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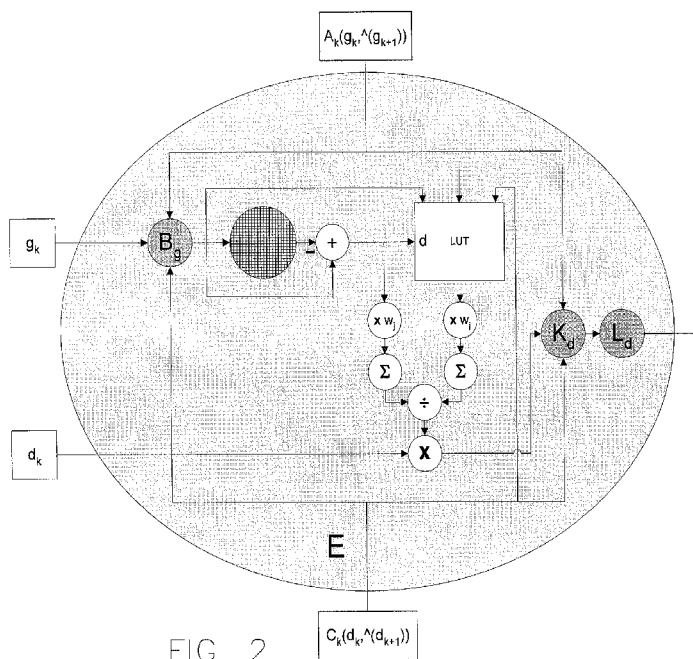


FIG. 2

(57) Abstract: A method of generating a multiscale contrast enhanced image is described wherein the shape of edge transitions is preserved. Detail images are subjected to a conversion, the conversion function of at least one scale being adjusted for each detail pixel value according to the ratio between the combination of the enhanced center differences and the combination of the unenhanced center differences. Several adaptive enhancement measures are described.

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METHOD OF ENHANCING THE CONTRAST OF AN IMAGE.

**[DESCRIPTION]**

5 FIELD OF THE INVENTION

The present invention relates to a method for enhancing the image quality of an image that is represented by a digital signal.

10 BACKGROUND OF THE INVENTION

Commonly images represented by a digital signal such as medical images are subjected to image processing during or prior to displaying or hard copy recording.

15

The conversion of grey value pixels into values suitable for reproduction or displaying may comprise a multi-scale image processing method (also called multi-resolution image processing method) by means of which the contrast of the image is enhanced.

20

According to such a multi-scale image processing method an image, represented by an array of pixel values, is processed by applying the following steps. First the original image is decomposed into a sequence of detail images at multiple scales and occasionally  
25 a residual image. Next, the pixel values of the detail images are modified by applying to these pixel values at least one conversion. Finally, a processed image is computed by applying a reconstruction algorithm to the residual image and the modified detail images.

30

There are limits for the behavior of the conversion functions. Grey value transitions in the image can be distorted to an extent that the appearance becomes unnatural if the conversion functions are excessively non-linear. The distortions are more pronounced in the vicinity of significant grey level transitions, which may result  
35 in overshoots at step edges and loss of homogeneity in regions of low variance facing strong step edges. The risk of creating

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artifacts becomes more significant for CT images since they have sharper grey level transitions, e.g. at the interface of soft tissue and contrast media. One has to be careful using the multi-scale techniques on CT images.

5

A multi-scale contrast enhancement algorithm which results in a contrast enhanced image while preserving the shape of the edge transitions has been described in co-pending European patent application 06 125 766.3 filed December 11, 2006.

10

In one embodiment of this method the contrast of an image that is represented by a digital signal is enhanced by performing the following steps.

The digital signal is decomposed into a multi-scale representation comprising at least two detail images representing detail at multiple scales and approximation images of which the detail images are derived, an approximation image at a scale representing the grey values of said image in which all details at that scale have been omitted.

Next, translation difference images are computed of at least one approximation image.

The values of these translation difference images are non-linearly modified.

Then, an amplification image is computed at at least one scale as the ratio of 2 images wherein the first image is computed by combining the modified translation difference images at the same or smaller scale and the second image is created by combining un-enhanced translation difference images at the same or smaller scale.

An enhanced multi-scale detail representation is then computed by modifying at at least one scale the detail image according to the amplification image at that scale.

