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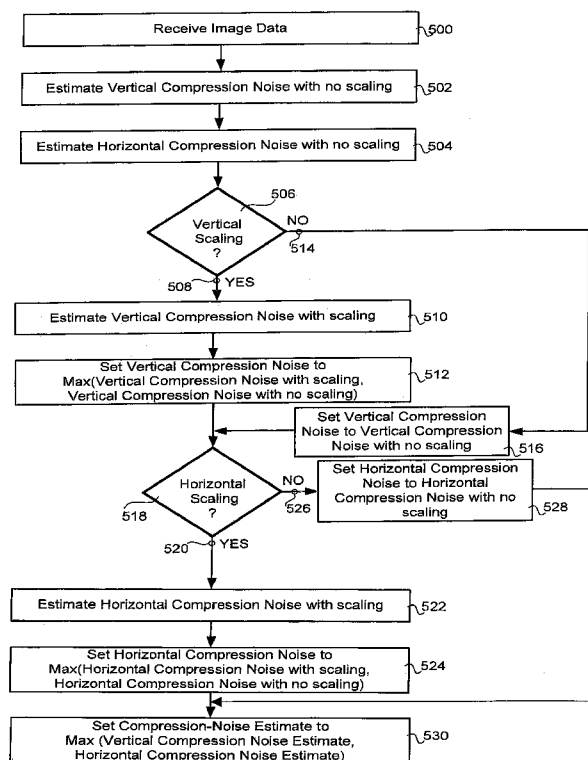
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[Continued on next page]

(54) Title: METHODS AND SYSTEMS FOR ESTIMATION OF COMPRESSION NOISE

FIG. 28



(57) Abstract: Aspects of the present invention are related to systems and methods for determining the compression noise present in an image or frame in a video sequence.



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DESCRIPTION

TITLE OF INVENTION: METHODS AND SYSTEMS FOR
ESTIMATION OF COMPRESSION NOISE

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TECHNICAL FIELD

The present invention relates to image and video processing and, in particular, to methods and systems for estimating compression noise in an image or in a video
10 sequence.

BACKGROUND ART

The quality of a video sequence or of an image may vary widely depending on the source. For example, computer-generated content may be of the highest quality, packaged
15 media content, for example, Blu-ray media, may be of relatively high quality, over-the-air high-definition (HD) broadcast content may be of relatively intermediate quality, while content distributed via cable and satellite, may be of a relatively lower quality and Internet protocol television (IPTV)
20 and streamed content may be of relatively low quality. Methods and systems for video and image enhancement that automatically adapt to image- or video-content quality may be desirable.

25

SUMMARY OF INVENTION

The present invention provides a method and a system for estimating compression noise in an image.

5 In one aspect of the invention, a method for estimating compression noise in an image is provided. The method comprises receiving an image in a noise-estimation system; determining a first vertical compression-noise estimate associated with no scaling of said image; determining a first horizontal compression-noise estimate associated with no
10 scaling of said image; when said image is scaled in the vertical direction, determining a second vertical compression-noise estimate associated with scaling of said image at a first scaling factor; and setting a third vertical compression-noise estimate to the maximum of said first vertical-compression
15 noise estimate and said second vertical-compression noise estimate; when said image is not scaled in the vertical direction, setting said third vertical compression-noise estimate to said first vertical compression-noise estimate; when said image is scaled in the horizontal direction,
20 determining a second horizontal compression-noise estimate associated with scaling of said image at a second scaling factor; and setting a third horizontal compression-noise estimate to the maximum of said first horizontal-compression noise estimate and said second horizontal-compression noise
25 estimate; when said image is not scaled in the horizontal

direction, setting said third horizontal compression-noise estimate to said first horizontal compression-noise estimate; and setting a compression-noise estimate for said image to the maximum of said third vertical compression-noise estimate and said third horizontal compression-noise estimate.

In another aspect of the invention, a system for estimating compression noise in an image. The system for estimating compression noise in an image, said system comprising: a noise estimating section for determining a first vertical compression-noise estimate associated with no scaling of said image; a noise estimating section for determining a first horizontal compression-noise estimate associated with no scaling of said image; a determining section for, when said image is scaled in the vertical direction, determining a second vertical compression-noise estimate associated with scaling of said image at a first scaling factor; a determining section for, when said image is scaled in the horizontal direction, determining a second horizontal compression-noise estimate associated with scaling of said image at a second scaling factor; a setting section for (i) setting a third vertical compression-noise estimate to the maximum of said first vertical-compression noise estimate and said second vertical-compression noise estimate when said image is scaled in the vertical direction, and (ii) setting said third vertical compression-noise

estimate to said first vertical compression-noise estimate when said image is not scaled in the vertical direction; a setting section for (i) setting a third horizontal compression-noise estimate to the maximum of said first horizontal-compression noise estimate and said second horizontal-compression noise estimate when said image is scaled in the horizontal direction, and (ii) setting said third horizontal compression-noise estimate to said first horizontal compression-noise estimate when said image is not scaled in the horizontal direction; and a setting section for setting a compression-noise estimate for said image to the maximum of said third vertical compression-noise estimate and said third horizontal compression-noise estimate.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a chart showing exemplary embodiments of the present invention comprising controlling the image separation effectuated by an edge-preserving filter using an estimate of the noise in the input image.

Fig. 2 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise

by accessing a look-up table.

Fig. 3 is an exemplary, original, decoded image frame.

Fig. 4 is an enhanced image resulting from processing, according to embodiments of the present invention, of the exemplary, original, decoded image frame shown in Figure 3, wherein the noise estimate used to control the bi-lateral filter parameter value was based only on sensor, thermal and grain noise.

Fig. 5 is an enhanced image resulting from processing, according to embodiments of the present invention, of the exemplary, original, decoded image frame shown in Figure 3, wherein the noise estimate used to control the bi-lateral filter parameter value was based on sensor, thermal and grain noise and compression noise.

Fig. 6 is an exemplary, original, decoded image frame associated with a lightly compressed image.

Fig. 7 is an enhanced image resulting from processing, according to embodiments of the present invention, of the exemplary, original decoded image frame shown in Figure 6, wherein the noise estimate used to control the bi-lateral filter parameter value was based only on compression noise.

Fig. 8 is an enhanced image resulting from processing, according to embodiments of the present invention, of the exemplary, original decoded image frame shown in Figure 6, wherein the noise estimate used to control the bi-lateral filter

parameter value was based on noise due to sensor, thermal and grain noise and compression noise.

Fig. 9 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data.

Fig. 10 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data for a still image or a single frame in a video sequence.

Fig. 11 is a picture illustrating exemplary pixel locations for determination of horizontal differences according to embodiments of the present invention.

Fig. 12 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data for a frame in a video sequence.

Fig. 13 is chart showing exemplary embodiments of the present invention comprising un-sharp masking.

Fig. 14 is a chart showing exemplary embodiments of the present invention comprising edge-preserving filter parameter value determination based on the level of sharpening associated with the un-sharp masking.

Fig. 15 is a chart showing exemplary embodiments of the present invention comprising edge-preserving filter parameter value determination based on the level of sharpening associated with the un-sharp masking and based on temporal

smoothing.

Fig. 16 is a plot showing two exemplary look-up tables for associating a sharpening factor with a multiplier.

5 Fig. 17 is a chart showing exemplary embodiments of the present invention comprising edge-preserving filter parameter value determination based on the level of sharpening associated with the un-sharp masking.

10 Fig. 18 is a chart showing an exemplary embodiment of the present invention comprising edge-preserving filter parameter value determination based on the level of sharpening associated with the un-sharp masking.

Fig. 19 is an exemplary, original noise image.

15 Fig. 20 shows a result of bi-lateral filtering, using a sigma range parameter value equal to the standard deviation of the noise, of the original noise image shown in Figure 19.

20 Fig. 21 shows a result of bi-lateral filtering, according to embodiments of the present invention, of the original noise image shown in Figure 19, where the bi-lateral filter parameter value was set based on the noise in the original noise image.

25 Fig. 22 shows a result of bi-lateral filtering, according to embodiments of the present invention, of the original noise image shown in Figure 19, where the bi-lateral filter parameter value was set based on the noise in the original noise image and the level of sharpening.

Fig. 23 shows an exemplary, original image.

Fig. 24 shows a result of bi-lateral filtering, according to embodiments of the present invention, of the original image shown in Figure 23, where the bi-lateral filter parameter value was set based on noise estimated from the original image.

Fig. 25 shows a result of bi-lateral filtering, according to embodiments of the present invention, of the original image shown in Figure 23, where the bi-lateral filter parameter value was set based on noise estimated from the original image and the level of sharpening.

Fig. 26 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data, wherein the image data may be resized prior to compression-noise estimation.

Fig. 27 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data for a still image or a single frame in a video sequence after resizing in a first direction.

Fig. 28 is a chart showing exemplary embodiments of the present invention comprising estimation of compression noise directly from image data, wherein the image may be scaled in either the vertical direction or the horizontal direction prior to compression-noise estimation.

Fig. 29 is a chart showing exemplary embodiments of the

present invention comprising estimation of compression noise directly from image data after resizing in the horizontal direction.

5 DESCRIPTION OF EMBODIMENTS

Some embodiments of the present invention comprise methods and systems for estimating compression noise in an image or a video sequence.

According to a first aspect of the present invention,
10 statistics based on standard deviations of horizontal differences and statistics based on standard deviations of vertical differences may be used to estimate horizontal compression noise and vertical compression noise, respectively. The estimated horizontal compression noise and
15 the estimated vertical compression noise may be combined to form a compression noise estimate.

According to a second aspect of the present invention, statistics based on standard deviations of horizontal differences and statistics based on standard deviations of
20 vertical differences may be used to estimate horizontal compression noise and vertical compression noise, respectively. Horizontal block-boundaries and vertical block-boundaries may be detected and examined for a plurality of video frames. The horizontal compression noise estimate may
25 be set to zero based on the horizontal block boundaries, and

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the vertical compression noise estimate may be set to zero based on the vertical block boundaries.

According to a third aspect of the present invention, compression noise may be estimated directly from image data, wherein the image data may be resized after decoding and prior to noise estimation.

According to a fourth aspect of the present invention, an edge-preserving filter may be controlled based on the estimated compression noise estimate.

According to a fifth aspect of the present invention, a bilateral filter may be controlled based on the estimated compression noise estimate.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention taken in conjunction with the accompanying drawings.

Embodiments of the present invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. The figures listed above are expressly incorporated as part of this detailed description.

It will be readily understood that the components of the present invention, as generally described and illustrated in the figures herein, could be arranged and designed in a wide

variety of different configurations. Thus, the following more detailed description of the embodiments of the methods and systems of the present invention is not intended to limit the scope of the invention but it is merely representative of the presently preferred embodiments of the invention.

Elements of embodiments of the present invention may be embodied in hardware, firmware and/or software. While exemplary embodiments revealed herein may only describe one of these forms, it is to be understood that one skilled in the art would be able to effectuate these elements in any of these forms while resting within the scope of the present invention.

The quality of a video sequence or of an image may vary widely depending on the source. For example, computer-generated content may be of the highest quality, packaged media content, for example, Blu-ray media, may be of relatively high quality, over-the-air high-definition (HD) broadcast content may be of relatively intermediate quality, while content distributed via cable and satellite, may be of a relatively lower quality and Internet protocol television (IPTV) and streamed content may be of relatively low quality. Methods and systems for video and image enhancement that automatically adapt to image- or video-content quality may be desirable.

When there is little, or no, noise in an image, either a

still image or a frame in a video sequence, the image may be sharpened aggressively, and small details in the image may not be attenuated. However, selective image sharpening may be required in the presence of noise. Stronger and larger-scale features, as defined relative to the degree of noise, may be identified and enhanced, while less significant and smaller-scale features may be unprocessed, or potentially attenuated to mitigate the noise present in the image.

U. S. Patent Application No. 12/228,774, entitled "Image Sharpening Technique," filed August 15, 2008, which is hereby incorporated by reference herein in its entirety, describes a technique for image sharpening wherein two image channels are generated from an image: a first channel which may include primarily texture information and a second channel which may include primarily edge and flat-region information. The first channel may be filtered to attenuate higher frequency content of the image in the first channel, and the second channel may be filtered to sharpen the image in the second channel. The filtered first channel and the filtered second channel may be combined to form an enhanced image associated with the input image.

In some embodiments of the present invention, an edge-preserving filter may be used to separate an input image into two channels: a first channel which may comprise image content to be sharpened; and a second channel which may

comprise image content to attenuate. In some embodiments of the present invention, the edge-preserving filter may comprise a bi-lateral filter. In alternative embodiments, another edge-preserving filter may be used to perform the separation. In
5 some embodiments, the assignment of the input-image content to the first channel and the second channel may be controlled by a parameter of the edge-preserving filter. For example, a range sigma parameter of a bi-lateral filter may control the assignment of input-image content to the first
10 channel and the second channel in embodiments wherein the edge-preserving filter comprises a bi-lateral filter. In some embodiments, in order to maximize the amount of sharpening, the filter parameter value, for example, the range sigma parameter value in a bi-lateral filter, may be set based on
15 noise statistics associated with the input image.

Some embodiments of the present invention may be understood in relation to Figure 1. An input image 2 and a noise estimate 3 associated with the input image 2 may be made available to an edge-preserving filter 4. In some
20 embodiments of the present invention, the edge-preserving filter may comprise a bi-lateral filter. In alternative embodiments, another edge-preserving filter may be used to perform the separation. The edge-preserving filter 4 may be used to divide the input image 2 into two channels 6, 10. A
25 first channel 6 may correspond to significant features in the

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input image 2, and the second channel 10, formed by removing 8 the first channel 6 from the input image 2, may contain the residual difference between the first channel 6 and the input image 2. The residual difference may comprise noise and texture data. The first channel 6 may be sharpened 12, and the second channel 10 may be attenuated 14. The sharpened channel 16 and the attenuated channel 18 may be combined 20 to form an enhanced image 22. The value of the filter parameter of the edge-preserving filter 4 may control the assignment of input-image content to the first channel 6 and the second channel 10. The value of the filter parameter of the edge-preserving filter 4 may be based on the noise estimate 3. In some embodiments of the present invention, the value of the filter parameter may be proportional to the noise estimate 3. However, the value of the filter parameter may not be equal to zero. In some embodiments, when the noise estimate 3 indicates that the filter parameter should be set to zero, a small, pre-determined value may be assigned to the filter parameter. In alternative embodiments, when the noise estimate 3 indicates that the filter parameter should be set to zero, the edge-preserving filter 4 may pass the input image 2 directly through as the first channel 6, thereby effectuating only sharpened data. In some embodiments of the present invention (not shown), the enhanced image 22 may be up-sampled to a resolution greater than that of the input

image 2.

Multiple noise processes may appear in an image or video sequence. At one extreme, an original image may be of very high quality, for example, computer generated imagery.

5 However, other images, or video sequences, may be of lower quality, for example, a sequence or image may be corrupted, during the acquisition process by thermal, sensor, or other noise. In some situations, film grain, or other analog noise, may corrupt an image or video sequence. Furthermore, 10 compression artifacts may corrupt an image or video sequence.

The degree of compression artifacts may be related to the bit-rate associated with a video sequence or image. Exemplary bit-rates and quality levels may be high quality Blu-ray discs compressed at approximately 40 Mbps (Mega bits per second), 15 lower quality over-the-air transmissions compressed at approximately 20 Mbps, further lower quality trans-coded cable transmissions compressed at approximately 12 Mbps and lowest quality satellite and IPTV services compressed at less than 10 Mbps.

