basis of a ratio of a first number of pixels of the first part of the first group of pixels and a second number of pixels of the first group of pixels. Segmentation and motion estimation might be strongly correlated. That means that e.g. the segmentation is done for groups of pixels and the motion estimation is performed on the same groups of pixels. However segmentation and motion estimation might be performed independently. In that case the segmentation is e.g. performed on a pixel base and the motion estimation on a block base. As a consequence, it might be that the first part of the pixels of a group of pixels, to be used for motion estimation, are classified as belonging to segment A and another part of pixels is classified as belonging to segment B. In this latter case an "overall probability of belonging to segment A" can be calculated for the group of pixels on basis of the ratio of the number of pixels of the first part and the number of pixels of the

entire group of pixels. The advantage of this approach is a more accurate second component and thus a more accurate match error.

In an embodiment of the motion estimation unit according to the invention the first group of pixels is a block of pixels. In principle, the group of pixels might have any
5 shape, even irregular. A block based shape is preferred because this reduces the complexity of the design of the motion estimation unit.

In another embodiment of the motion estimation unit according to the invention, the selection unit is arranged to select, from the set of candidate motion vectors, a particular motion vector as the current motion vector, if the corresponding match error is the
10 smallest of the match errors. This is a relatively easy approach for selecting the current motion vector from the set of candidate motion vectors.

In another embodiment of the motion estimation unit according to the invention, the match error unit is designed to calculate the match error of the first one of the candidate motion vectors by means of subtracting luminance values of pixels of the first
15 group of pixels from luminance values of pixels of the second group of pixels of the second image. Preferably the sum of absolute luminance differences (SAD) is calculated. The SAD is a relatively reliable measure for correlation which can be calculated relatively fast.

It is a further object of the invention to provide a method of the kind described in the opening paragraph which provides more accurate motion vector fields.

20 This object of the invention is achieved in modulating the second component on basis of a result of segmentation for the first image, into segments of pixels, the result of segmentation being related to a probability that a first part of the first group of pixels and a first part of the third group of pixels both correspond to a particular one of the segments.

It is advantageous to apply an embodiment of the motion estimation unit
25 according to the invention in an image processing apparatus as described in the opening paragraph. The image processing apparatus may comprise additional components, e.g. a display device for displaying the processed images or storage means for storage of the processed images. The motion compensated image processing unit might support one or more of the following types of image processing:

30 - De-interlacing: Interlacing is the common video broadcast procedure for transmitting the odd or even numbered image lines alternately. De-interlacing attempts to restore the full vertical resolution, i.e. make odd and even lines available simultaneously for each image;

- Up-conversion: From a series of original input images a larger series of output images is calculated. Output images are temporally located between two original input images;

- Temporal noise reduction. This can also involve spatial processing, resulting in spatial-temporal noise reduction; and

- Video compression, i.e. encoding or decoding, e.g. according to the MPEG standard or H26L standard.

Modifications of the image processing apparatus and variations thereof may correspond to modifications and variations thereof of the motion estimation unit described.

10

These and other aspects of the motion estimation unit, of the method and of the image processing apparatus according to the invention will become apparent from and will be elucidated with respect to the implementations and embodiments described hereinafter and with reference to the accompanying drawings, wherein:

15

Fig. 1 schematically shows a motion estimation unit in combination with an image segmentation unit;

Fig. 2 schematically shows a motion vector field; and

Fig. 3 schematically shows elements of an image processing apparatus, comprising a motion estimation unit, according to the invention.

20

Corresponding reference numerals have the same meaning in all of the Figs.

Fig. 1 schematically shows a motion estimation unit 100 in combination with an image segmentation unit 108 and a memory device 110 for storage of images. The motion estimation unit 100 is arranged to estimate a current motion vector for a first group 212 of pixels of a first image and comprises:

25

- A generating unit 106 for generating a set of candidate motion vectors for the first group 212 of pixels, with the candidate motion vectors being extracted from a set of previously estimated motion vectors;

30

- a match error unit 102 for calculating match errors of respective candidate motion vectors, with the match error of a first one of the candidate motion vectors being based on a first component and a second component; and

- a selection unit 104 for selecting the current motion vector from the candidate motion vectors by means of comparing the match errors of the respective candidate motion vectors.