Finally an enhanced image representation is computed by applying a reconstruction algorithm to the enhanced multi-scale detail representation.

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It is an object of the present invention to further enhance this method.

## SUMMARY OF THE INVENTION

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The above-mentioned further enhancement is obtained by a method having the specific steps set out in claim 1. Specific elements for preferred embodiments of the invention are set out in the dependent claims.

10

In the context of the present invention specific terms are defined as follows:

## Multi-scale decomposition mechanism:

15

A multi-scale (or multi-resolution) decomposition of an image is a process that computes detail images of said image at multiple scales of a grey value image. A multi-scale decomposition mechanism generally involves filter banks for computing the detail images. Well-known techniques are for example: the Laplacian pyramid, the Burt pyramid, the Laplacian stack, the wavelet decomposition, QMF (quadrature mirror filter) filter banks.

20

## Approximation image:

25

An approximation image is a grey value image that represents the original grey value image at the same or a larger scale, or at the same or a lower resolution. An approximation image at a specific scale is equivalent to the original grey value image in which all details at that scale have been omitted (Mallat S.G., "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation", IEEE Trans. On Pattern Analysis and Machine Intelligence, vol. 11, no. 7, July 1989).

30

## Detail image:

35

A detail image is defined as the difference of information between an approximation image at a certain scale and an approximation image

at a smaller scale.

Conversion operator:

A conversion operator is an operator which generates the pixel-wise  
5 modification of the detail pixel values as an intermediate step to  
create a contrast enhanced version of the grey value image. Such an  
operator has for example been described in European patent EP 527  
525. The modification is defined by a conversion function and can  
e.g. be implemented as a look up table or as a multiplicative  
10 amplification.

Translation difference image:

The translation difference images at a scale  $s$  are a measurement of  
elementary contrast in each pixel of an approximation image at scale  
15  $s$ . They can be computed by taking the difference of the  
approximation image at that scale  $s$  and a translated version. Other  
computations for elementary contrast are possible, e.g. the ratio of  
pixel with a neighboring pixel can be used in case the processing  
steps are preceded by an exponential transform and followed by a log  
20 transform.

Center difference image:

A center difference image is computed by applying a combining  
operator (for example the summation) to translation difference  
25 images.

The combining operator can be a linear or non-linear function of  
corresponding pixel values in the translation difference images.

The prior art method described higher is enhanced by steering  
30 the non-linear modification of the values of the translation  
difference images by one or more characteristics computed out of the  
approximation images at at least one scale or by an approximation  
image itself.

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Examples of these characteristics that are described further on are the average grey value in an area, the local standard deviation etc.

Another example of a characteristic is the presence of  
5 predefined image structures or abnormal patterns in an approximation image. An example of such a pattern is a microcalcification in a mammographic image.

The detection of these abnormal patterns can be performed by several techniques reaching from simple filtering to a complex  
10 computer aided detection algorithm. For example by means of a binary localization mask the presence of these abnormal patterns can be used to steer the non-linear modification.

In another embodiment the non-linear modification of the values  
15 of the translation difference images is steered by (a) characteristic(s) computed out of the detail images or by a detail image itself. Examples are described below.

Approximation images may be filtered as will be explained  
20 further on.

The center differences may also be subjected to adaptive or non-adaptive filtering.

25 In one embodiment the center difference images are identical to the multi-scale detail images or a close approximation of the multi-scale detail images.

The present invention is generally implemented as a computer  
30 program product adapted to carry out the method of any of the claims when run on a computer and is stored on a computer readable medium.

The methods of the present invention can be applied for enhancing the image quality of medical images such as mammographic  
35 images, images obtained by computed tomography etc.

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Further advantages and embodiments of the present invention will become apparent from the following description and drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

5

Fig. 1 shows a multi-resolution image processing scheme with different control paths according to this invention, center difference images are computed out of the approximation images at the same scale,

10

Fig. 2 shows an advanced enhancement functional block making use of characteristics derived from approximation images and/or detail images as steering inputs,

Fig. 3 and 5 show different implementations of the multi-resolution image processing of the present invention,

15

Fig. 4 illustrates the image enhancement step of the multi-resolution image processing method illustrated in figure 3,

Fig. 6 illustrates the image processing step of the multi-resolution image processing method illustrated in figure 5,

20

Fig. 7 is a legend pertaining to the symbols used in the above figures.