20 In some embodiments of the present invention described in relation to Figure 2, an input bitstream 30, associated with a still image or a video sequence, may be decoded by an appropriate decoder 32. The image data 34 may be made available, to an image-noise statistic estimator 38, from the 25 decoder 32, and the decoded coding parameters 36 may be

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made available, to a codec (coder/decoder) -noise statistic estimator 40, from the decoder 32. In alternative embodiments, the coding parameters 36 may be made available to the codec-noise statistic estimator 40 through meta-data or other external means.

The image-noise statistic estimator 38 may analyze the image data 34 to determine the amount of thermal, sensor, grain, or other image noise present in the image data 34. Many existing methods are known in the art for estimating the image noise present in image data. In an exemplary embodiment of the present invention, the image-noise statistic estimator 38 may identify one, or more, substantially smooth regions in the image data 34 and may calculate the standard deviation of the pixel values within each region. The maximum standard deviation value may be associated with the image-noise statistic 44.

The codec-noise statistic estimator 40 may receive coding parameters 36 associated with the input bitstream 30. In some embodiments, the coding parameters 36 may comprise the quantization interval used for coding the current slice or frame in a video sequence. In alternative embodiments, the coding parameters 36 may comprise the number of bits used to represent the source data. The coding parameters 36 may be used in a look-up operation to determine the amount of noise due to compression. In some embodiments of the

present invention, the codec type may be used to select a look-up table from multiple, pre-computed look-up tables 42. The coding parameters 36 may be used as an index into the selected table, and the output may be a measure of the image noise due to compression 46. The measurement provided by the look-up tables 42 may be normalized, either at the time the look-up tables 42 are created or in a post-processing operation (not shown) to have the same units of measurement as the noise estimate 44 provided by the image-noise statistic estimator 38.

In some embodiments of the present invention, a look-up table 42 may be constructed by selecting multiple images and video sequences that are representative of input data. The images and videos sequences may be compressed using a variety of codecs and codec settings, and each result may be subsequently decoded. The decoded results may be compared to the original data, and the noise due to the compression system may be computed, for example. the standard deviation of the error. This computation may be performed over all images and video sequences that are compressed using the same codec and parameter settings, and the result may be stored in the look-up table as the noise statistic for the combination of codec and codec parameter settings. In some embodiments, if additional values are needed, the test image and video sequence data may be compressed with the desired

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configuration settings. In alternative embodiments, noise statistics may be interpolated from values with a similar compression configuration.

5 The image-noise statistic 44 and the codec-noise statistic 46 may be combined by a combiner 48 to produce a final noise estimate 50, which may be made available to the edge-preserving filter to control the filter parameter. In one embodiment of the present invention, the maximum of the image-noise statistic 44 and the codec-noise statistic 46 may
10 be assigned to the noise estimate 50. Alternative fusion methods for combining 48 the image-noise statistic 44 and the codec-noise statistic 46 may be used to produce a final noise estimate 50 which may be made available to the edge-preserving filter, and the value of the filter parameter of the
15 edge-preserving filter may be based on the noise estimate. In some embodiments of the present invention, the value of the filter parameter may be proportional to the noise estimate.

The effectiveness of some embodiments of the present invention may be illustrated in Figures 3-8. Figure 3 depicts
20 an exemplary, original, decoded image 60 with two regions 62, 64 that exhibit coding artifacts shown inside two white circles superimposed on the image 60. One region 62 is along the road, and another region 64 is around a car. Figure 4 shows an enhancement 70 of the decoded image 60 shown in Figure
25 3. The enhanced image 70 was generated using a bi-lateral

filter using only an estimate of the image noise to select the range sigma parameter value of the bi-lateral filter. The coding artifacts are visibly enhanced, for example, the regions 72, 74 that are shown in the two superimposed, white circles.

5 However, the enhanced image 80 shown in Figure 5, by contrast, was enhanced according to embodiments of the present invention wherein a noise estimate accounting for both the image noise, for example, sensor, thermal, grain and other image noise, and the compression noise in the image
10 frame was used to select the range sigma parameter value of the bi-lateral filter. Using this noise estimate produces an enhanced image 80, but without amplifying the coding artifacts, for example, again examine the regions 82, 84 inside the superimposed, white circles.

15 A second exemplary, original, decoded image 90 is depicted in Figure 6. Here, the image 90 is the result of light compression. Inspection of Figure 6 shows a significant amount of grain noise, which may become much more visible if enhanced. Shown in Figure 7 is an enhanced image 100
20 wherein the noise estimate controlling the parameter selection in the bi-lateral filter considered only the coding noise. As can be seen in Figure 7, the enhanced image 100 contains amplified grain noise. However, the enhanced image 110 shown in Figure 8 resulting from image enhancement
25 according to embodiments of the present invention wherein

the noise estimate used to select the range sigma parameter for the bi-lateral filter accounted for both the image noise, for example, sensor, thermal, grain and other noise, and the compression noise in an image frame. As can be seen from Figure 8, the resulting image is enhanced but without amplifying grain noise artifacts.

Embodiments of the present invention described in relation to Figure 2 comprise codec-noise statistic estimation from the coding parameters. In alternative embodiments described in relation to Figure 9, the compression noise may be estimated from the decoded image data.

In some embodiments of the present invention, described in relation to Figure 9, comprising a noise-estimation system 115, an input bitstream 120, associated with a still image or a video sequence, may be decoded by a decoder 122. The image data 124 may be made available, from the decoder 122, to an image-noise statistic estimator 126 and to a codec-noise statistic estimator 128. The image-noise statistic estimator 126 may estimate an image-noise statistic 130 associated with the amount of image noise present in the image data 124, and the codec-noise statistic estimator 128 may estimate a codec-noise statistic 132 associated with the compression noise. The image-noise statistic 130 and the codec-noise statistic 132 may be combined by a combiner 134 to produce a final noise estimate 136 associated with the image data. In

one embodiment of the present invention, the maximum value of the image-noise statistic 130 and the codec-noise statistic 132 may be assigned to the noise estimate 136. Alternative fusion methods for combining 134 the image-noise statistic 130 and the codec-noise statistic 132 may be used to produce a final noise estimate 136.

The image-noise statistic estimator 126 may analyze the image data 124 to determine the amount of thermal, sensor, grain and other image noise present in the image data 124. Many existing methods are known in the art for estimating the image noise. In an exemplary embodiment of the present invention, the image-noise statistic estimator 126 may identify one, or more, substantially smooth regions in the image data 124 and may calculate the standard deviation of the pixel values within each region. The maximum standard-deviation value may be associated with the image-noise statistic 130.

In some embodiments of the present invention, the codec-noise statistic estimator 128 may calculate an estimate for the codec noise 132 according to Figure 10. In these embodiments, a luminance image may be computed 140 from an input RGB (Red Green Blue), or other color space, image. The luminance may be denoted $I(x,y)$, where x and y may denote the horizontal and vertical indices, respectively. A horizontal difference value at each point may be computed

142, thereby producing a plurality of horizontal difference values, and a vertical difference value at each point may be computed 144, thereby producing a plurality of vertical difference values, according to:

5
$$D_H(x,y)=I(x+1,y)-I(x,y)$$

and

$$D_V(x,y)=I(x,y+1)-I(x,y),$$

respectively, where $D_H(x,y)$ may denote a horizontal difference value at pixel location (x,y) and $D_V(x,y)$ may denote
10 a vertical difference value at pixel location (x,y) .

The standard deviation of the horizontal differences at a plurality of horizontal offsets may be computed 146, and the standard deviation of the vertical differences at a plurality of vertical offsets may be computed 148. In some embodiments
15 of the present invention, a standard deviation value may be calculated for each offset within a coding block, thereby producing a plurality of horizontal standard deviation values and a plurality of vertical standard deviation values. The number of offsets may be determined by the structure of the
20 image, or video, codec and any processing or scaling of the decoded data that may be performed prior to estimating the compression noise. In an exemplary embodiment comprising the use of eight offsets, the standard deviation values of the horizontal differences may be calculated 146 according to:

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$$\begin{aligned}
Mean_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Width/8} \frac{D_H(x, 8 \cdot y + i)}{Height \cdot (Width/8)}, & i = 0 \dots 7 \\
Mean2_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Width/8} \frac{D_H(x, 8 \cdot y + i)^2}{Height \cdot (Width/8)}, & i = 0 \dots 7 \\
STD_H[i] &= \text{sqrt}(Mean2_H[i] - Mean_H[i]^2), & i = 0 \dots 7
\end{aligned}$$

Figure 11 depicts an exemplary portion of an image 160 with pixel locations shown as squares. The pixel locations shown in cross hatch, for example 162, may be the locations used for computing the horizontal standard deviation associated with an offset of zero, $STD_v[0]$, and the pixel locations shown in white, for example 164, may be the locations used for computing the horizontal standard deviation associated with an offset of two, $STD_v[2]$. The standard deviation values of the vertical differences may be similarly calculated 148 according to:

$$\begin{aligned}
Mean_v[i] &= \sum_{x=0}^{Height/8} \sum_{y=0}^{Width} \frac{D_v(8 \cdot x + i, y)}{(Height/8) \cdot Width}, & i = 0 \dots 7 \\
Mean2_v[i] &= \sum_{x=0}^{Height/8} \sum_{y=0}^{Width} \frac{D_v(8 \cdot x + i, y)^2}{(Height/8) \cdot Width}, & i = 0 \dots 7 \\
STD_v[i] &= \text{sqrt}(Mean2_v[i] - Mean_v[i]^2), & i = 0 \dots 7
\end{aligned}$$

Referring again to Figure 10, statistics may be computed for the horizontal standard deviation values, and statistics may be computed for the vertical standard deviation values. The statistics computed for the horizontal standard deviation values may be referred to as

horizontal statistics and the statistics computed 152 for the vertical standard deviation values may be referred to as vertical statistics. In some embodiments of the present invention, the average of the horizontal standard deviation values and the maximum horizontal standard deviation value may be computed 150, and the average of the vertical standard deviation values and the maximum vertical standard deviation value may be computed 152. These values may be computed according to:

$$\begin{aligned}
 STD_{H_MEAN} &= \sum_{i=0}^7 \frac{STD_H[i]}{8} \\
 STD_{H_MAX} &= \max(STD_H[i]), \quad i=0..7 \\
 STD_{V_MEAN} &= \sum_{i=0}^7 \frac{STD_V[i]}{8} \\
 STD_{V_MAX} &= \max(STD_V[i]), \quad i=0..7
 \end{aligned}$$

respectively. In alternative embodiments, other statistical values may be calculated, for example, the median, the skew, the kurtosis and other statistical measures.

The computed statistics associated with the horizontal standard deviation values may be combined 154 to form an estimate of the horizontal compression noise. The computed statistics associated with the vertical standard deviation values may be combined 156 to form an estimate of the vertical compression noise. In an exemplary embodiment of the present invention, an estimate of the horizontal compression noise may be calculated according to a weighted

average given by:

$$Noise_{Compression_H} = 4.64 \cdot STD_{H_MAX} - 4.26 \cdot STD_{H_MEAN} + 0.58,$$

and an estimate of the vertical compression noise may be calculated according to a weighted average given by:

$$5 \quad Noise_{Compression_V} = 4.64 \cdot STD_{V_MAX} - 4.26 \cdot STD_{V_MEAN} + 0.58,$$

where the values 4.64, 4.26 and 0.58 are exemplary weighting parameters. In alternative embodiments, other weighting values may be used.

The estimate for the horizontal compression noise and
 10 the estimate for the vertical compression noise may be combined 158 to form a single compression noise estimate. Any data fusion method known in the art may be used to combine the estimate for the horizontal compression noise and the estimate for the vertical compression noise. In some
 15 embodiments of the present invention, the compression-noise estimate may be determined according to:

$$Noise_{Compression} = \max(Noise_{Compression_H}, Noise_{Compression_V}).$$

In alternative embodiments of the present invention, the codec-noise statistic estimator 128 may calculate an estimate
 20 for the codec noise 132 according to Figure 12. In these embodiments, the input image may be a frame in a video sequence, and past frames may be considered in determining the noise estimate. In these embodiments, a luminance image may be computed 170 from an input RGB, or other color
 25 space, image, and the luminance may be denoted $I(x,y)$,

where x and y may denote the horizontal and vertical indices, respectively. A horizontal difference value at each point may be computed 172, thereby producing a plurality of horizontal difference values, and a vertical difference value at each point
5 may be computed 174, thereby producing a plurality of vertical difference values, according to:

$$D_H(x,y) = I(x+1,y) - I(x,y)$$

and

$$D_V(x,y) = I(x,y+1) - I(x,y),$$

10 respectively, where $D_H(x,y)$ may denote a horizontal difference value at pixel location (x,y) and $D_V(x,y)$ may denote a vertical difference value at pixel location (x,y) .

The standard deviation of the horizontal differences at a plurality of horizontal offsets may be computed 176, and the
15 standard deviation of the vertical differences at a plurality of vertical offsets may be computed 178. In some embodiments of the present invention, a standard deviation value may be calculated for each offset within a coding block, thereby producing a plurality of horizontal standard deviation values
20 and a plurality of vertical standard deviation values. The number of offsets may be determined by the structure of the video codec and any processing or scaling of the decoded data that may be performed prior to estimating the compression
25 noise. In an exemplary embodiment comprising the use of eight offsets, the standard deviation values of the horizontal

differences may be calculated 176 according to:

$$\begin{aligned}
 Mean_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Width/8} \frac{D_H(x, 8 \cdot y + i)}{Height \cdot (Width/8)}, & i = 0 \dots 7 \\
 Mean2_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Width/8} \frac{D_H(x, 8 \cdot y + i)^2}{Height \cdot (Width/8)}, & i = 0 \dots 7 \\
 STD_H[i] &= \sqrt{Mean2_H[i] - Mean_H[i]^2}, & i = 0 \dots 7
 \end{aligned}$$

5 The standard deviation values of the vertical differences
may be similarly calculated 178 according to:

$$\begin{aligned}
 Mean_V[i] &= \sum_{x=0}^{Height/8} \sum_{y=0}^{Width} \frac{D_V(8 \cdot x + i, y)}{(Height/8) \cdot Width}, & i = 0 \dots 7 \\
 Mean2_V[i] &= \sum_{x=0}^{Height/8} \sum_{y=0}^{Width} \frac{D_V(8 \cdot x + i, y)^2}{(Height/8) \cdot Width}, & i = 0 \dots 7 \\
 STD_V[i] &= \sqrt{Mean2_V[i] - Mean_V[i]^2}, & i = 0 \dots 7
 \end{aligned}$$

10 Statistics may be computed 180 for the horizontal standard
deviation values, and statistics may be computed 182 for the
vertical standard deviation values. In some embodiments of the
present invention, the average of the horizontal standard
deviation values and the maximum horizontal standard deviation
value may be computed 180, and the average of the vertical
standard deviation values and the maximum vertical standard
15 deviation value may be computed 182. These values may be
computed according to:

$$\begin{aligned}
STD_{H_MEAN} &= \sum_{i=0}^7 \frac{STD_H[i]}{8} \\
STD_{H_MAX} &= \max(STD_H[i]), \quad i=0...7 \\
STD_{V_MEAN} &= \sum_{i=0}^7 \frac{STD_V[i]}{8} \\
STD_{V_MAX} &= \max(STD_V[i]), \quad i=0...7
\end{aligned}$$

respectively. In alternative embodiments, other statistical values may be calculated, for example, the median, the skew, the kurtosis and other statistical measures.

5 The computed statistics associated with the horizontal standard deviation values may be combined 184 to form an estimate of the horizontal compression noise. The computed statistics associated with the vertical standard deviation values may be combined 186 to form an estimate of the
10 vertical compression noise. In an exemplary embodiment of the present invention, an estimate of the horizontal compression noise may be calculated according to a weighted average given by:

$$Noise_{Compression_H} = 4.64 \cdot STD_{H_MAX} - 4.26 \cdot STD_{H_MEAN} + 0.58,$$

15 and an estimate of the vertical compression noise may be calculated according to a weighted average given by:

$$Noise_{Compression_V} = 4.64 \cdot STD_{V_MAX} - 4.26 \cdot STD_{V_MEAN} + 0.58,$$

where the values 4.64, 4.26 and 0.58 are exemplary weighting parameters. In alternative embodiments, other
20 weighting values may be used.