The first component of the match error is calculated by means of making a comparison of values of pixels of the first group 212 of pixels with values of pixels of a second group of pixels of a second image. In this case the first component of the match error corresponds to the SAD: sum of absolute luminance differences between pixels in a block of the first image, and the pixels of a block in a reference image, i.e. the second image, shifted by the candidate motion vector. If the reference image and the first image directly succeed each other the SAD can be calculated with:

$$SAD(x, y, d_x, d_y, n) := \sum_{i=0}^N \sum_{j=0}^M |Y(x+i, y+j, n) - Y(x+d_x+i, y+d_y+j, n+1)| \quad (1)$$

Here (x, y) is the position of the block, (d_x, d_y) is a motion vector, n is the image number, N and M are the width and height of the block, and $Y(x, y, n)$ is the value of the luminance of a pixel at position (x, y) in image n .

The motion estimation unit 100 is arranged to modulate the second component on basis of a result of segmentation for the first image, into segments of pixels. First it is assumed that the segmentation unit 108 is arranged to perform segmentation on a block base. During image segmentation every block $B(x, y)$ is assigned a label l_k corresponding to the segment S_k it belongs to. This information is stored in the image segmentation mask $M(x, y)$. In order to reduce the spatial consistency of the motion estimation unit on object boundaries, the second component C_2 is modulated according to:

$$C_2 = \begin{cases} c_{low} & \text{if } M(x, y) = M(x_p, y_p) \\ c_{high} & \text{if } \textit{Otherwise} \end{cases} \quad (2)$$

where c_{low} is a small value in order to enforce spatial consistency, c_{high} is a high value in order to discourage consistency across objects, (x, y) is the position of the current block and (x_p, y_p) is the position of the other block of pixels, i.e. the block of pixels for which the motion vector has been estimated and on which the motion vector candidate is based. In this case there are two different values for the second component C_2 :

- c_{low} if the result of segmentation yields that the current block and the other block both belong to the same segment S_k ; and

- c_{high} if the result of segmentation yields that the current block and the other block do not belong to the same segment S_k .

- 5 The match error $ME(x, y, d_x, d_y, n)$ of a particular motion vector candidate is calculated by summation of the first component and the second component of the particular motion vector candidate.

$$ME(x, y, d_x, d_y, n) = SAD(x, y, d_x, d_y, n) + C_2(x, y, d_x, d_y, n) \quad (3)$$

- 10 Next it is assumed that the segmentation unit 108 is arranged to perform segmentation on a pixel base. That means that to each pixel a probability of belonging to segment S_k is assigned. The motion estimation is still on block base, i.e. motion vectors are estimated for blocks of pixels. The second component is based on the probability that pixels of the current block and pixels of the other block belong to the same segment S_k for $k \in K$. S_k is one out of the set of segments. The second component C_2 can be calculated with

- 15 Equation 4:

$$C_2 = C / \sum_{k=0}^K \frac{\sum_{i=0}^N \sum_{j=0}^M P((x+i, y+j) \in S_k)}{N * M} * \frac{\sum_{i=0}^N \sum_{j=0}^M P((x_p+i, y_p+j) \in S_k)}{N * M}, (4)$$

with C a constant. If the probability that pixels of the current block belong to

$$\text{segment } S_k, \text{ i.e. } \frac{\sum_{i=0}^N \sum_{j=0}^M P((x+i, y+j) \in S_k)}{N * M}$$

and the probability that pixels of the other block belong to

20 segment S_k , i.e. $\frac{\sum_{i=0}^N \sum_{j=0}^M P((x_p+i, y_p+j) \in S_k)}{N * M}$

are relatively high, then the second component C_2 is relatively low.