## DETAILED DESCRIPTION OF THE INVENTION

25

This contrast enhancement algorithm is applicable to all multi-scale detail representation methods from which the original image can be computed by applying the inverse transformation.

30

It is applicable to the reversible multi-scale detail representation that can be computed as a weighted sum of translation difference images.

35

The weighing factors and the translation offsets of the translation difference images can be deducted from the multi-scale decomposition in such a way that the resulting weighted sum of the translation difference images is either identical or an approximation of the detail pixel values.

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For these multi-scale detail representations the contrast can be enhanced by applying the conversion operator to the center differences before the weighted sum is computed.

5 To compute the weighted sum of translation difference images, the approximation image at the same scale (or resolution level) or the approximation images at the smaller scales (or finer resolution levels) can be used.

10 State-of-the-art multi-scale contrast enhancement algorithms decompose an image into a multi-scale representation comprising detail images representing detail at multiple scales and a residual image.

Some of the important multi-scale decompositions are the wavelet decomposition, the Laplacian-of-Gaussians (or LoG decomposition), the Difference-of-Gaussians (or DoG) decomposition and the Burt pyramid.

20 The wavelet decomposition is computed by applying a cascade of high-pass and low-pass filters followed by a subsampling step.

The high-pass filter extracts the detail information out of an approximation image at a specific scale.

25 In the Burt pyramid decomposition the detail information is extracted out of an approximation image at scale  $k$  by subtracting the upsampled version of the approximation image at scale  $k+1$ .

30 In a state of the art methods as the one disclosed in EP 527 525 a contrast enhanced version of the image is created by conversion of the pixel values in the detail images followed by multi-scale reconstruction.

35 All above implementations of multiscale decomposition have a common property. Each pixel value in the detail images can be computed out of an approximation image by combining the pixel values in a moving neighborhood.

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In the above cases the combining function is a weighted sum.

For the wavelet decomposition the pixel values in the detail image at scale  $k$  are computed as:

$$\begin{aligned} d_{k+1} &= \downarrow ( h_d * g_k ) \\ g_{k+1} &= \downarrow ( l_d * g_k ) \end{aligned}$$

with  $h_d$  a high-pass filter,  $l_d$  a low-pass filter,  $*$  the convolution operator and  $\downarrow$  the subsampling operator (i.e. leaving out every second row and column).

10

For the wavelet reconstruction the enhanced approximation image at scale  $k$  is computed as:

$$h_k = l_r * ( \uparrow h_{k+1} ) + h_r * ( \uparrow f ( d_{k+1} ) )$$

with  $h_r$  a high-pass filter,  $l_r$  a low-pass filter and  $\uparrow$  the upsampling operator (i.e. inserting pixels with value 0 in between any two rows and columns).

15

For the Burt decomposition the pixel values in the detail image at scale  $k$  are computed as:

$$d_k = g_k - 4g * ( \uparrow g_{k+1} )$$

or

$$d_k = g_k - 4g * ( \uparrow ( \downarrow ( g * g_k ) ) )$$

or

$$d_k = ( 1 - 4g * ( \uparrow ( \downarrow g ) ) ) * g_k$$

25

with  $g$  a Gaussian low-pass filter and  $1$  the identity operator.

For the Burt reconstruction the enhanced approximation image at scale  $k$  is computed as:

$$h_k = 4g * ( \uparrow h_{k+1} ) + f ( d_k )$$

with  $f(x)$  the conversion operator.

30

### ***The multi-scale detail pixel values as weighted sums***

35 Suppose that in the Burt multi-scale decomposition a 5x5 Gaussian

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filter is used with coefficients  $w_{k,1}$  with  $k = -2, \dots, 2$  and  $l = -2, \dots, 2$ , the subsampling operator removes every second row and column and the upsampling operator inserts pixels with value 0 in between any two rows and columns.