The location of block boundaries in the current image

frame may be estimated 188, 190 using the statistics previously computed. In an exemplary embodiment, a horizontal-block boundary location may be estimated 188 using the maximum horizontal standard deviation value according to:

$$Block_H[frame_num]=i, \text{ where } STD_{H_MAX} = STD_H[i],$$

where *frame_num* may denote a time index associated with the current frame. A vertical block-boundary location may be estimated 190 by the maximum vertical standard deviation value according to:

$$Block_V[frame_num]=i, \text{ where } STD_{V_MAX} = STD_V[i],$$

where *frame_num* may denote a time index associated with the current frame.

The number of unique horizontal block-boundary locations and the number of unique vertical block-boundary locations in a temporal block may be determined 192, 194 by counting the number of unique values for $Block_H[i]$ and $Block_V[i]$, respectively, where *i* is an index with values from *frame_num* to *frame_num-N* and *N* is a constant. If the number of unique values for the horizontal direction is above a threshold, then the estimate for the horizontal compression noise may be set equal to zero, and if the number of unique values for the vertical direction is above a threshold, then the estimate for the vertical compression noise may be set equal to zero.

The estimate for the horizontal compression noise and

the estimate for the vertical compression noise may be combined 196 to form a single compression noise estimate. Any data fusion method known in the art may be used to combine the estimate for the horizontal compression noise and the estimate for the vertical compression noise. In some embodiments of the present invention, the compression-noise estimate may be determined according to:

$$Noise_{Compression} = \max(Noise_{Compression_H}, Noise_{Compression_V}).$$

In some embodiments of the present invention, the parameters of an edge-preserving filter may be adjusted based on a sharpening value used in a sharpening filter. In some exemplary embodiments, the edge-preserving filter may comprise a bi-lateral filter. In exemplary embodiments of the present invention shown in Figure 13 and Figure 14, an edge-preserving filter 204 may be used to separate an input image 200 into two channels: a first channel 206 which may comprise image content to be sharpened by un-sharp masking (USM) 212; and a second channel 210 which may comprise image content to attenuate. The level of sharpening associated with the un-sharp masking 212 may be controlled by the value of the USM alpha 213 set for the USM filter 212. In these embodiments, a filter parameter value 203 of the edge-preserving filter 204 may control the assignment of input-image content to the first channel 206 and the second channel 210. In some embodiments of the present invention

wherein the edge-preserving filter comprises a bi-lateral filter, the filter parameter value may be the range sigma parameter value associated with the bi-lateral filter.

In some embodiments, in order to maximize the amount of sharpening, the filter parameter 203 may be set based on the noise statistics associated with the input image 200, and additionally, in order to mitigate noise amplification due to sharpening, the filter parameter 203 may be set based on the sharpening value 213 used in the sharpening filter 212.

An input image 200 and a filter parameter value 203 associated with the input image may be made available to an edge-preserving filter 204. The edge-preserving filter 204 may be used to divide the input image 200 into two channels 206, 210. The first channel 206 may correspond to significant features in the input image 200, and the second channel 210, formed by removing 208 the first channel 206 from the input image 200, may contain the residual difference between the first channel 206 and the input image 200. The residual difference 210 may comprise noise and texture data. The first channel 206 may be sharpened using un-sharp masking 212, and the second channel 210 may be attenuated 214. The sharpened channel 216 and the attenuated channel 218 may be combined 220 to form an enhanced image 222. The filter parameter value 203 of the edge-preserving filter 204 may control the assignment of input-image content to the first

channel 206 and the second channel 210. In some embodiments of the present invention (not shown), the enhanced image 222 may be up-sampled to a resolution greater than that of the input image 200.

5 Referring to Figure 14, the input image 200 may be received by a noise estimator 230 which may generate a noise estimate 231 based on an estimate of the image noise and the codec noise present in the input image 200. The noise estimate 231 may be determined according to the previously
10 described embodiments of the present invention. The noise estimate 231 may be adjusted by a USM sharpening compensator 232 to account for the sharpening value, and the resulting sharpening-adjusted value 233 may be temporally filtered 234 to reduce noise in the control process. The output
15 of the temporal filter 234 may be the filter parameter value 203 provided to the edge-preserving filter 204.

In some embodiments of the present invention described in relation to Figure 14 and Figure 15, the noise estimator 230 may comprise an image-noise statistic estimator 250 and
20 a codec-noise statistic estimator 252 for estimating image noise and codec noise associated with an input image 200, respectively. The noise estimator 230 may comprise a combiner 254 for combining the image noise estimated by the image-noise statistic estimator 250 and the codec noise
25 codec-noise statistic estimator 252. The noise estimate 231

may be provided to the USM sharpening compensator 232. In some embodiments, the noise estimate 231 may be converted to a standard deviation value in the noise estimator 230. In alternative embodiments, the noise estimate may be converted to a standard deviation value in the USM sharpening compensator 232.

The USM sharpening compensator 232 may adjust the noise estimate 231 by a value associated with the level of sharpening 213. In some embodiments of the present invention, a sharpening compensator controller 256 may use the USM alpha value 213 as an index into a look-up table 258 to determine a multiplier 257 which may be used to multiplicatively adjust 260 the standard-deviation-value noise estimate 231. Figure 16 depicts two plots 280, 282 each associated with an exemplary look-up table derived to maintain a constant noise level with increasing sharpening factor.

In addition to adjusting the noise estimate 231 by the value 257 associated with the level of sharpening 213, the noise estimate 231 may be multiplicatively 260 adjusted by a value associated with control parameter, which may be denoted M , that controls how quickly the estimated parameter values may change as a function of time. In some embodiments the multiplicative adjustment 260 may be $1-M$. In some embodiments of the present invention, a smaller

value for M may correspond to a faster change, while a larger value for M may correspond to a slower change. In some embodiments of the present invention, M may be set to 0.5. A filter parameter value associated with a previous frame may be retrieved from storage 262 and multiplied 264 by the control parameter M . The results of the two multiplications 260, 264 may be added 266 to form the edge-preserving filter parameter 203 for the next frame.

In alternative embodiments described in relation to Figure 17, an edge-preserving filter parameter may be determined for filtering of a still image, or a video frame. An input image 300 may be received by a noise estimator 302 which may generate a noise estimate 303 based on an estimate of the image noise and the codec noise present in the input image 300. The noise estimate 303 may be determined according to the previously described embodiments of the present invention. The noise estimate 303 may be adjusted by a USM sharpening compensator 304 to account for the sharpening value 305, and the resulting sharpening-adjusted value 306 may be the filter parameter value 306 provided to the edge-preserving filter 204.

In some embodiments of the present invention described in relation to Figure 17 and Figure 18, the noise estimator 302 may comprise an image-noise statistic estimator 310 and a codec-noise statistic estimator 312 for estimating image

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noise and codec noise associated with an input image 300, respectively. The noise estimator 302 may comprise a combiner 314 for combining the image noise estimated by the image-noise statistic estimator 310 and the codec noise
5 codec-noise statistic estimator 312. The noise estimate 303 may be provided to the USM sharpening compensator 304. In some embodiments, the noise estimate 303 may be converted to a standard deviation value in the noise estimator 302. In alternative embodiments, the noise estimate 303 may be
10 converted to a standard deviation value in the USM sharpening compensator 304.

The USM sharpening compensator 304 may adjust the noise estimate 303 by a value associated with the level of sharpening 305. In some embodiments of the present
15 invention, a sharpening compensator controller 316 may use the USM alpha value 305 as an index into a look-up table 318 to determine a multiplier 319 which may be used to multiplicatively adjust 320 the standard-deviation-value noise estimate 303 to produce a sharpening-adjusted edge-preserving filter parameter value 306. Figure 16 depicts two
20 plots 280, 282 each associated with an exemplary look-up table derived to maintain a constant noise level with increasing sharpening factor.

The effectiveness of embodiments of the present
25 invention may be illustrated in Figures 19-25. Figure 19

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depicts an exemplary, original, synthetic noise target 350. Figure 20 shows the result 352 of bi-lateral filtering, using a sigma range parameter value equal to the standard deviation of the noise, of the original image 250 shown in Figure 19. An enhanced image 354 is shown in Figure 21. This enhanced image 354 exhibits significant amplification of the image noise. Figure 22 depicts an enhanced image 356 enhanced according to embodiments of the present invention in which the bi-lateral filter sigma range parameter is set according to the noise statistics of the image in addition to accounting for the sharpening strength of the sharpening filter. The noise in Figure 22 is similar to the noise in Figure 20, but the degree of enhancement is different.

A second exemplary, original image 360 is depicted in Figure 23. A superimposed, white circle 361 is shown on the image 360 in a region wherein the noise in the image 360 is visible. Figure 24 depicts an image 362 which results from bi-lateral filtering according to embodiments of the present invention with a range sigma parameter that has been set accounting for the noise, but not the sharpening process. Inspection of the region inside the overlaid white circle 363 shows that the noise is amplified relative to the input image 360. Figure 25 depicts an image 364 which results from bi-lateral filtering according to embodiments of the present invention with a range sigma parameter that has been set

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accounting for both noise and the sharpening process. Inspection of the region inside the overlaid white circle 365 shows that the noise is not amplified relative to the original image 360, but the desired increase in sharpening of image content is visible.

In some embodiments of the present invention described in relation to Figure 26, a compression noise estimate may be determined from decoded image data, wherein the decoded image data may be resized prior to estimation of the compression noise. An input bitstream 400, associated with a still image or a video sequence, may be decoded by a decoder 402 producing image data 404. The image data 404 may be made available, from the decoder 402, to an image scaler 406 which may resize the image data 404 producing scaled image data 408. The scaled image data 408 may be made available to a codec-noise statistic estimator 410. The codec-noise statistic estimator 410 may estimate a codec-noise statistic 412 associated with the compression noise in the scaled image data 408.

In some embodiments of the present invention, the codec-noise statistic estimator 410 may calculate a first-direction estimate, associated with a first image direction, for example, the horizontal direction or the vertical direction, for the codec noise according to Figure 27,

wherein the first-direction estimate may be based on a scaling factor in the first image direction.

In these embodiments, a luminance image may be computed 440 from an input RGB (Red Green Blue), or other color space, image. The luminance image may be denoted $I(x,y)$, where x and y may denote the horizontal and vertical image indices, respectively. A first-direction difference value at each point may be computed 442, thereby producing a plurality of first-direction difference values, according to:

$$D_H(x,y) = I(x+1,y) - I(x,y)$$

when the first image direction is the horizontal direction, where $D_H(x,y)$ may denote a horizontal difference value at pixel location (x,y) , and

$$D_V(x,y) = I(x,y+1) - I(x,y),$$

when the first image direction is the vertical direction, where $D_V(x,y)$ may denote a vertical difference value at pixel location (x,y) .

The standard deviation of a plurality of subsets of the first-direction difference values may be computed 444. The number of subsets may be determined by the structure of the image, or video, codec and any processing or scaling of the decoded data that may be performed prior to estimating the compression noise. In some embodiments, a subset may be described by an initial base offset and a plurality of

offset values, wherein each offset value may be relative to the previous location.

In an exemplary embodiment of the present invention comprising a block-based codec and imaging scaling from 1440 to 1920 in a first image direction, thirty-two subsets, $i=0...31$, may be used, where a subset may comprise first-direction difference values according to locations described by $[i, \overline{10, 11, 11}]$, where the first entry denotes the initial base offset and the subsequent entries denote the offset from the previous location, and, in this example, the offset values repeat every three values, and the line over the sequence 10, 11, 11 denotes the repetition. Thus, for example, the first subset contains values at locations in the first direction at 0, 10, 21, 32, 42, 53, 64, 74, 85, 96, ... and the $i=15$ subset contains values at locations in the first direction at 15, 25, 36, 47, 57, 68, 79,

Thus, when the first image direction is the horizontal direction, the standard deviation value of the horizontal differences for subset i may be calculated according to:

$$\begin{aligned} Mean_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Cy} \frac{D_H(x, M_{i,y})}{Height \cdot (Cy-1)}, & i=0...31 \\ Mean2_H[i] &= \sum_{x=0}^{Height} \sum_{y=0}^{Cy} \frac{D_H(x, M_{i,y})^2}{Height \cdot (Cy-1)}, & i=0...31 \\ STD_H[i] &= \sqrt{Mean2_H[i] - Mean_H[i]^2}, & i=0...31 \end{aligned}$$

where $M_{i,y}$ corresponds to the y^{th} location in the i^{th} subset and Cy is the cardinal number associated with the i^{th} subset, and when the first image direction is the vertical direction, the standard deviation value of the vertical differences for subset i may be calculated according to:

$$\begin{aligned} \text{Mean}_v[i] &= \sum_{x=0}^{Cx} \sum_{y=0}^{Width} \frac{D_v(M_{i,x},y)}{(Cx-1) \cdot Width}, & i=0...31 \\ \text{Mean2}_v[i] &= \sum_{x=0}^{Cx} \sum_{y=0}^{Width} \frac{D_v(M_{i,x},y)^2}{(Cx-1) \cdot Width}, & i=0...31 \\ \text{STD}_v[i] &= \text{sqrt}(\text{Mean2}_v[i] - \text{Mean}_v[i]^2), & i=0...31 \end{aligned}$$

where $M_{i,x}$ corresponds to the x^{th} location in the i^{th} subset and Cx is the cardinal number associated with the i^{th} subset.

A second set of standard deviation values may be computed 446 from the previously computed 444 standard deviation values. The second set of standard deviation values may be a weighted combination of the previously computed 444 standard deviation values. The weighted values may be computed, when the first image direction is the horizontal direction, according to:

$$\text{STD}_{H2}[j] = \sum_{\forall i} W[j,i] \text{STD}_H[i],$$

where i indexes the number of subsets and j indexes the desired number of combined values and $W[j,i]$ denotes a

weight function, and when the first image direction is the vertical direction, the values may be computed according:

$$STD_{V2}[j] = \sum_{\forall i} W[j, i] STD_V[i]$$

In some embodiments of the present invention, eight combined values may be generated 446.

Statistics may be computed 448 from the weighted standard deviation values. The statistics may be computed according to:

$$\begin{aligned} STD_{H2_MEAN} &= \sum_{i=0}^N \frac{STD_{H2}[i]}{N+1} \\ STD_{H2_MAX} &= \max(STD_{H2}[i]), \quad i = 0 \dots N \\ STD_{V2_MEAN} &= \sum_{i=0}^N \frac{STD_{V2}[i]}{N+1} \\ STD_{V2_MAX} &= \max(STD_{V2}[i]), \quad i = 0 \dots N \end{aligned}$$

for a first image direction of horizontal and a first image direction of vertical, respectively, where N+1 is the number of combined values.

The computed statistics associated with the weighted first-direction standard deviation values may be combined 450 to form an estimate of the first-direction compression noise. In an exemplary embodiment of the present invention, when the first image direction is the horizontal direction, an estimate of the horizontal compression noise may be calculated according to a weighted average given by:

$$Noise_{Compression_H} = 4.64 \cdot STD_{H2_MAX} - 4.26 \cdot STD_{H2_MEAN} + 0.58,$$

and when the first image direction is the vertical direction, an estimate of the vertical compression noise may be calculated according to a weighted average given by:

$$Noise_{Compression_V} = 4.64 \cdot STD_{V2_MAX} - 4.26 \cdot STD_{V2_MEAN} + 0.58,$$

where the values 4.64, 4.26 and 0.58 are exemplary weighting parameters. In alternative embodiments, other weighting values may be used.