- It will be clear that both the value of the probability of belonging to a particular segment S_k per pixel is relevant and the number of pixels having a certain probability. In the case of a binary segmentation, only the number of pixels of the part of a block which is located in a segment S_k has to be counted, since the probability of belonging to a particular segment S_k is equal for these pixels: i.e. 100%.
- 25

In Fig.1 a connection 116 is depicted from the output 114 of the motion estimation unit 100 to the segmentation unit 108. This connection 116 is optional. By means of this connection 116, motion estimation results, e.g. a motion vector field, can be applied for segmentation of an image into segments of pixels. This might be for the same image as
5 for which the motion estimation is performed or for another image of the series of images. Besides that, it is also possible that a result of segmentation of a particular image is used for the motion estimation of an image pair which does not comprise the particular image but another image of the series of images.

The match error unit 102, the selection unit 104 and the generating unit 106 of
10 the motion estimation unit 100 may be implemented using one processor. Normally, these functions are performed under control of a software program product. During execution, normally the software program product is loaded into a memory, like a RAM, and executed from there. The program may be loaded from a background memory, like a ROM, hard disk, or magnetically and/or optical storage, or may be loaded via a network like Internet.
15 Optionally an application specific integrated circuit provides the disclosed functionality.

Fig. 2 schematically shows a part of a motion vector field 200, i.e. a motion vector field under construction, of an image representing a scene with a white background in front of which a ball 202 is moving in an opposite direction related to the background. Assume that for a number of blocks 204-210 of pixels motion vectors 214-226 have been
20 estimated and that for the current block 212 of pixels the motion vector has to be estimated. For this estimation, a set of candidate motion vectors 214-220 is created on basis of the motion vectors 214-226 previously calculated for the blocks 204-210 of pixels. In Fig. 1 can be seen that the current block 212 of pixels is located in the segment that corresponds to the ball 202. Also block 204 of pixels is located in the segment that corresponds to the ball 202.
25 However block 210 of pixels corresponds to the background and the blocks 206 and 208 partly belong to the ball 202 and partly belong to the background. The second components for the respective candidate motion vectors will depend on the respective number of pixels of the blocks 204-210 which are labeled, by means of segmentation, as belonging to the segment representing the ball 202. Consequently the second component of the match error of
30 the candidate motion vector 220 derived from block 204 of pixels will be the lowest and the second component of the match error of the candidate motion vector 218 derived from block 210 of pixels will be the lowest.

Fig. 3 schematically shows elements of an image processing apparatus 300 comprising:

- receiving unit 302 for receiving a signal representing images to be displayed after some processing has been performed. The signal may be a broadcast signal received via an antenna or cable but may also be a signal from a storage device like a VCR (Video Cassette Recorder) or Digital Versatile Disk (DVD). The signal is provided at the input
5 connector 310.

- a processing unit 304 comprising a motion estimation unit 100 and segmentation unit 108 as described in connection with Fig. 1;
- a motion compensated image processing unit 306; and
- a display device 308 for displaying the processed images. This display device
10 308 is optional.

The motion compensated image processing unit 306 requires images and motion vectors as its input. The motion compensated image processing unit 306 might support one or more of the following types of image processing: de-interlacing; up-conversion; temporal noise reduction; and video compression.

15 It should be noted that the above-mentioned embodiments illustrate rather than limit the invention and that those skilled in the art will be able to design alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be constructed as limiting the claim. The word 'comprising' does not exclude the presence of elements or steps not listed in a
20 claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention can be implemented by means of hardware comprising several distinct elements and by means of a suitable programmed computer. In the unit claims enumerating several means, several of these means can be embodied by one and the same item of hardware.

CLAIMS:

1. A motion estimation unit for estimating a current motion vector for a first group of pixels of a first image, comprising:
 - generating means for generating a set of candidate motion vectors for the first group of pixels, the candidate motion vectors being extracted from a set of previously estimated motion vectors;
 - 5 - a match error unit for calculating match errors of respective candidate motion vectors, the match error of a first one of the candidate motion vectors being based on a first component and a second component, the first component corresponding to a comparison of values of pixels of the first group of pixels with values of pixels of a second group of pixels
 - 10 of a second image, and the second component depending on a relation between the first group of pixels and a third group of pixels for which a first one of the previously estimated motion vectors has been estimated, the first one of the candidate motion vectors being based on the first one of the previously estimated motion vectors; and
 - a selection unit for selecting the current motion vector from the candidate
 - 15 motion vectors by means of comparing the match errors of the respective candidate motion vectors, characterized in that the motion estimation unit is arranged to modulate the second component on basis of a result of segmentation for the first image, into segments of pixels, the result of segmentation being related to a probability that a first part of the first group of pixels and a first part of the third group of pixels both correspond to a particular one of the
 - 20 segments.
2. A motion estimation unit as claimed in claim 1, characterized in that the motion estimation unit (100) is arranged to modulate the second component on basis of the size of the probability.
- 25 3. A motion estimation unit as claimed in claim 1, characterized in that the motion estimation unit is arranged to modulate the second component on basis of a ratio of a first number of pixels of the first part of the first group of pixels and a second number of pixels of the first group of pixels.

4. A motion estimation unit as claimed in claim 1, characterized in that the first group of pixels is a block of pixels.
- 5 5. A motion estimation unit as claimed in claim 1, characterized in that the selection unit is arranged to select, from the set of candidate motion vectors, a particular motion vector as the current motion vector, if the corresponding match error is the smallest of the match errors.
- 10 6. A motion estimation unit as claimed in claim 1, characterized in that the match error unit is designed to calculate the match error of the first one of the candidate motion vectors by means of subtracting luminance values of pixels of the first group of pixels from luminance values of pixels of the second group of pixels of the second image.
- 15 7. A method of estimating a current motion vector for a first group of pixels of a first image, comprising:
- generating a set of candidate motion vectors for the first group of pixels, the candidate motion vectors being extracted from a set of previously estimated motion vectors;
 - calculating match errors of respective candidate motion vectors, the match
- 20 error of a first one of the candidate motion vectors being based on a first component and a second component, the first component corresponding to a comparison of values of pixels of the first group of pixels with values of pixels of a second group of pixels of a second image, and the second component depending on a relation between the first group of pixels and a third group of pixels for which a first one of the previously estimated motion vectors has
- 25 been estimated, the first one of the candidate motion vectors being based on the first one of the previously estimated motion vectors; and
- selecting the current motion vector from the candidate motion vectors by means of comparing the match errors of the respective candidate motion vectors,
- 30 characterized in modulating the second component on basis of a result of segmentation for the first image, into segments of pixels, the result of segmentation being related to a probability that a first part of the first group of pixels and a first part of the third group of pixels both correspond to a particular one of the segments.
8. An image processing apparatus comprising:

- receiving means for receiving a signal representing a series of images, comprising a first image;

- a motion estimation unit as claimed in claim 1 for estimating a current motion vector for a first group of pixels of the first image; and

5 - a motion compensated image processing unit (306) for determining processed images on basis of the images and the current motion vector.

9. An image processing apparatus as claimed in claim 8, characterized in that the motion compensated image processing unit is designed to perform video compression.

10

10. An image processing apparatus as claimed in claim 8, characterized in that the motion compensated image processing unit is designed to reduce noise in the series of images.

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11. An image processing apparatus as claimed in claim 8, characterized in that the motion compensated image processing unit is designed to de-interlace the series of images.

12. An image processing apparatus as claimed in claim 8, characterized in that the motion compensated image processing unit is designed to perform an up-conversion.