5 The pixel at position  $i, j$  in the approximation image  $g_{k+1}$  is computed as:

$$g_{k+1}(i, j) = \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(2i+s, 2j+t)$$

The pixel at position  $i, j$  in the upsampled image  $u_k$  is computed as:

$$10 \quad u_k(i, j) = \begin{cases} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s, j+t) & \text{if } i \text{ and } j \text{ are even} \\ 0 & \text{otherwise} \end{cases}$$

The pixel at position  $i, j$  in the upsampled, smoothed image  $gu_k$  is computed as:

$$gu_k(i, j) = \begin{cases} \sum_{m=\{-2,0,2\}} \sum_{n=\{-2,0,2\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ and } j \text{ are even} \\ \sum_{m=\{-1,1\}} \sum_{n=\{-2,0,2\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ is odd and } j \text{ is even} \\ \sum_{m=\{-2,0,2\}} \sum_{n=\{-1,1\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ is even and } j \text{ is odd} \\ \sum_{m=\{-1,1\}} \sum_{n=\{-1,1\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ and } j \text{ are odd} \end{cases}$$

15 Finally, the pixel at position  $i, j$  in the detail image  $d_k$  is computed as:

$$d_k(i, j) = \begin{cases} g_k(i, j) - 4 \sum_{m=\{-2,0,2\}} \sum_{n=\{-2,0,2\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ and } j \text{ are even} \\ g_k(i, j) - 4 \sum_{m=\{-1,1\}} \sum_{n=\{-2,0,2\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ is odd and } j \text{ is even} \\ g_k(i, j) - 4 \sum_{m=\{-2,0,2\}} \sum_{n=\{-1,1\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ is even and } j \text{ is odd} \\ g_k(i, j) - 4 \sum_{m=\{-1,1\}} \sum_{n=\{-1,1\}} w_{m,n} \sum_{s=-2}^2 \sum_{t=-2}^2 w_{s,t} g_k(i+s+m, j+t+n) & \text{if } i \text{ and } j \text{ are odd} \end{cases}$$

- 10 -

Generally, the pixel at position  $i, j$  in the detail image  $d_k$  can be computed as a weighted sum of pixels in the approximation image at the same or smaller scale  $k, k-1, k-2, \dots$  :

$$d_k(i, j) = g_l(ri, rj) - \sum_m \sum_n v_{m,n} g_l(ri + m, rj + n)$$

with  $l \in \{0, \dots, k\}$  and  $r = \text{subsampling\_factor}^{(l-k)}$

10 Because

$$\sum_m \sum_n v_{m,n} = 1$$

the pixel at position  $i, j$  in the detail image  $d_k$  can be computed as:

$$d_k(i, j) = g_l(ri, rj) - \sum_m \sum_n v_{m,n} g_l(ri + m, rj + n)$$

$$15 \quad d_k(i, j) = \sum_m \sum_n v_{m,n} g_l(ri, rj) - \sum_m \sum_n v_{m,n} g_l(ri + m, rj + n)$$

$$d_k(i, j) = c_k(i, j) = \sum_m \sum_n v_{m,n} (g_l(ri, rj) - g_l(ri + m, rj + n))$$

The term  $g_l(ri, rj) - g_l(ri + m, rj + n)$  is called a translation difference.

It expresses the difference in pixel value between a central pixel and a neighboring pixel in an approximation image. It is a measure of local contrast.

The weighted sum of the translation differences is called a centre difference  $c_k(i, j)$ .

25 In a similar way it can be proven that the detail images in other multi-scale decomposition methods can also be represented as a combination of translation difference images.

### 30 **The conversion operation**

In state-of-the-art methods like the one disclosed in EP 527 525

contrast enhancement is obtained by applying a conversion operator  $f(x)$  to the detail image  $d_k$  or, equivalently:

$$f(d_k(i, j)) = f\left(g_i(ri, rj) - \sum_m \sum_n v_{m,n} g_i(ri + m, rj + n)\right)$$

5

An example of such a conversion operator is the sigmoid function. Another example of such conversion operator is the contrast enhancement function like the one disclosed in EP 525 527. The shape of the conversion operator depends on the specific requirements of the enhancement which is intended to amplify the low-value detail pixel more than the high-value detail pixels.

10

The conversion step may cause deformations of the shape of the edge transitions in the reconstructed, contrast enhanced image.

15

The reason is the non-linearity of the conversion function.

Generally, the following applies to non-linear functions:

$$f(x + y) \neq f(x) + f(y)$$

or

$$f\left(\sum_i x_i\right) \neq \sum_i f(x_i)$$

20

State-of-the-art algorithms first compute the pixel values in the detail image  $d_k$  as weighted sums and apply the conversion step afterwards.

25

By rewriting the pixel values in the detail image  $d_k$  as a weighted sum of translation differences, it is possible to apply the conversion step before the summation instead of afterwards.