The location of first-direction block boundaries in the current image frame may be estimated using the statistics previously computed. In an exemplary embodiment, a horizontal-block boundary location may be estimated using the maximum horizontal standard deviation value according to:

$$Block_{H2}[frame_num] = i, \text{ where } STD_{H2_MAX} = STD_{H2}[i],$$

where *frame_num* may denote a time index associated with the current frame. A vertical block-boundary location may be estimated by the maximum vertical standard deviation value according to:

$$Block_{V2}[frame_num] = i, \text{ where } STD_{V2_MAX} = STD_{V2}[i],$$

where *frame_num* may denote a time index associated with the current frame.

The number of unique first-direction block-boundary locations in a temporal block may be determined by counting the number of unique values for $Block_H[i]$ when the first image direction is the horizontal direction and

$Block_v[i]$ when the first image direction is the vertical direction, where i is an index with values from frame_num to frame_num-N and N is a constant. The number of unique values for the first direction may be compared 456 to a threshold. If the number of unique values for the first-direction is 458 above a threshold, then the estimate for the first-direction compression noise may be set 460 equal to zero, and the estimation process may termination 462. If the number of unique values for the first-direction is not 464 above a threshold, then the estimation process may termination 462.

In some embodiments of the present invention described in relation to Figure 28, a codec-noise statistic estimator may estimate a codec-noise statistic associated with a compression noise in image data. In some embodiments of the present invention, the image data may comprise scaled image data. In some embodiments, the image data may be scaled in one dimension only. In some embodiments, the image data may be scaled in both dimensions. In embodiments of the present invention, the image data may not be scaled.

Image data may be received 500, and a vertical compression-noise estimate associated with no scaling may be generated 502 using eight subsets of the vertical direction differences, where a subset may comprise vertical

direction differences at offsets of eight from the previous location and initially starting at a base offset i , $i=0...7$. This may be denoted as $[i, \overline{8}]$, where the first entry denotes the initial base offset and the second entry denotes the offset from the previous location, and since all offsets are eight, the line over the eight indicates a repeating offset value. A horizontal compression-noise estimate associated with no scaling may be generated 504 using eight subsets of the horizontal direction differences, where a subset may comprise horizontal direction differences at offsets of eight from the previous location and initially starting at a base offset i , $i=0...7$.

A determination may be made 506 as to whether or not the image data has been scaled in the vertical direction. If the image data has been scaled in the vertical direction 508, then an estimate of the vertical compression noise associated with a vertical-direction scaling factor may be generated 510. The estimate of the vertical compression noise may be set 512 to the maximum of the vertical compression-noise estimate associated with no scaling and the vertical compression-noise estimate associated with scaling. If the image data has not been scaled in the vertical direction 514, then the vertical compression-noise estimate may be set 516 to the vertical compression-noise estimate associated with no scaling.

A determination may be made 518 as to whether or not the image data has been scaled in the horizontal direction. If the image data has been scaled in the horizontal direction 520, then an estimate of the horizontal compression noise associated with a horizontal-direction scaling factor may be generated 522. The estimate of the horizontal compression noise may be set 524 to the maximum of the horizontal compression-noise estimate associated with no scaling and the horizontal compression-noise estimate associated with scaling. If the image data has not been scaled in the horizontal direction 526, then the horizontal compression-noise estimate may be set 526 to the horizontal compression-noise estimate associated with no scaling.

The compression-noise estimate may be set 530 to the maximum of the horizontal compression-noise estimate and the vertical compression-noise estimate.

An exemplary embodiment of the present invention may be described in relation to Figure 29 for a decoded image of resolution 1440x1080 scaled to 1920x1080 prior to compression-noise estimation. In these embodiments, image data may be received 550. A vertical compression-noise estimate associated with no scaling may be generated 552 using eight subsets of the vertical direction differences, where a subset may comprise vertical direction differences at offsets of eight from the previous location and initially

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starting at a base offset i , $i=0...7$. This may be denoted as $[i, \overline{8}]$, where the first entry denotes the initial base offset and the second entry denotes the offset from the previous location, and since all offsets are eight, the line over the eight indicates a repeating offset value. A horizontal compression-noise estimate associated with no scaling may be generated 554 using eight subsets of the horizontal direction differences, where a subset may comprise horizontal direction differences at offsets of eight from the previous location and initially starting at a base offset i , $i=0...7$. The vertical compression noise may be set 556 to the vertical compression-noise estimate associated with no scaling. An estimate of the horizontal compression noise associated with the horizontal-direction scaling factor may be generated 558 using thirty-two subsets, $i=0...31$, where a subset may comprise horizontal difference values according to locations described by $[i, \overline{10, 11, 11}]$, where the first entry denotes the initial base offset and the subsequent entries denote the offset from the previous location, and, in this example, the offset values repeat every three values, and the line over the sequence 10, 11, 11 denotes the repetition. The estimate of the horizontal compression noise may be set 560 to the maximum of the horizontal compression-noise estimate associated with no scaling and the horizontal compression-noise estimate associated with scaling. The

compression-noise estimate may be set 562 to the maximum of the horizontal compression-noise estimate and the vertical compression-noise estimate.

Some embodiments of the present invention described herein comprise an edge-preserving filter. In some embodiments, the edge-preserving filter may comprise a bi-lateral filter. A person of ordinary skill in the art will recognize the existence of many edge-preserving filters and many forms of bi-lateral filters.

Although the charts and diagrams in figures may show a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of the blocks may be changed relative to the shown order. Also, as a further example, two or more blocks shown in succession in the figure may be executed concurrently, or with partial concurrence. It is understood by those with ordinary skill in the art that software, hardware and/or firmware may be created by one of ordinary skill in the art to carry out the various logical functions described herein.

Some embodiments of the present invention may comprise a computer program product comprising a computer-readable storage medium having instructions stored thereon/in which may be used to program a computing system to perform any of the features and methods described

herein. Exemplary computer-readable storage media may include, but are not limited to, flash memory devices, disk storage media, for example, floppy disks, optical disks, magneto-optical disks, Digital Versatile Discs (DVDs), Compact Discs (CDs), micro-drives and other disk storage media, Read-Only Memory (ROMs), Programmable Read-Only Memory (PROMs), Erasable Programmable Read-Only Memory (EPROMs), Electrically Erasable Programmable Read-Only Memory (EEPROMs), Random-Access Memory (RAMS), Video Random-Access Memory (VRAMs), Dynamic Random-Access Memory (DRAMs) and any type of media or device suitable for storing instructions and/or data.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding equivalence of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims which follow.

CLAIMS

1. A method for estimating compression noise in an image, said method comprising:

receiving an image in a noise-estimation system;

5 determining a first vertical compression-noise estimate associated with no scaling of said image;

determining a first horizontal compression-noise estimate associated with no scaling of said image;

when said image is scaled in the vertical direction:

10 determining a second vertical compression-noise estimate associated with scaling of said image at a first scaling factor; and

setting a third vertical compression-noise estimate to the maximum of said first vertical-compression noise estimate and said second vertical-compression noise estimate;

when said image is not scaled in the vertical direction, setting said third vertical compression-noise estimate to said first vertical compression-noise estimate;

20 when said image is scaled in the horizontal direction:

determining a second horizontal compression-noise estimate associated with scaling of said image at a second scaling factor; and

25 setting a third horizontal compression-noise estimate to the maximum of said first horizontal-compression noise

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estimate and said second horizontal-compression noise estimate;

when said image is not scaled in the horizontal direction, setting said third horizontal compression-noise estimate to said first horizontal compression-noise estimate; and

setting a compression-noise estimate for said image to the maximum of said third vertical compression-noise estimate and said third horizontal compression-noise estimate.

2. The method according to claim 1, wherein:

said determining said first vertical compression-noise estimate associated with no scaling of said image comprises:

computing a vertical difference value for each pixel in a first plurality of pixels in said image, thereby producing a plurality of vertical difference values;

computing a plurality of vertical standard deviation values, wherein each of said vertical standard deviation values in said plurality of vertical standard deviation values is associated with a vertical offset within said image;

calculating a first vertical statistic associated with said plurality of vertical standard deviation values;

calculating a second vertical statistic associated with said plurality of vertical standard deviation values; and

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combining said first vertical statistic and said second vertical statistic to form said first vertical compression-noise estimate; and

said determining said first horizontal compression-noise estimate associated with no scaling of said image comprises:

computing a horizontal difference value for each pixel in a second plurality of pixels in said image, thereby producing a plurality of horizontal difference values;

computing a plurality of horizontal standard deviation values, wherein each of said horizontal standard deviation values in said plurality of horizontal standard deviation values is associated with a horizontal offset within said image;

calculating a first horizontal statistic associated with said plurality of horizontal standard deviation values;

calculating a second horizontal statistic associated with said plurality of horizontal standard deviation values; and

combining said first horizontal statistic and said second horizontal statistic to form said first horizontal compression-noise estimate.

3. The method as described in claim 2, wherein said horizontal offset and said vertical offset are related to a

coding block offset associated with a codec associated with said image.

4. The method as described in claim 2, wherein:

5 said first horizontal statistic is a mean of said horizontal standard deviation values; and

 said first vertical statistic is a mean of said vertical standard deviation values.

10 5. The method as described in claim 2, wherein:

 said second horizontal statistic is a maximum of said horizontal standard deviation values; and

 said second vertical statistic is a maximum of said vertical standard deviation values.

15 6. The method as described in claim 5, wherein:

 said first horizontal statistic is a mean of said horizontal standard deviation values; and

 said first vertical statistic is a mean of said vertical
20 standard deviation values.

7. The method as described in claim 2, wherein:

 said combining said first horizontal statistic and said second horizontal statistic comprises computing a weighted

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average of said first horizontal statistic and said second horizontal statistic; and

said combining said first vertical statistic and said second vertical statistic comprises computing a weighted average of said first vertical statistic and said second vertical statistic.

8. The method as described in claim 2, wherein said image is a first frame in a video sequence and further comprising:

estimating a horizontal block-boundary location associated with each frame in a plurality of frames in said video sequence, wherein said first frame is in said plurality of frames, thereby producing a plurality of horizontal block-boundary locations;

estimating a vertical block-boundary location associated with each frame in said plurality of frames in said video sequence, thereby producing a plurality of vertical block-boundary locations;

determining a number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations;

determining a number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations;

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comparing said number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations to a horizontal threshold;

5 comparing said number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations to a vertical threshold;

10 setting said first horizontal compression-noise estimate to zero when said number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations and said horizontal threshold meet a horizontal criterion; and

15 setting said first vertical compression-noise estimate to zero when said number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations and said vertical threshold meet a vertical criterion.

9. The method as described in claim 1, wherein said receiving said image comprises:

20 receiving a bitstream associated with said image; and
decoding said bitstream.

25 10. The method as described in claim 1, wherein said determining said second horizontal compression-noise estimate comprises:

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computing a horizontal difference value for each pixel in a first plurality of pixels in said image, thereby producing a plurality of horizontal difference values;

5 computing a first plurality of horizontal standard deviation values, wherein each of said horizontal standard deviation values in said plurality of horizontal standard deviation values is associated with a subset of horizontal offsets associated with a horizontal base offset within said image;

10 combining said first plurality of horizontal standard deviation values to form a second plurality of horizontal standard deviation values;

15 calculating a first horizontal statistic associated with said second plurality of horizontal standard deviation values;

calculating a second horizontal statistic associated with said second plurality of horizontal standard deviation values; and

20 combining said first horizontal statistic and said second horizontal statistic to form said second horizontal compression-noise estimate.

11. The method as described in claim 10, wherein:

said first horizontal statistic is a mean of said second plurality of horizontal standard deviation values; and

said second horizontal statistic is a maximum of said second plurality of horizontal standard deviation values.

5

12. The method as described in claim 10, wherein said combining said first horizontal statistic and said second horizontal statistic comprises computing a weighted average of said first horizontal statistic and said second horizontal statistic.

10

13. The method as described in claim 10, wherein said image is a first frame in a video sequence and further comprising:

15 estimating a horizontal block-boundary location associated with each frame in a plurality of frames in said video sequence, wherein said first frame is in said plurality of frames, thereby producing a plurality of horizontal block-boundary locations;

20 determining a number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations;

25 comparing said number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations to a horizontal threshold;

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setting said second horizontal compression-noise estimate to zero when said number of unique horizontal block-boundary locations in said plurality of horizontal block-boundary locations and said horizontal threshold
5 meet a horizontal criterion.

14. The method as described in claim 1, wherein said determining said second vertical compression-noise estimate comprises:

10 computing a vertical difference value for each pixel in a first plurality of pixels in said image, thereby producing a plurality of vertical difference values;

computing a first plurality of vertical standard deviation values, wherein each of said vertical standard deviation values in said plurality of vertical standard
15 deviation values is associated with a subset of vertical offsets associated with a vertical base offset within said image;

combining said first plurality of vertical standard deviation values to form a second plurality of vertical
20 standard deviation values;

calculating a first vertical statistic associated with said second plurality of vertical standard deviation values;

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calculating a second vertical statistic associated with said second plurality of vertical standard deviation values; and

5 combining said first vertical statistic and said second vertical statistic to form said second vertical compression-noise estimate.

15. The method as described in claim 14, wherein:

10 said first vertical statistic is a mean of said second plurality of vertical standard deviation values; and

said second vertical statistic is a maximum of said second plurality of vertical standard deviation values.

16. The method as described in claim 14, wherein

15 said combining said first vertical statistic and said second vertical statistic comprises computing a weighted average of said first vertical statistic and said second vertical statistic.

17. The method as described in claim 14, wherein

20 said image is a first frame in a video sequence and further comprising:

estimating a vertical block-boundary location associated with each frame in a plurality of frames in said video sequence, wherein said first frame is in said plurality

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of frames, thereby producing a plurality of vertical block-boundary locations;

determining a number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations;

comparing said number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations to a vertical threshold;

setting said second vertical compression-noise estimate to zero when said number of unique vertical block-boundary locations in said plurality of vertical block-boundary locations and said vertical threshold meet a horizontal criterion.

18. The method as described in claim 1, wherein said receiving said image comprises:

receiving a bitstream associated with said image;
decoding said bitstream to form a first image; and
resizing said first image to form said image.

19. The method as described in claim 18, wherein said resizing comprises resizing said first image one direction selected from the group consisting of the horizontal direction and the vertical direction.

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20. The method as described in claim 18, wherein said resizing comprises resizing said first image in the vertical direction and in the horizontal direction.

21 A system for estimating compression noise in an image, said system comprising:

a noise estimating section for determining a first vertical compression-noise estimate associated with no scaling of said image;

a noise estimating section for determining a first horizontal compression-noise estimate associated with no scaling of said image;

a determining section for, when said image is scaled in the vertical direction, determining a second vertical compression-noise estimate associated with scaling of said image at a first scaling factor;

a determining section for, when said image is scaled in the horizontal direction, determining a second horizontal compression-noise estimate associated with scaling of said image at a second scaling factor;

a setting section for (i) setting a third vertical compression-noise estimate to the maximum of said first vertical-compression noise estimate and said second vertical-compression noise estimate when said image is scaled in the vertical direction, and (ii) setting said third vertical compression-noise estimate to said first vertical

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compression-noise estimate when said image is not scaled in the vertical direction;

a setting section for (i) setting a third horizontal compression-noise estimate to the maximum of said first horizontal-compression noise estimate and said second horizontal-compression noise estimate when said image is scaled in the horizontal direction, and (ii) setting said third horizontal compression-noise estimate to said first horizontal compression-noise estimate when said image is not scaled in the horizontal direction; and

a setting section for setting a compression-noise estimate for said image to the maximum of said third vertical compression-noise estimate and said third horizontal compression-noise estimate.