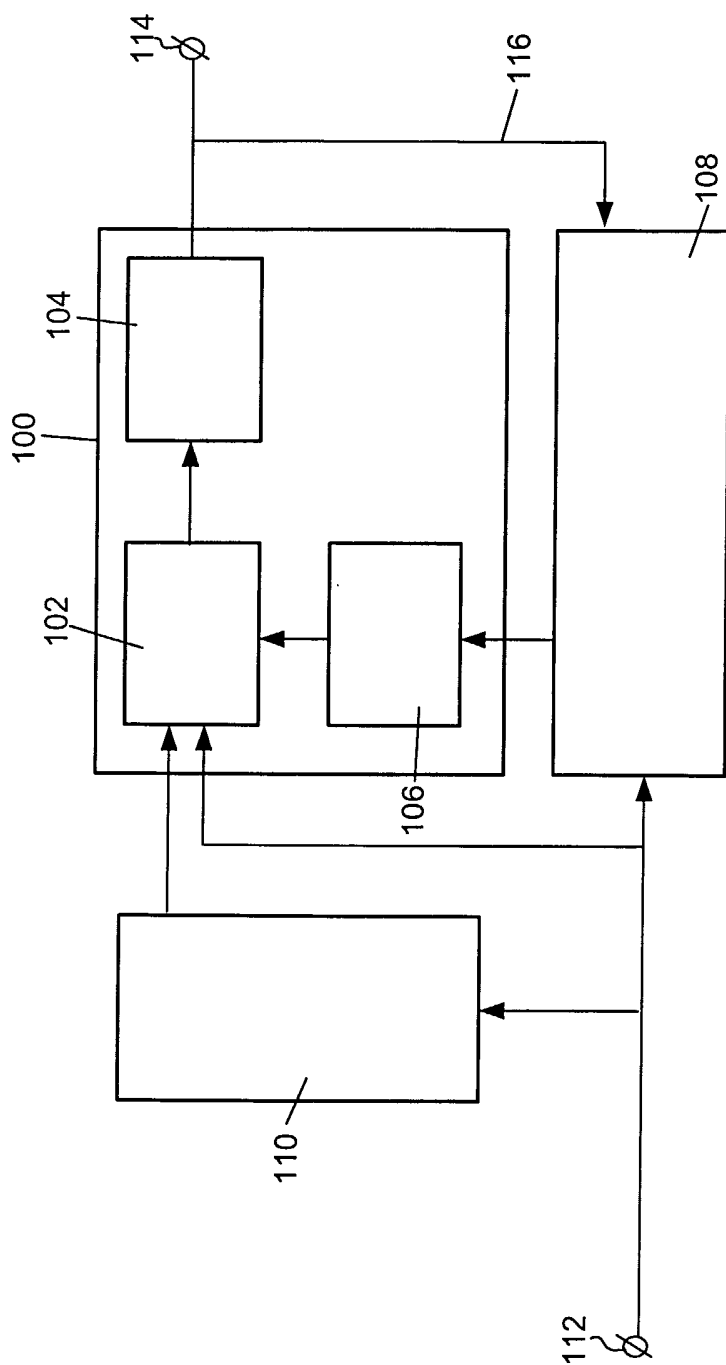


FIG. 1

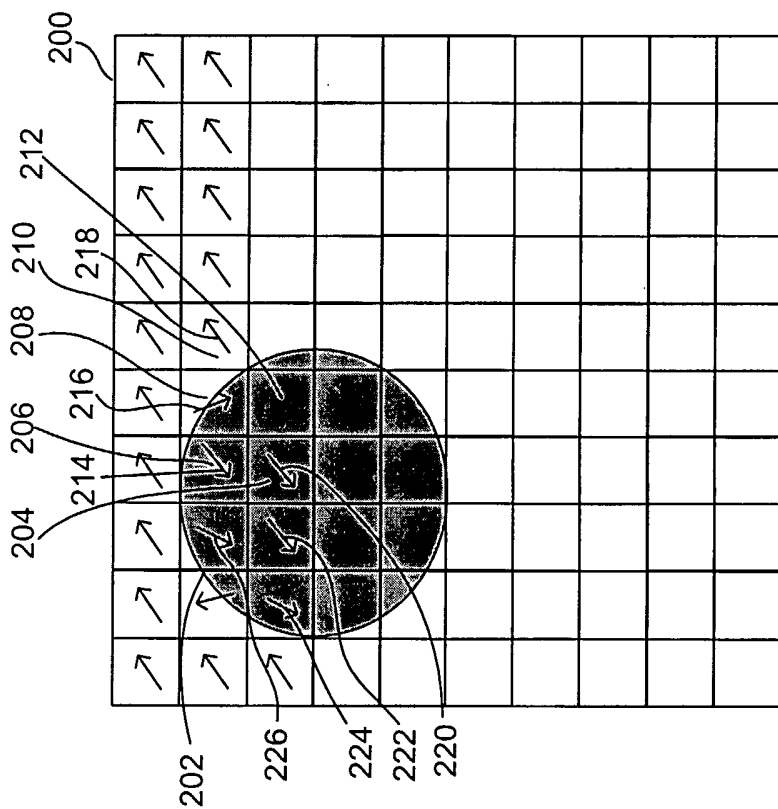