30

Contrast enhancement is now obtained by applying the conversion step to the translation differences:

$$f(d_k(i, j)) = \sum_m \sum_n v_{m,n} f(g_i(ri, rj) - g_i(ri + m, rj + n))$$

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In this way the shape of the edge transitions is better preserved in the contrast enhanced, reconstructed image.

5 If for every scale  $k$  the detail image at that scale is computed out of the full resolution image  $g_0$ , and enhancement is applied to the center differences, then the shapes of the edge transitions are best preserved after reconstruction.

10 Different implementations of the present invention are illustrated in figures 1, 3 and 5. Corresponding enhancement steps are shown in figures 2, 4, and 6.

#### **Functional blocks $A_k$**

15

With the functional blocks  $A_k$  desired characteristics can be extracted out of the approximation images  $g_k$  and/or  $g_{k+1}$ . These characteristics can be used as control inputs for the LUT operation in the enhancement block E and/or for optional adaptive filtering of the approximation images and/or the enhanced center difference images.

20

An approximation image can be used as input for determining any useful characteristic (e.g. histogram, filter coefficients, standard deviation image, gradient image, ... ).

25

An example of such a characteristic is an averaging filter to compute the average grey value in a specific neighborhood which makes grey value dependent enhancement possible.

30

Another characteristic can be the local standard deviation which will result in image activity dependent enhancement.

Still another example is the computation of a gradient image out of an approximation image to perform gradient-driven image enhancement for the purpose of noise reduction.

35

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State of the art multi-scale image processing methods can be used to reduce the noise in a digital image by filtering the detail images. A straightforward implementation is local averaging of the detail images so as to reduce differences between detail coefficients that are due to noise.

However, these straightforward methods are not satisfactory with respect to reducing the noise in the image while retaining the edges, e.g. small details with low contrast can become even less visible.

Better results can be achieved by adaptive filtering (e.g. weighted averaging) of the enhanced center difference images steered by the local gradient. The steering block  $A_k$  can thus be used to compute gradient images out of approximation images.

#### **Functional block Ck**

This transformation block can be used to extract certain characteristics out of the detail images. These characteristics can be used as optional control input for the LUT operator and the adaptive filters Bg and Kd (as will be explained further on).

An example of such a characteristic is the computation of the local standard deviation in the detail images as a measurement of noise-exceeding signal in the image. This makes noise-dependent image enhancement possible (e.g. to prevent an increase of the noise in the resulting, enhanced image).

The input to this block is a detail image, the output is a useful characteristic such as a histogram, filter coefficients, standard deviation image, gradient image, ... These characteristics are used to control the transformation block, described below.

It is one of the most apparent merits of digital image processing, that contrast can be raised to any feasible level. There is another side of the picture however, in that noise is amplified to the same extent. For that reason secondary control mechanisms are introduced to reduce the amount of contrast enhancement in areas where strong contrast enhancement is undesirable.

A suitable technique is to attenuate the enhancement of the

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translation differences in regions without prominent image features. An image of the local standard deviation can be computed out of a detail image as  $C_k(d_k)$ . This image can be used to attenuate the translation differences in regions with low standard deviation (almost homogeneous regions).

The result is a reduction of noise in the result image while retaining and even enhancing the edges in the image.

### Functional block LUT

This transformation block is used to create an enhanced version of the center difference images by modifying the translation differences  $d$ .

As control input a combination can be used of:

- $A_{k-m}(g_{k-m}, \uparrow(g_{k+1-m}))$
- $B_g(g_{k-m})$
- $C_k(d_{k-m}, \uparrow(d_{k+1-m}))$

The LUT operator can be implemented as a n-dimensional look up table or as an analytic function or as an adaptive filter or as any combination of the previous ones.

- Input: (optionally filtered) translation differences.

- Optional inputs:

- $A_{k-m}(g_{k-m}, \uparrow(g_{k+1-m}))$
- $B_g(g_{k-m})$
- $C_{k-m}(d_{k-m}, \uparrow(d_{k+1-m}))$

- Output: enhanced translation differences.

- Application:

Visualization of a digital image is generally improved by amplifying the contrast of subtle image features, and at the same time attenuating the strong components without the risk of omitting information.

This contrast equalization is done by generating enhanced multi-scale center difference images.