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FIG. 1

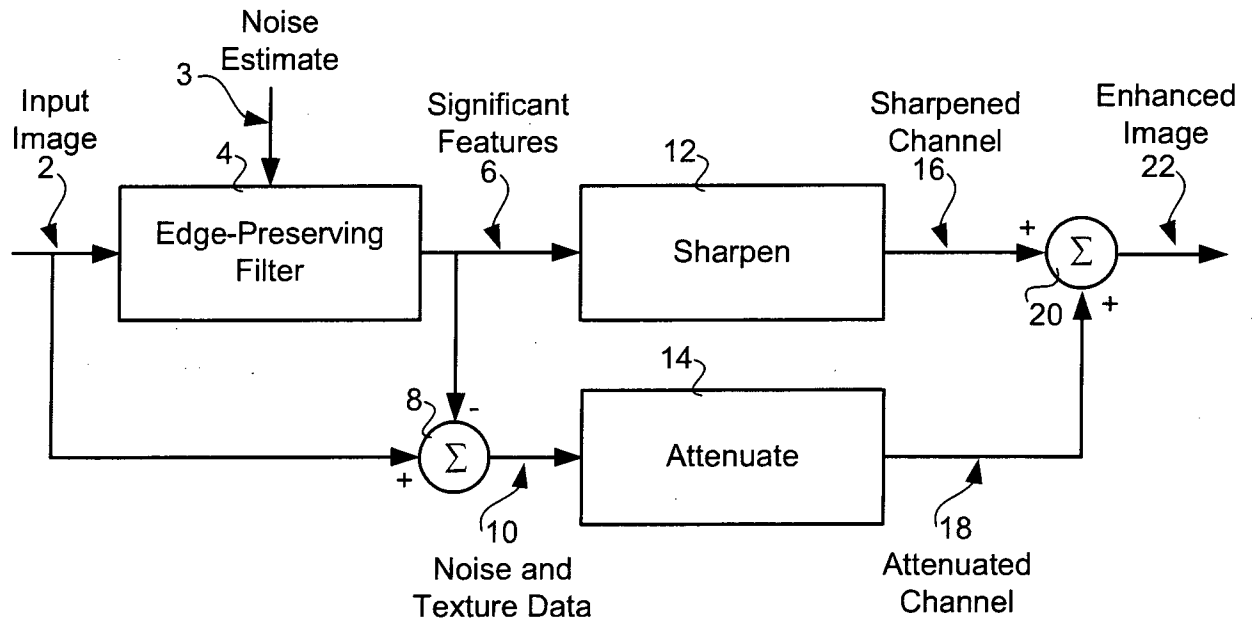
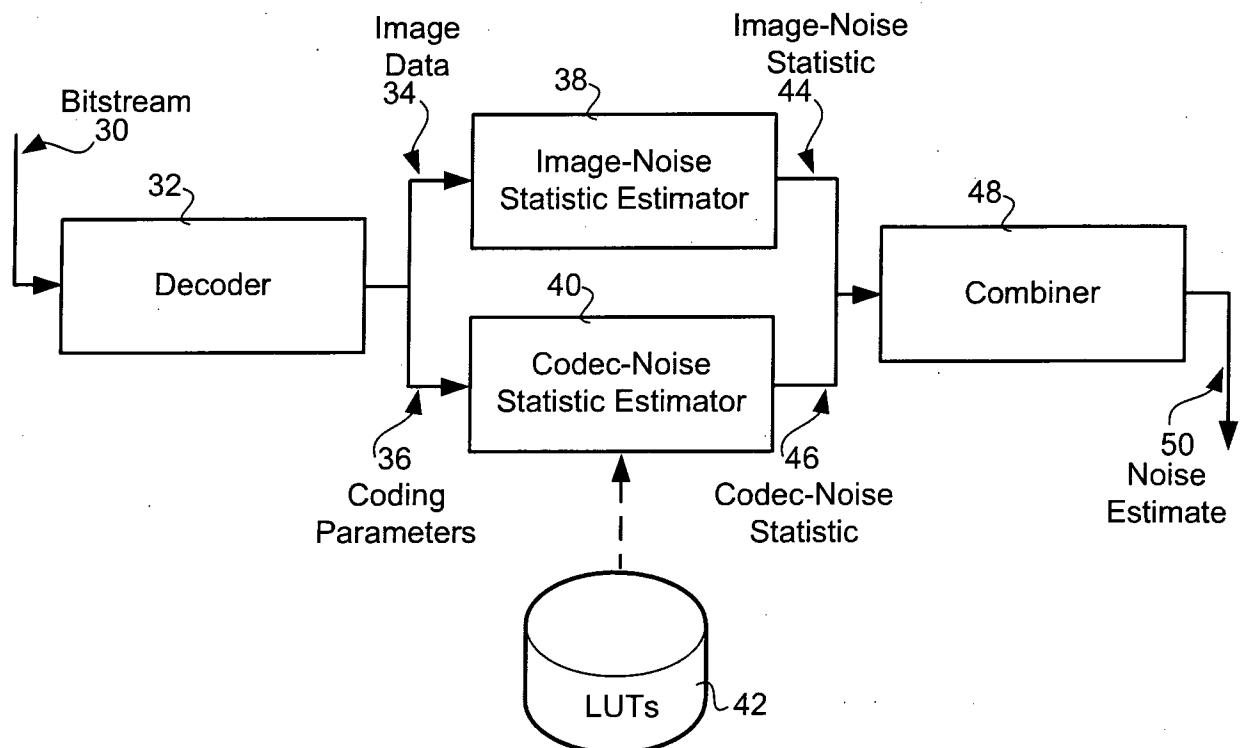
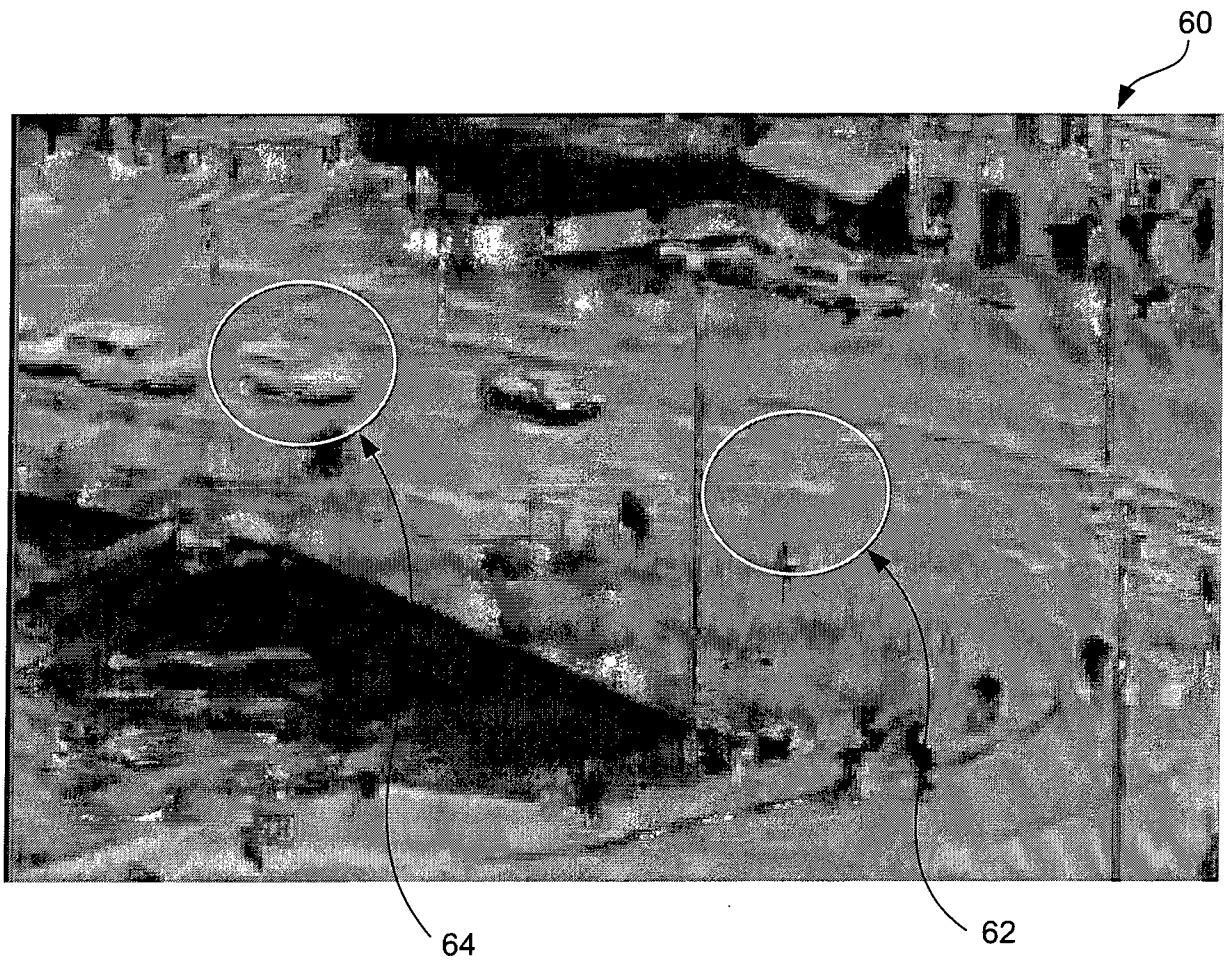


FIG. 2



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FIG. 3



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FIG. 4



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FIG. 5



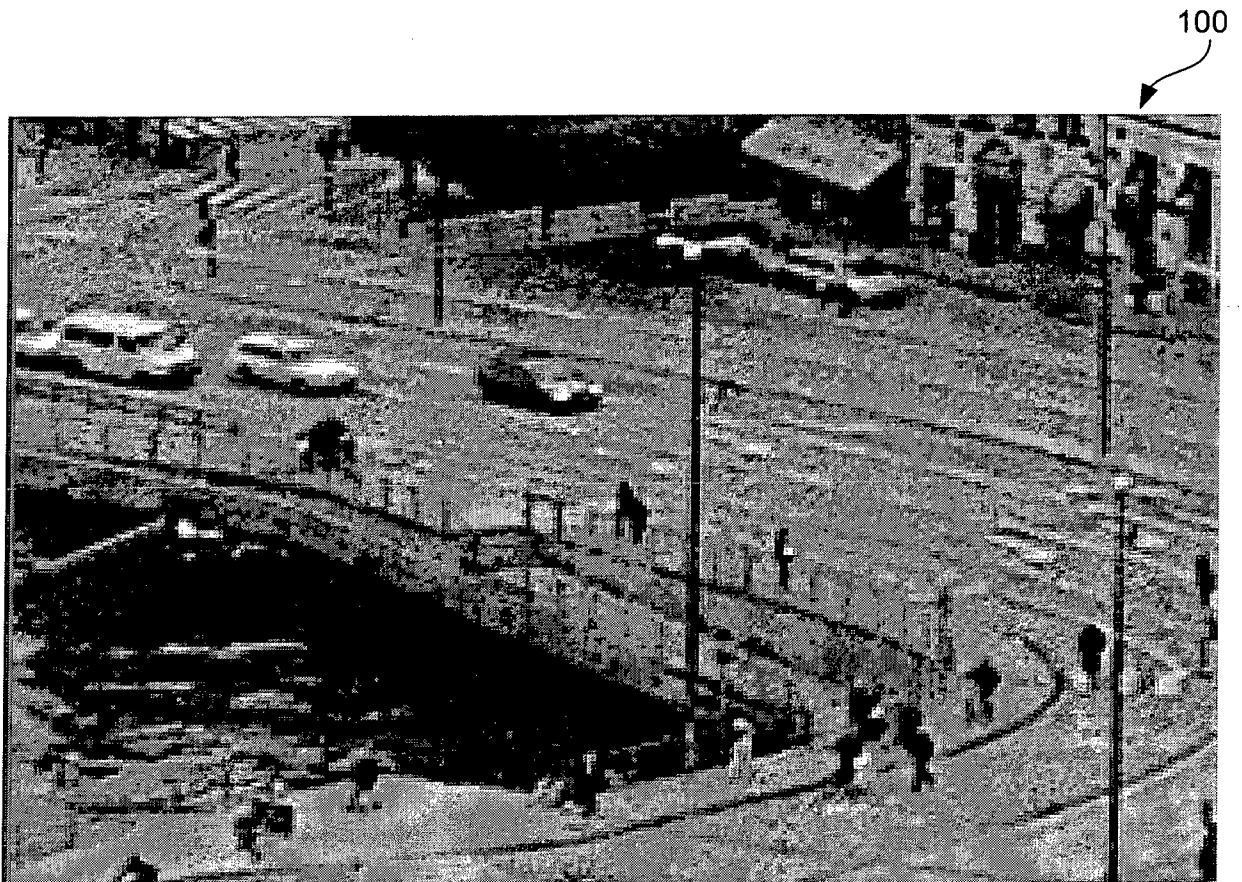
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FIG. 6