FIG. 2

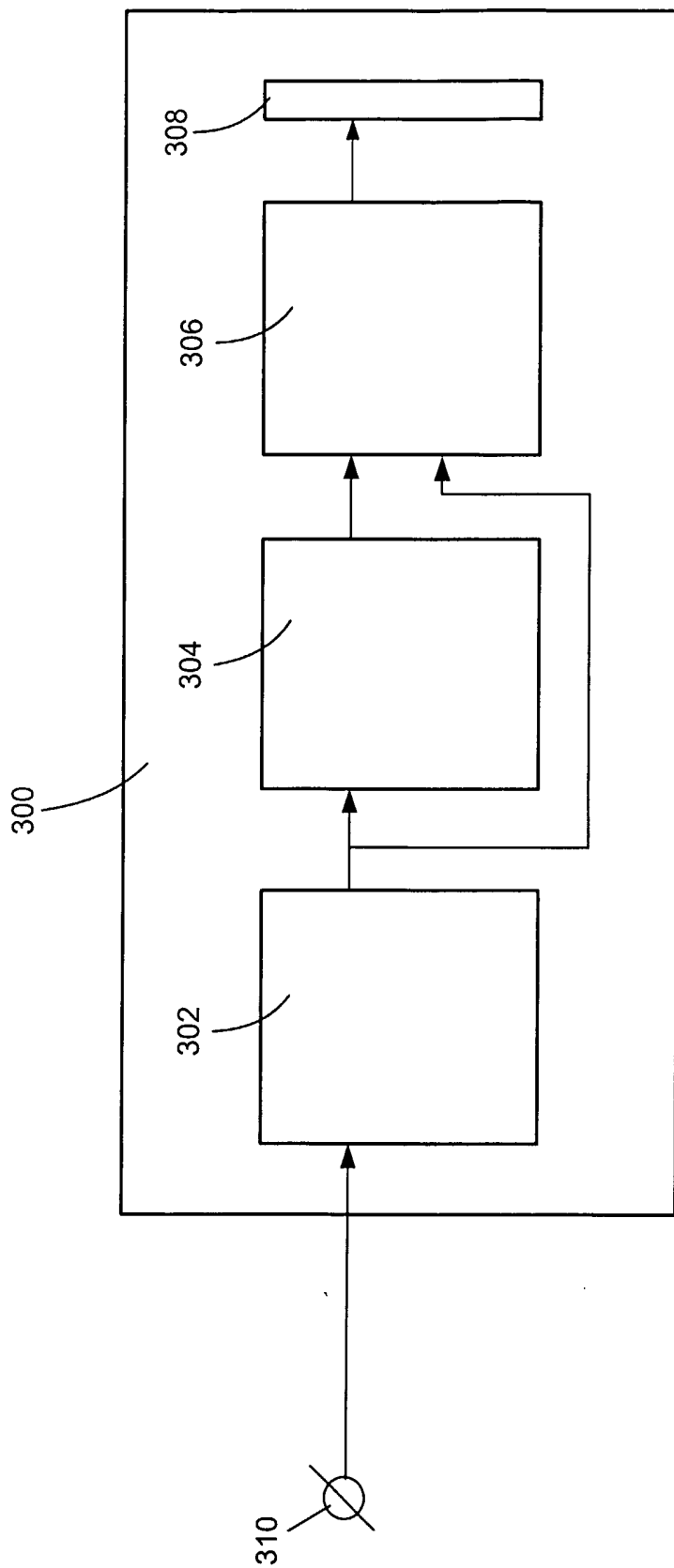


FIG. 3