For this enhancement, the LUT operator is used to generate

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enhanced translation differences and these are combined to create enhanced center difference images.

The degree of enhancement can be steered by any characteristic derived from the approximation images or detail images.

5 By using the filtered grey value approximation image itself  $B_g(g_{k-m})$ , a grey-value dependent enhancement can be applied. For example, it can be useful to enhance the subtle contrasts more in the brighter image regions than the ones in the dark regions (e.g. to make the fine image structures of a  
10 mammographic image more visible within the fibroglandular tissue).

### Functional block $B_g$

15 The functional block  $B_g$  is an optional adaptive or non-adaptive filtering of the approximation images at each scale before the center difference images are computed.

The adaptive filter can be based on the characteristics of the approximation images at the same scale and/or coarser scale  $A_k(g_k, \uparrow(g_{k+1}))$  and/or on the characteristics of the detail images at the  
20 same scale and/or coarser scale  $C_k(d_k, \uparrow(d_{k+1}))$ .

Input: approximation image.

Optional inputs are

25 - characteristics of the approximation image at the scale  $k-m$  or scale  $k+1-m$

(with  $m = 0 \Rightarrow$  multi-scale processing scheme in figure 1;

with  $m >$  number of scales  $-1 \Rightarrow$  multi-scale processing scheme in figure 3; for intermediate values see fig.5).

30 - characteristics of the detail image at the scale  $k-m$  and/or scale  $k+1-m$

(with  $m = 0 \Rightarrow$  multi-scale processing scheme in figure 1,

with  $m >$  number of scales  $-1 \Rightarrow$  multi-scale processing scheme in figure 3; for intermediate values see fig. 5).

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Output: filtered approximation image.

This embodiment can be used as an anti-aliasing measure.

Aliasing is a common problem with the conventional image enhancement  
 5 processes. Aliasing is produced by the downsampling and upsampling  
 of the approximation images.

If the detail images are not modified, these aliasing effects are  
 cancelled out in the reconstruction process. However, if the  
 adaptive filtering and the LUT conversion are applied to the detail  
 10 images, there is no proper cancellation of the aliasing effects in  
 the reconstruction process. This will generate artefacts in the  
 enhanced digital image.

The appearance of these aliasing artefacts is reduced by computing  
 the enhanced center difference images instead of the direct  
 15 enhancement of the detail images.

However, even better image enhancement results can be achieved by  
 pre-filtering the approximation images  $g_k$  before computing the  
 translation differences.

#### 20 **Adaptive filter $K_d$**

The functional block  $K_d$  is an optional adaptive or non-adaptive  
 filtering of the enhanced center difference images.

This adaptive filter can be based on the characteristics of the  
 25 approximation images at the same scale and/or coarser scale  $A_k(g_{k-m},$   
 $\uparrow(g_{k+1-m}))$  and/or on the characteristics of the detail images at the  
 same scale and/or coarser scale  $C_k(d_{k-m}, \uparrow(d_{k+1-m}))$ .

An example is adaptive smoothing of the enhanced center difference  
 30 image where the steering input  $A_k(g_{k-m}, \uparrow(g_{k+1-m}))$  is e.g. a gradient  
 image of the approximation image at the coarser scale.

- Input: enhanced center difference image.

- Optional inputs:

o characteristics of the approximation image at the scale  
 35  $k-m$  and/or scale  $k+1-m$

(with  $m = 0 \Rightarrow$  multi-scale processing scheme in figure 1;

- 17 -

with  $m > \text{number of scales} - 1 \Rightarrow$  multi-scale processing scheme in figure 3; for intermediate values see fig. 5)  
 o characteristics of the detail image at the scale  $k-m$  and/or scale  $k+1-m$

5 (with  $m = 0 \Rightarrow$  multi-scale processing scheme in figure 1, with  $m > \text{number of scales} - 1 \Rightarrow$  multi-scale processing scheme in figure 3, for intermediate values see figure 5).

- Output: filtered enhanced center difference image.

10 • Application: It is one of the most apparent merits of digital image processing, that contrast can be raised to any feasible level. However, noise is amplified to the same extent. For that reason secondary control mechanisms are preferably introduced to reduce the amount of contrast enhancement in areas where  
 15 strong contrast enhancement is undesirable.