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FIG. 7



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FIG. 8

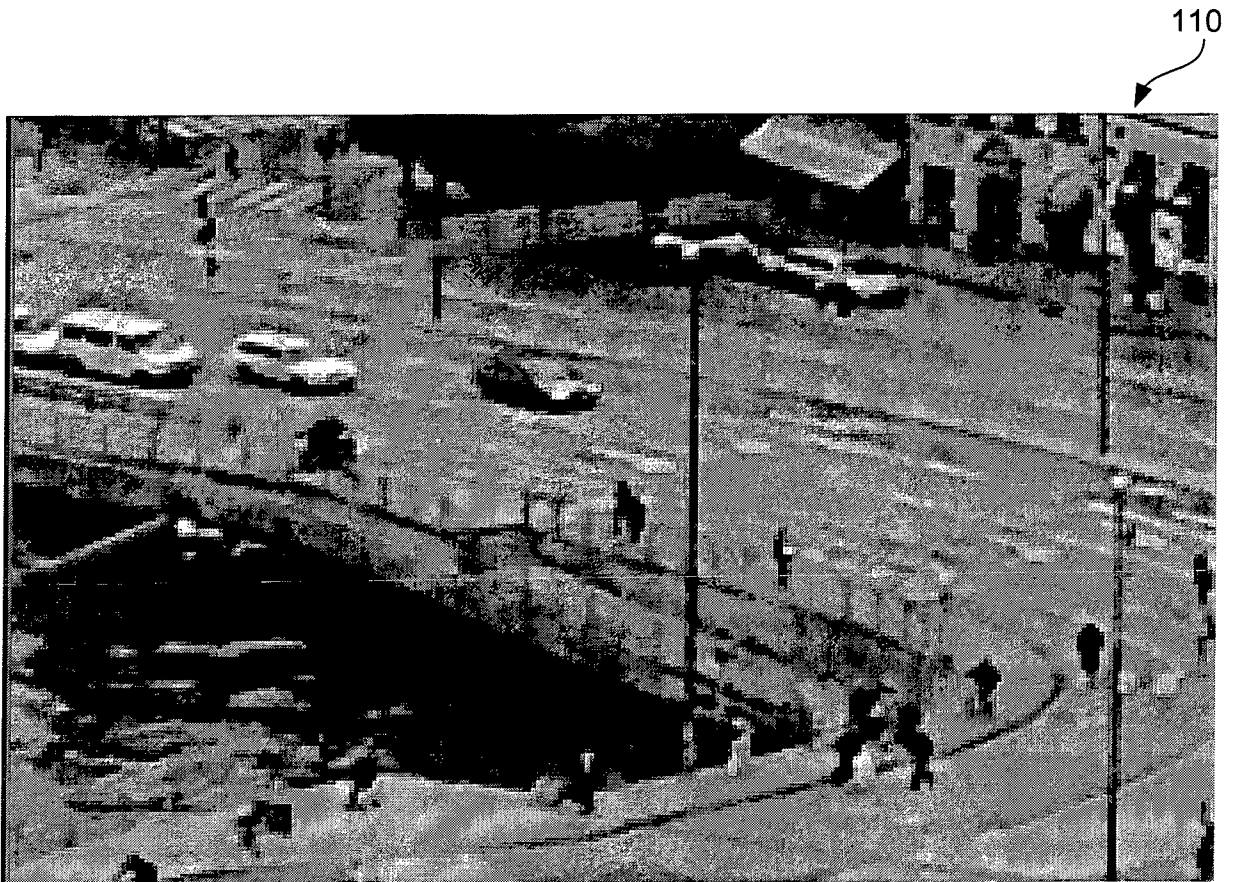
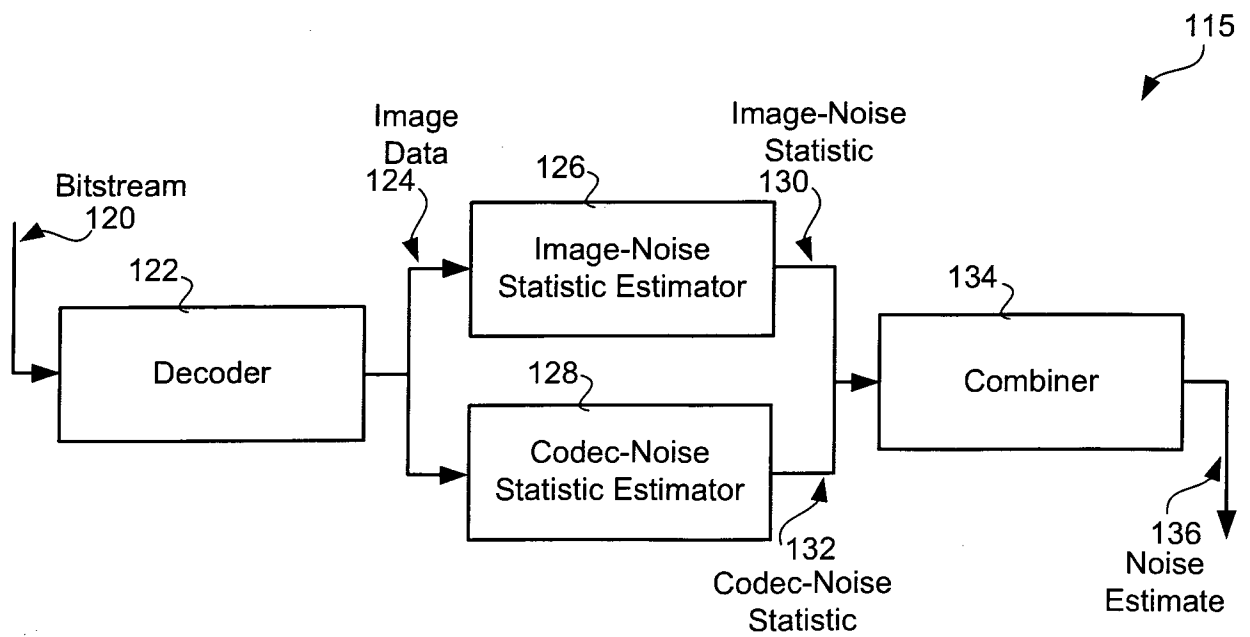
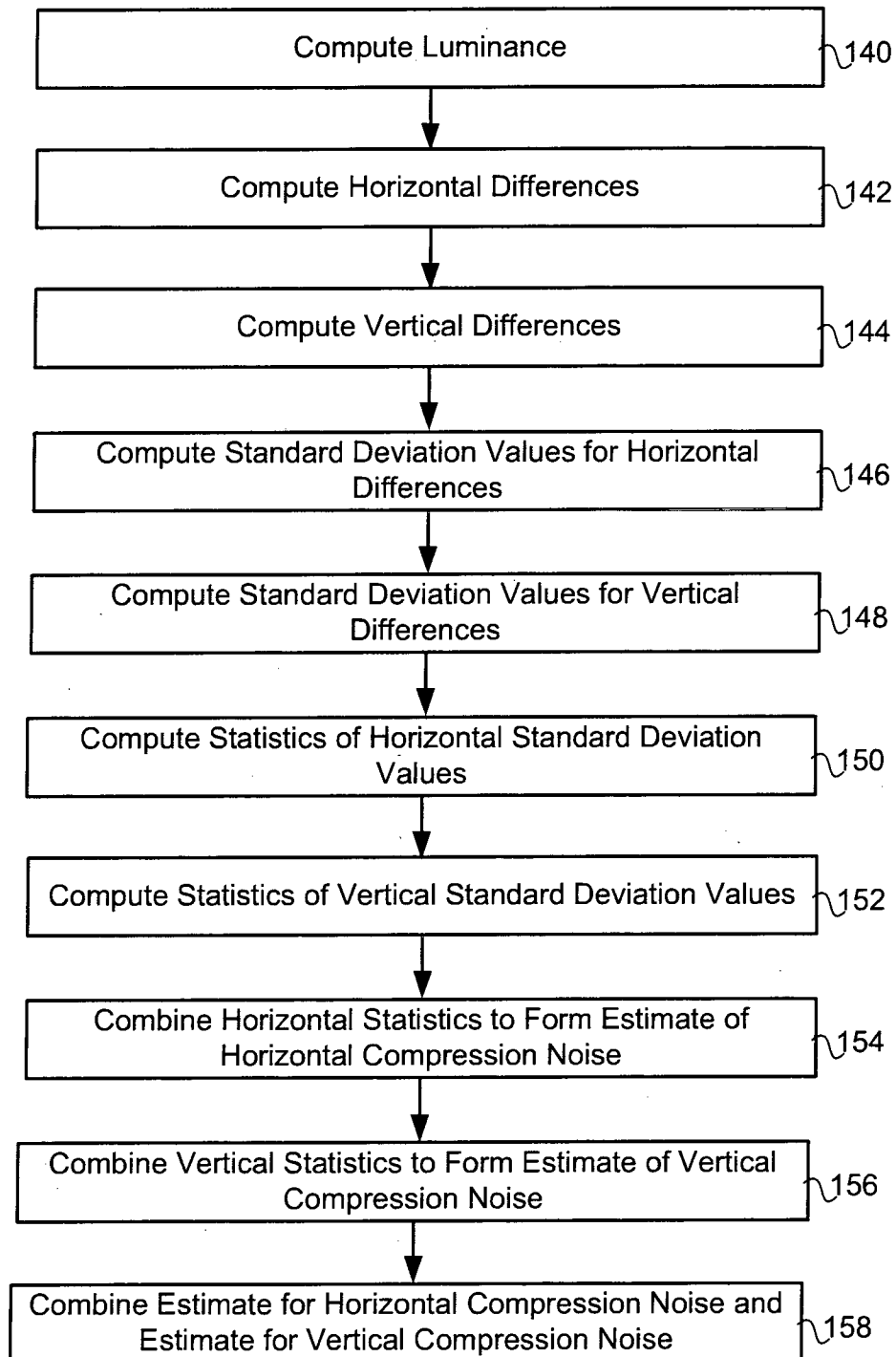


FIG. 9



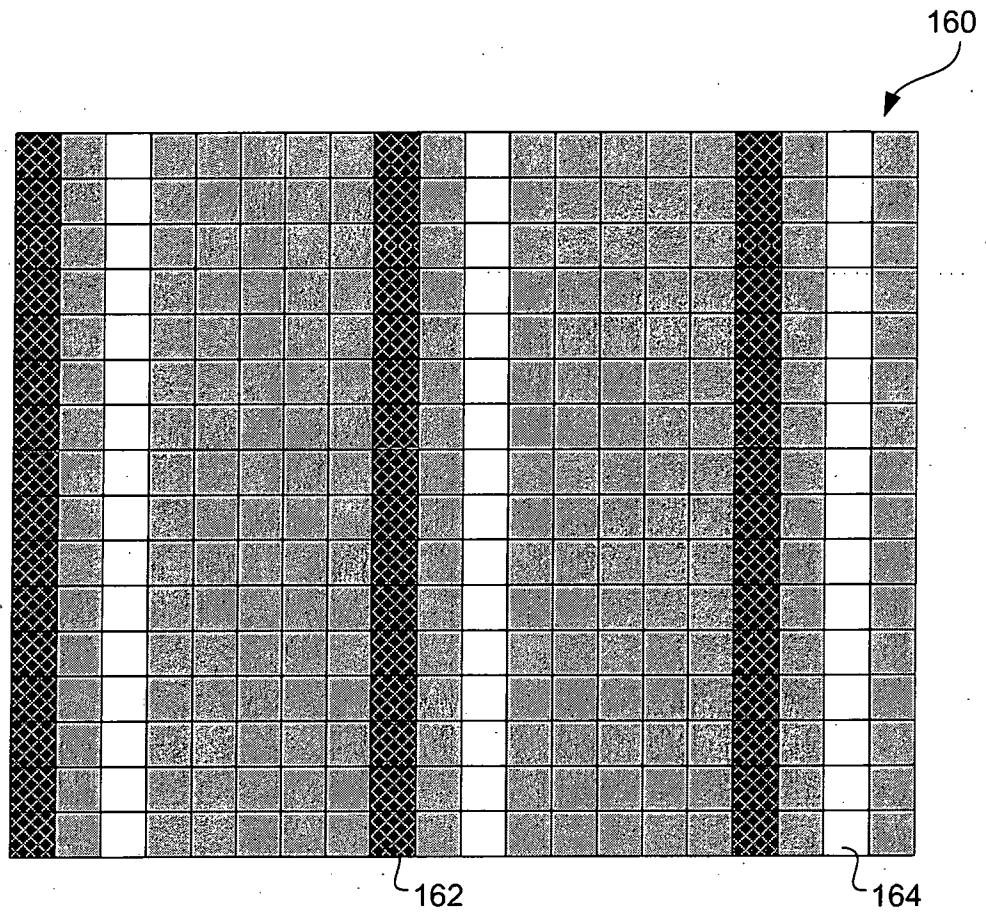
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FIG. 10



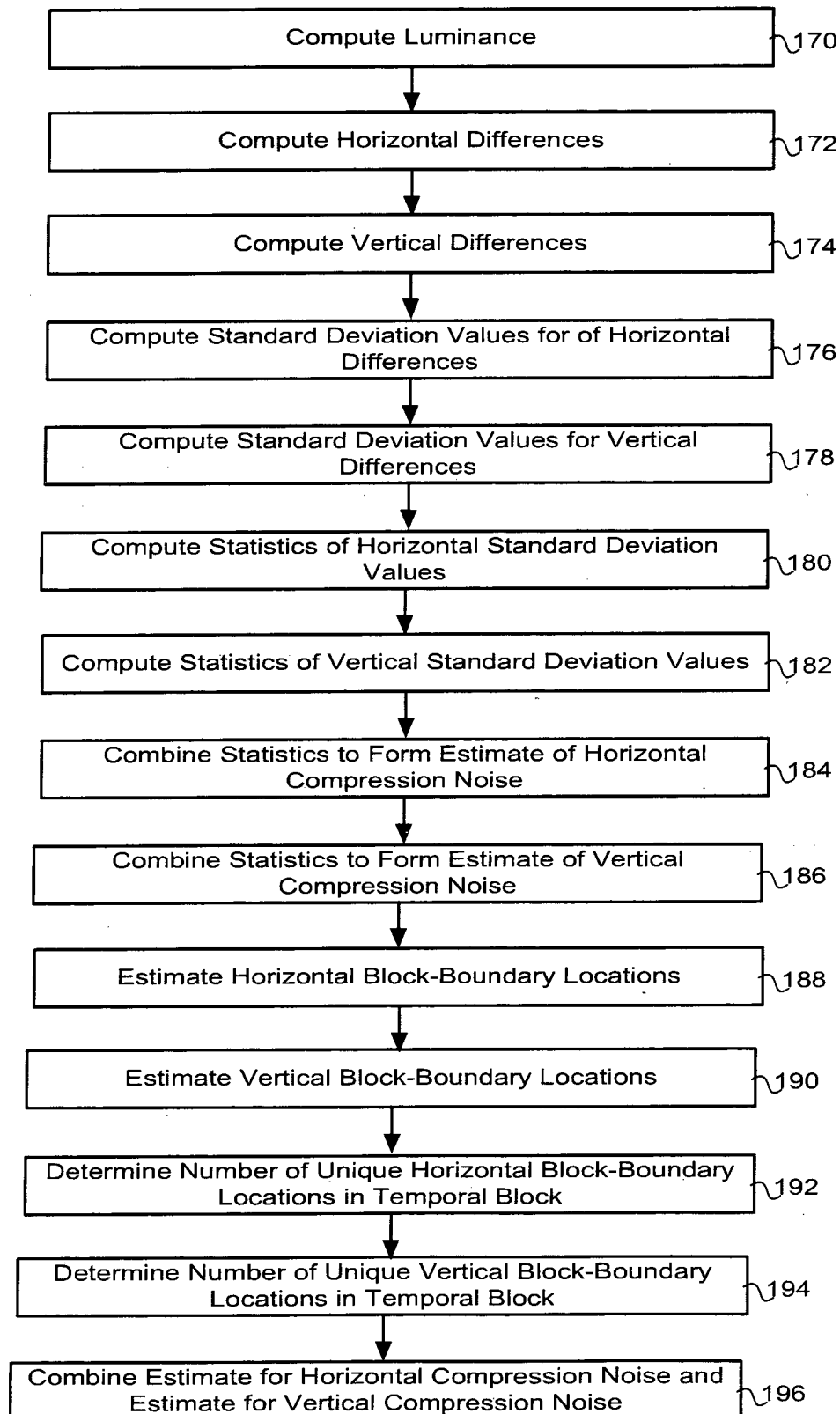
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FIG. 11



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FIG. 12



1 1 / 2 0

FIG. 13

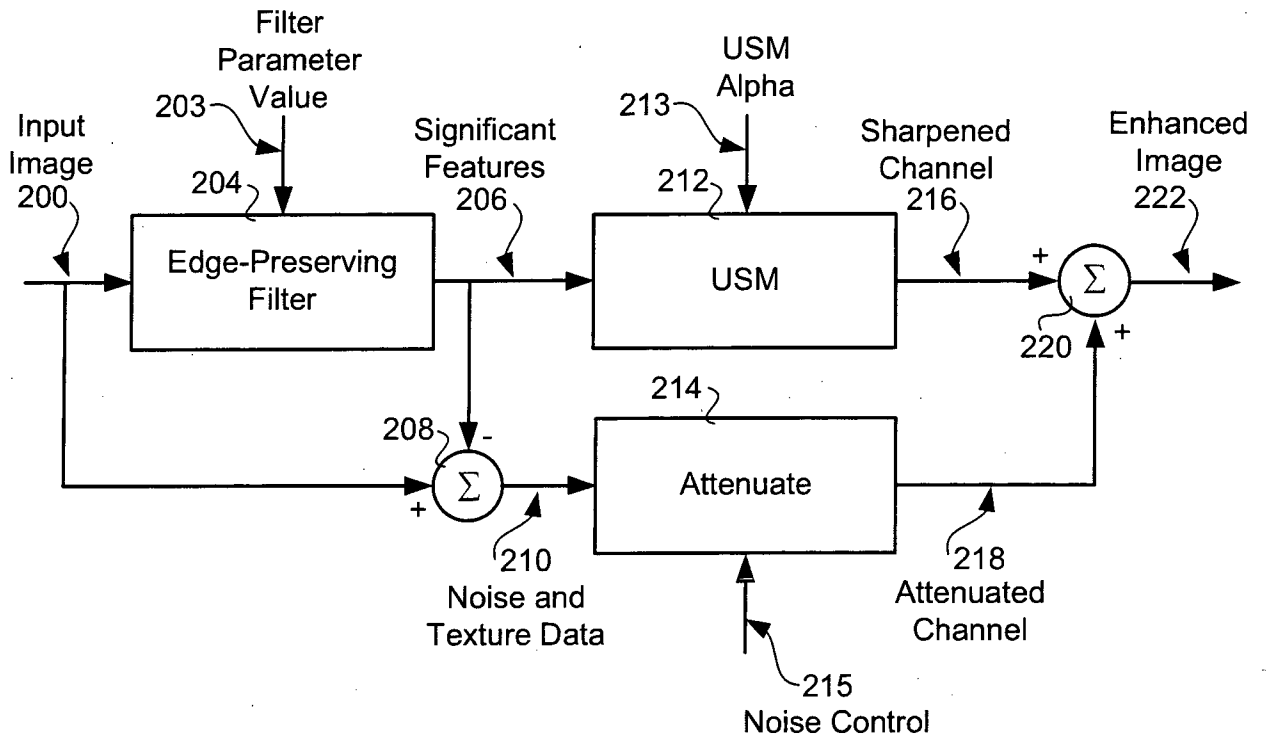
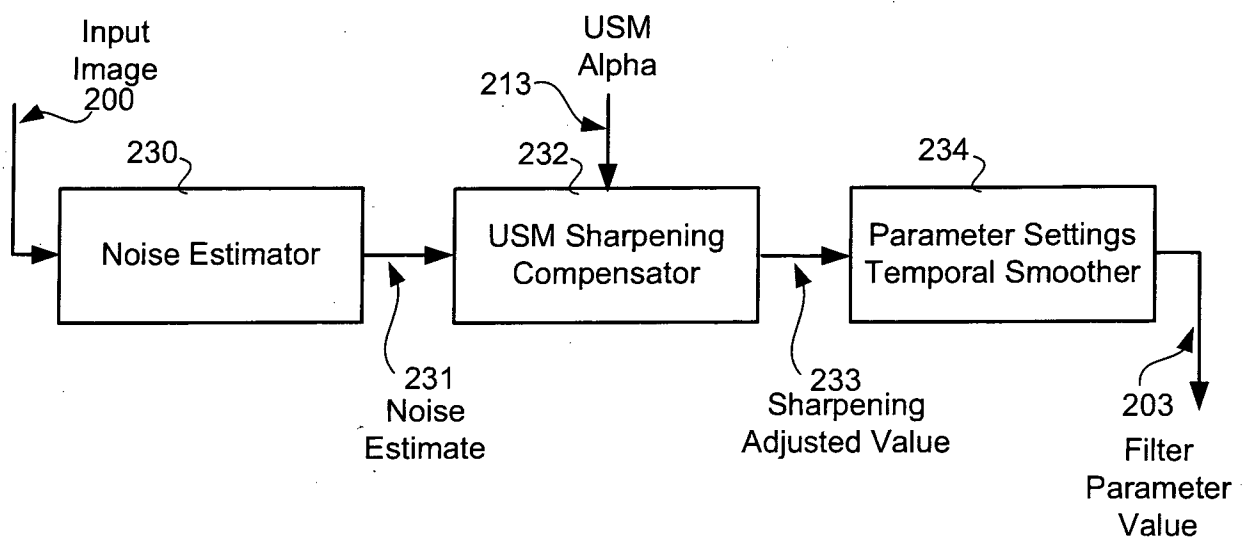
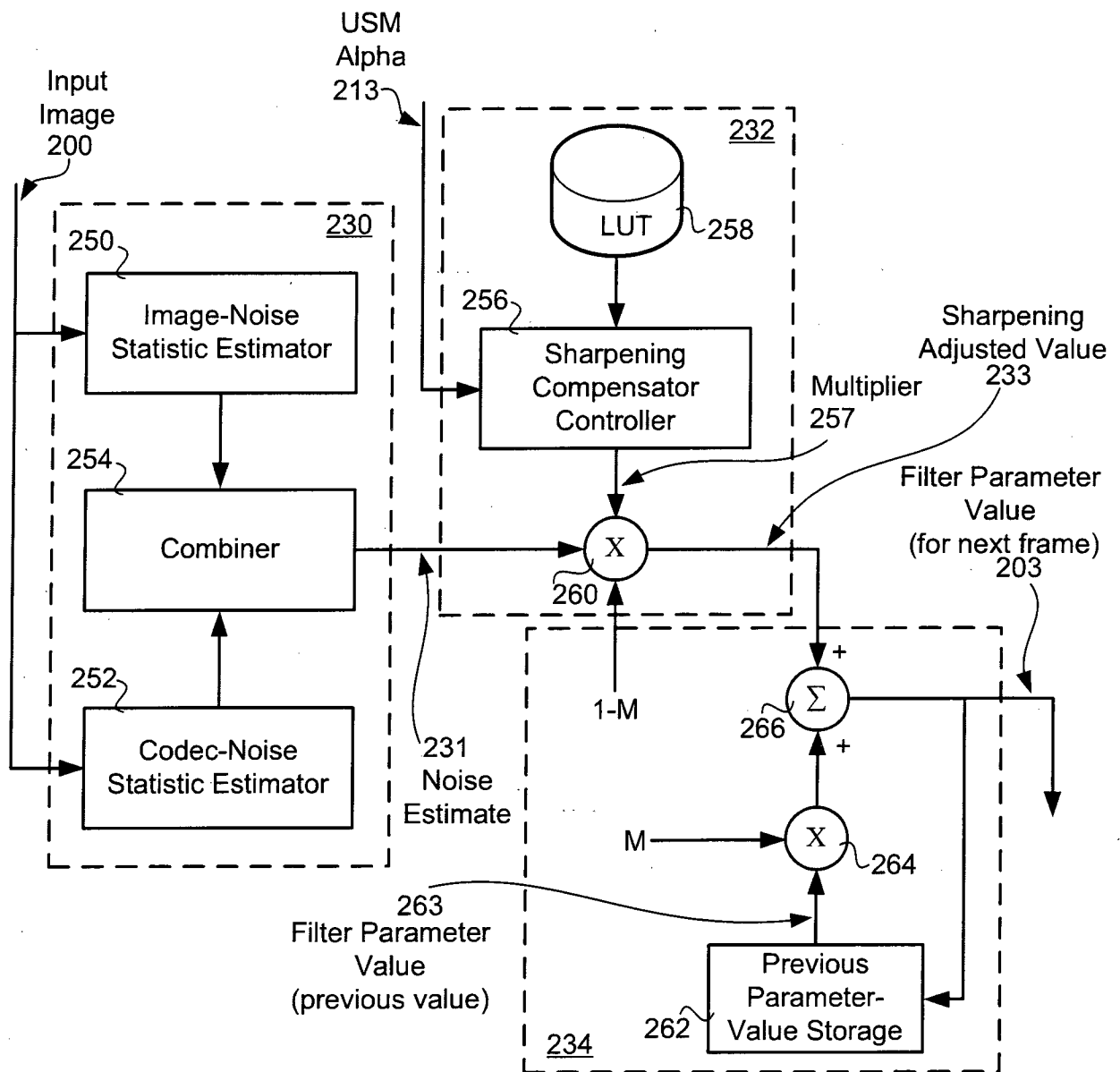


FIG. 14



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FIG. 15



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FIG. 16

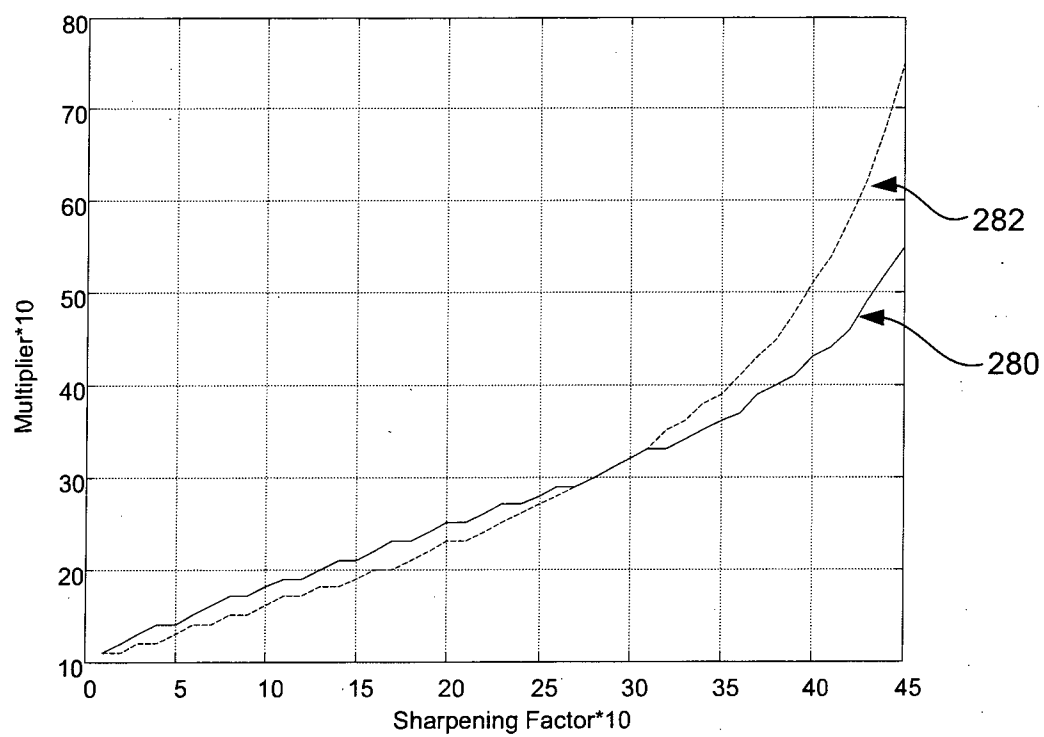
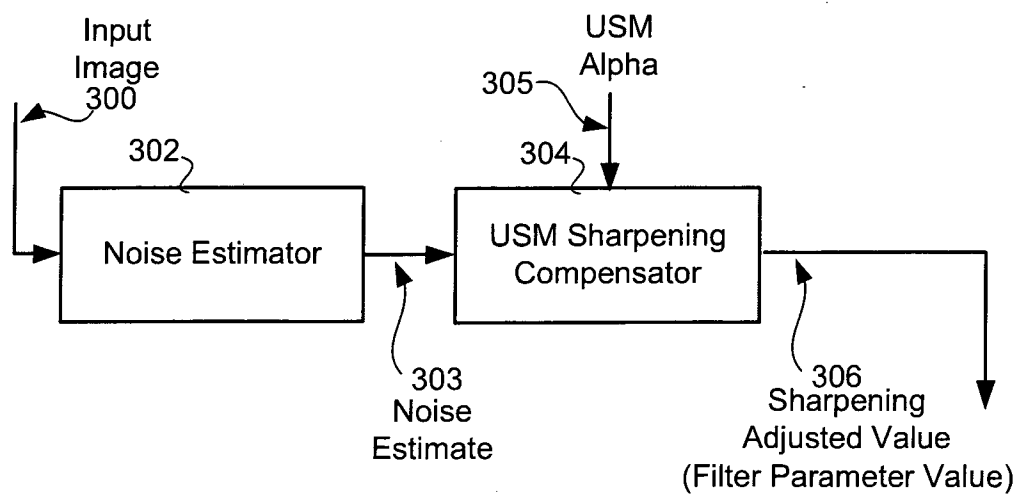


FIG. 17



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FIG. 18

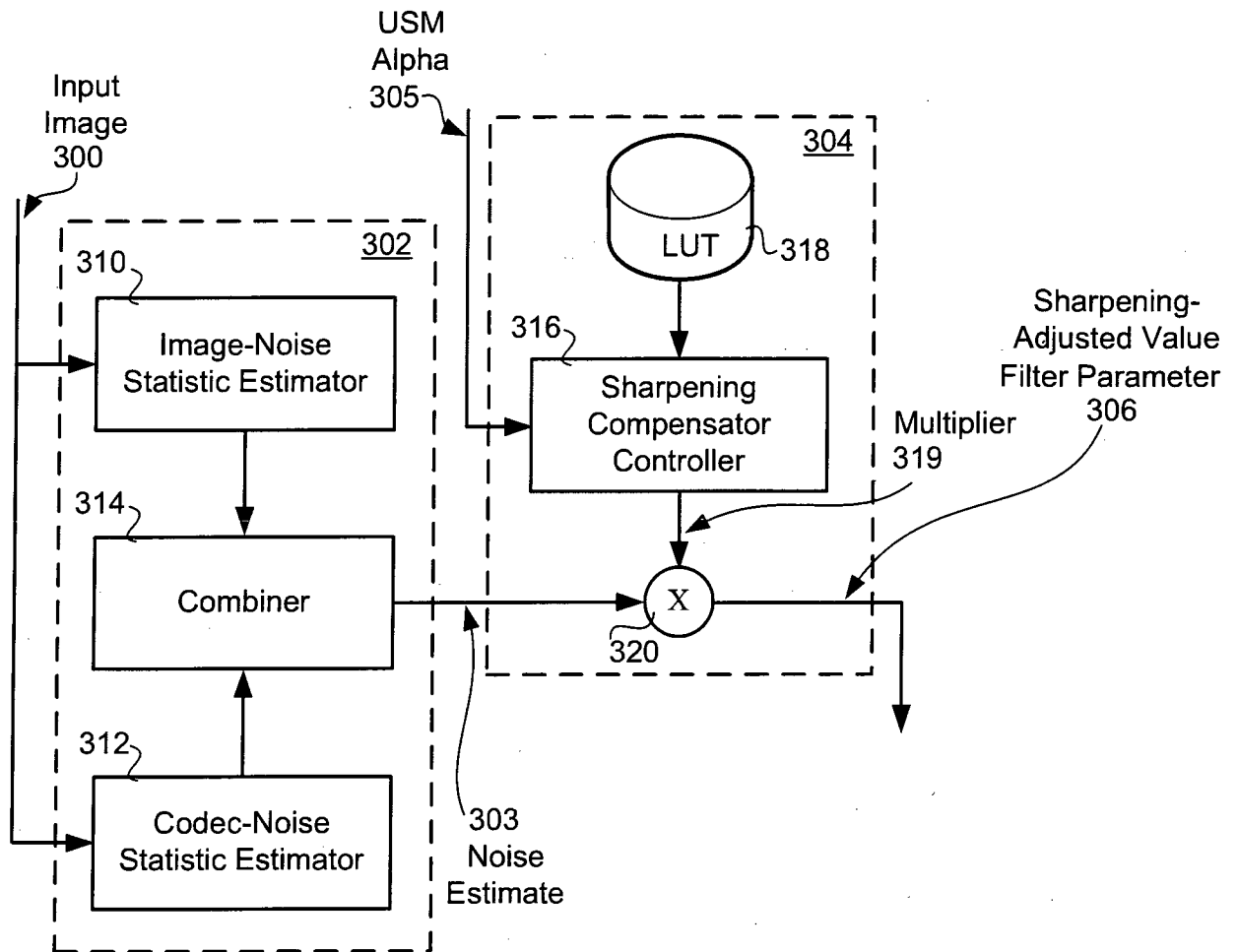
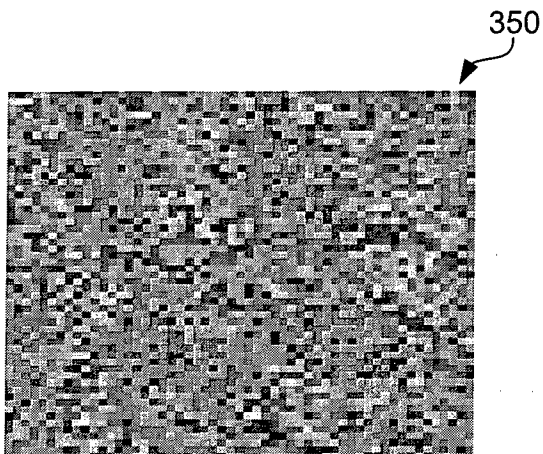


FIG. 19



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FIG. 20

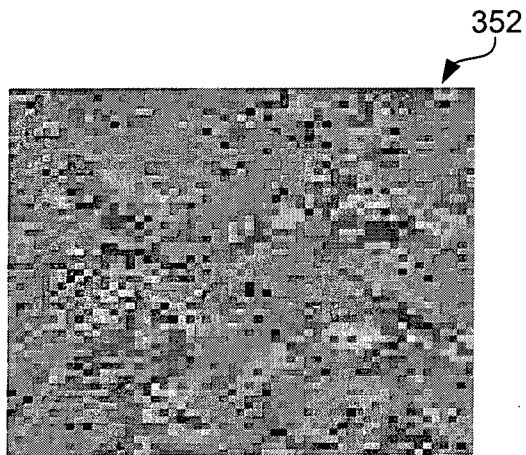


FIG. 21

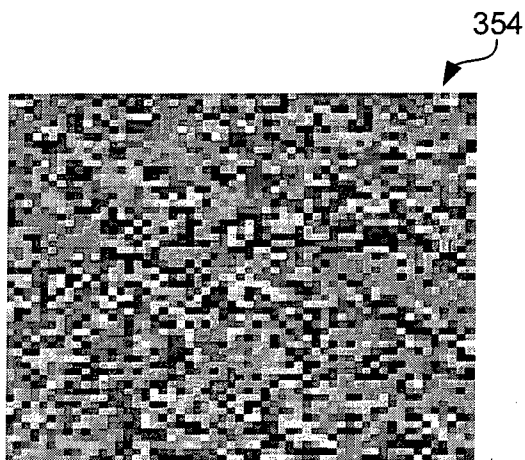
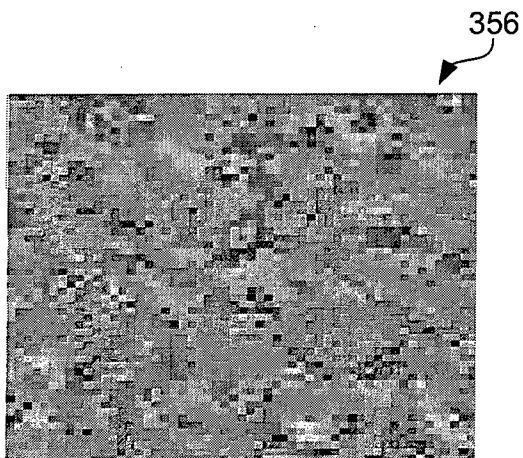


FIG. 22



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FIG. 23



FIG. 24

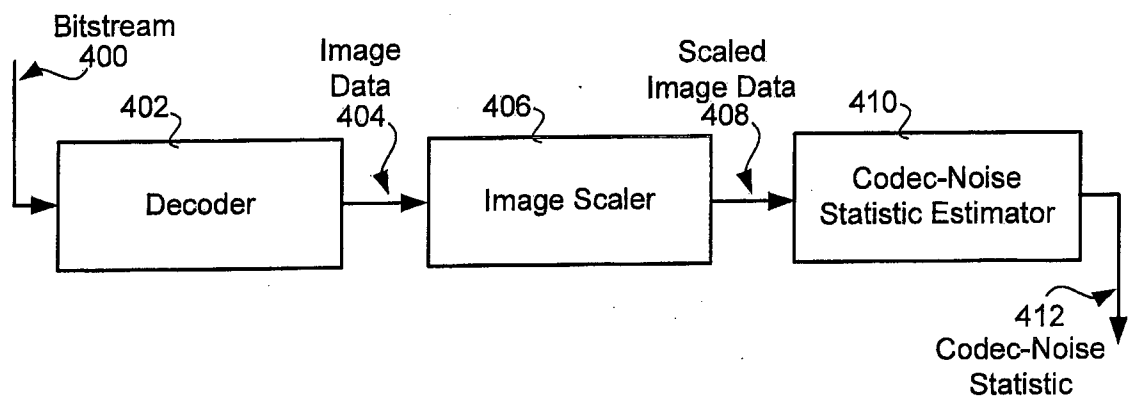


FIG. 25



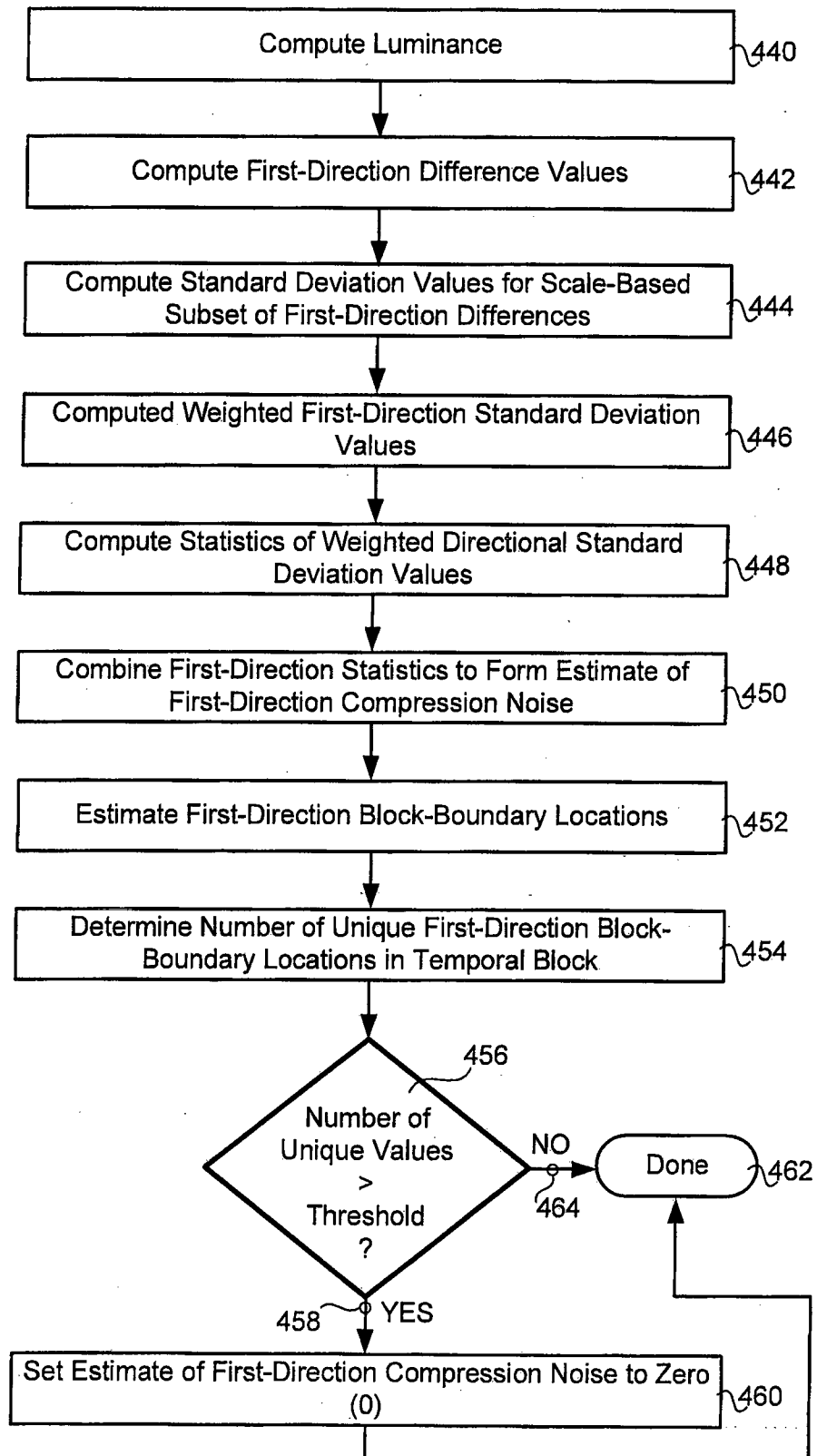
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FIG. 26



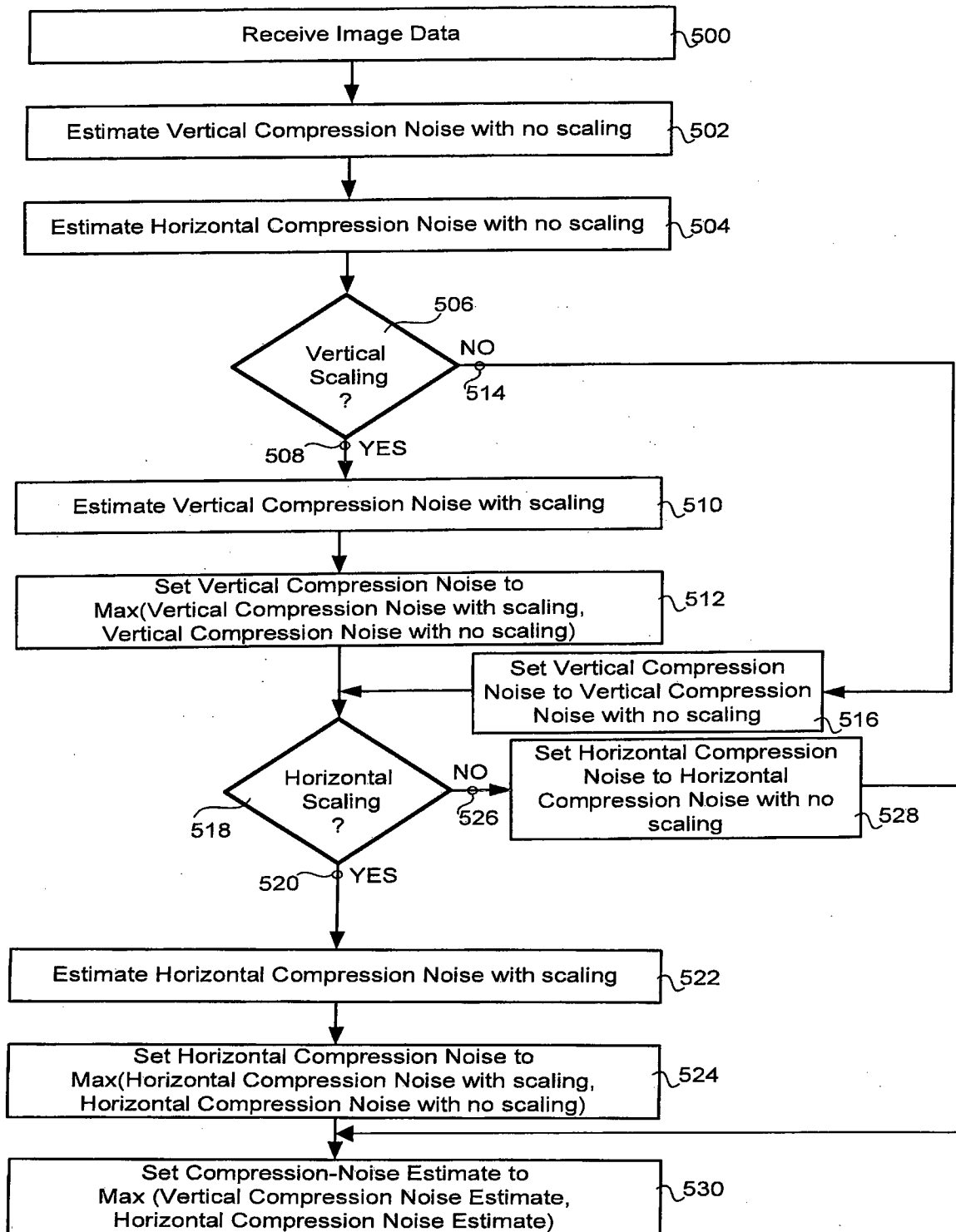
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FIG. 27



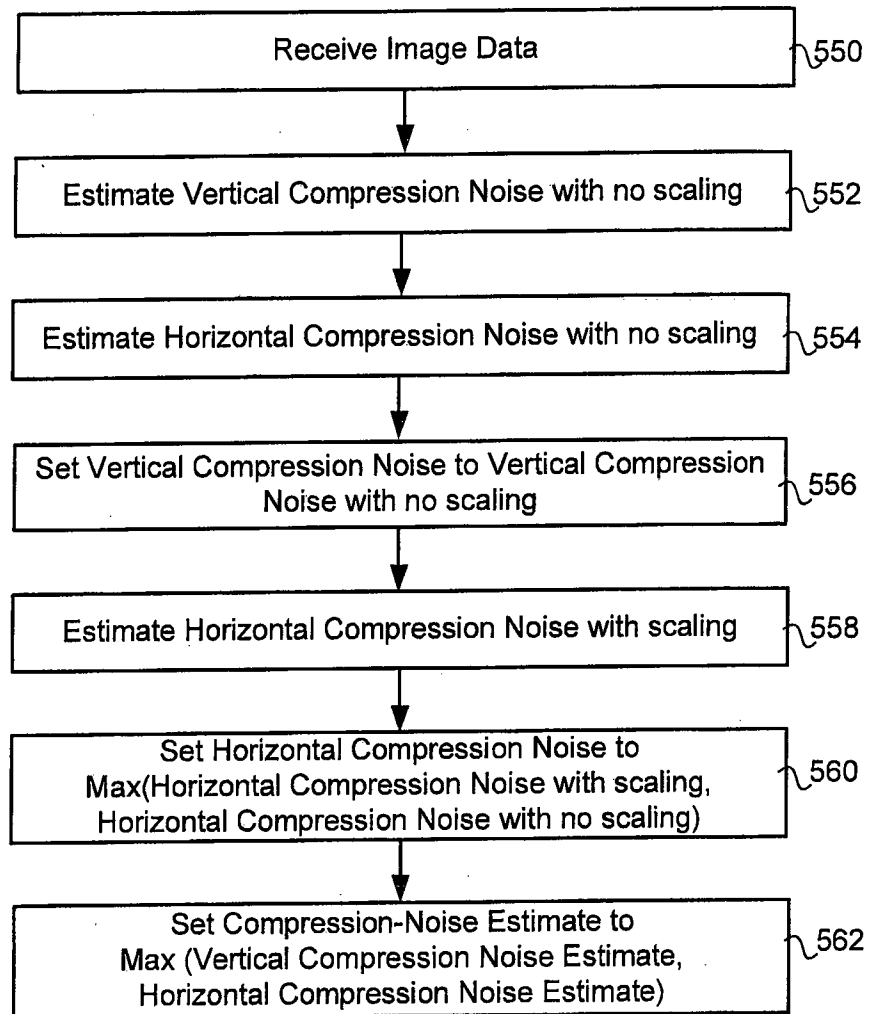
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FIG. 28



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FIG. 29



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/055870

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H04N5/21 (2006.01) i, G06T5/00 (2006.01) i, H04N7/26 (2006.01) i

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)

Int.Cl. H04N5/21, G06T5/00, H04N7/26

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2011
 Registered utility model specifications of Japan 1996-2011
 Published registered utility model applications of Japan 1994-2011

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-206713 A (Sony Corporation) 2009.09.10, [0027]-[0269], Fig.1-28 & US 2009/0214133 A1	1-21
A	JP 2007-266684 A (Fujitsu Ltd.) 2007.10.11, [0037]-[0040], Fig.10-13 & US 2007/0223835 A1	1-21
A	JP 2002-77914 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 2002.03.15, [0031]-[0048], Fig.1-3 (No Family)	1-21
A	JP 2004-140759 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 2004.05.13, [0029]-[0038], Fig.5-7 (No Family)	1-21



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Date of the actual completion of the international search

30.05.2011

Date of mailing of the international search report

07.06.2011

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