For this purpose the enhanced center difference images can be smoothed in a direction perpendicular to the local gradient (derived from the approximation images  $A_k(g_{k-m}, \uparrow(g_{k+1-m}))$ ). This reduces the noise in the resulting image while retaining and  
 20 even enhancing the edges in the result image.

#### Transformation block $L_d$

The functional block  $L_d$  applies an optional pixel-wise transform to the enhanced center difference images.  
 25

- Input: enhanced center difference image.
- Output: transformed, enhanced center difference image.
- Application:

30 In case an overall increase of the sharpness of the resulting image is preferred, this can be achieved by amplification of the finest, enhanced center difference images.

Another example of such an optional transform is the Normalization of the amplitudes of the enhanced center difference images.

35 ■

**[CLAIMS]**

1. A method for enhancing the contrast of an image that is  
5 represented by a digital signal wherein

a. said digital signal is decomposed into a multi-scale  
representation comprising at least two detail images  
representing detail at multiple scales and approximation  
10 images of which the detail images are derived, an  
approximation image at a scale representing the grey  
values of said image in which all details at that scale  
have been omitted,

b. translation difference images are computed by pixel-wise  
subtracting the values of an approximation image at scale  
15 s and the values of translated versions of said  
approximation image,

c. the values of said translation difference images are non-  
linearly modified,

d. an amplification image is computed at at least one scale  
20 as the ratio of 2 images wherein the first image is  
computed by combining said modified translation  
difference images at the same or smaller scale and the  
second image is created by combining un-enhanced  
translation difference images at the same or smaller  
25 scale, said un-enhanced translation difference images  
being different from said detail images,

e. an enhanced multi-scale detail representation is computed  
by modifying at at least one scale the detail image  
according to the amplification image at that scale,

f. an enhanced image representation is computed by applying  
30 a reconstruction algorithm inverting the multi-scale  
decomposition to the enhanced multi-scale detail  
representation,

35 **wherein** at least one of the following actions is performed:

- 19 -

(1) said non-linear modification of the values of said translation difference images is steered by (a) characteristic(s) computed out of said approximation image(s) at at least one scale;

5 (2) said non-linear modification of the values of said translation difference images is steered by (a) characteristic(s) computed out of said detail images;

(3) said approximation images at a scale are subjected to an adaptive or non-adaptive filter to generate filtered approximation images;

(4) an adaptive or non-adaptive filter is applied to the enhanced center difference images;

(5) a transform is applied to the enhanced and filtered center difference images.

15

2. A method according to claim 1 wherein said characteristic computed out of said approximation image is the average grey value in a predefined image area.

20

3. A method according to claim 1 wherein said characteristic computed out of said approximation image is the local standard deviation.

25

4. A method according to claim 1 wherein said characteristic computed out of said approximation image is the presence of predefined image structures or abnormal patterns in said approximation image.

30

5. A method according to claim 1 wherein said characteristic computed out of the detail images is an image of the local standard deviation.

35

6. A method according to claim 1 wherein said filtering applied to said approximation images is based on the characteristics of said approximation images at said scale or a coarser scale

- 20 -

or on the characteristics of detail images at said scale or a coarser scale.

- 5 7. A method according to claim 1 wherein said filter applied to said enhanced center difference images is based on the characteristics of the approximation images at the same or a coarser scale or on the characteristics of the detail images at the same or a coarser scale.
- 10 8. A method according to claim 1 wherein said transform applied to the enhanced and filtered center difference images is a normalization.
- 15 9. A method according to any of the preceding claims wherein a translation difference image at a specific scale is computed out of an approximation image at the same scale.
- 20 10. A method according to any of the preceding claims modified in that all of said translation difference images are computed out of the original image.
- 25 11. A method according to any of the preceding claims wherein a translation image at a scale  $k$  is computed out of an approximation image at scale  $m$ , wherein  $m$  represents a scale between scale 1 and scale  $k-1$ .
- 30 12. A method according to any of the preceding claims wherein the center difference images are identical to the multi-scale detail images or a close approximation of the multi-scale detail images.
13. A method according to any of the preceding claims wherein said image is a mammographic image.

14. A method according to any of the preceding claims wherein said image is a CT image.

5 15. A computer program product adapted to carry out the method of any of the preceding claims when run on a computer.

16. A computer readable medium comprising computer executable program code adapted to carry out the steps of any of the preceding claims.

10 ■

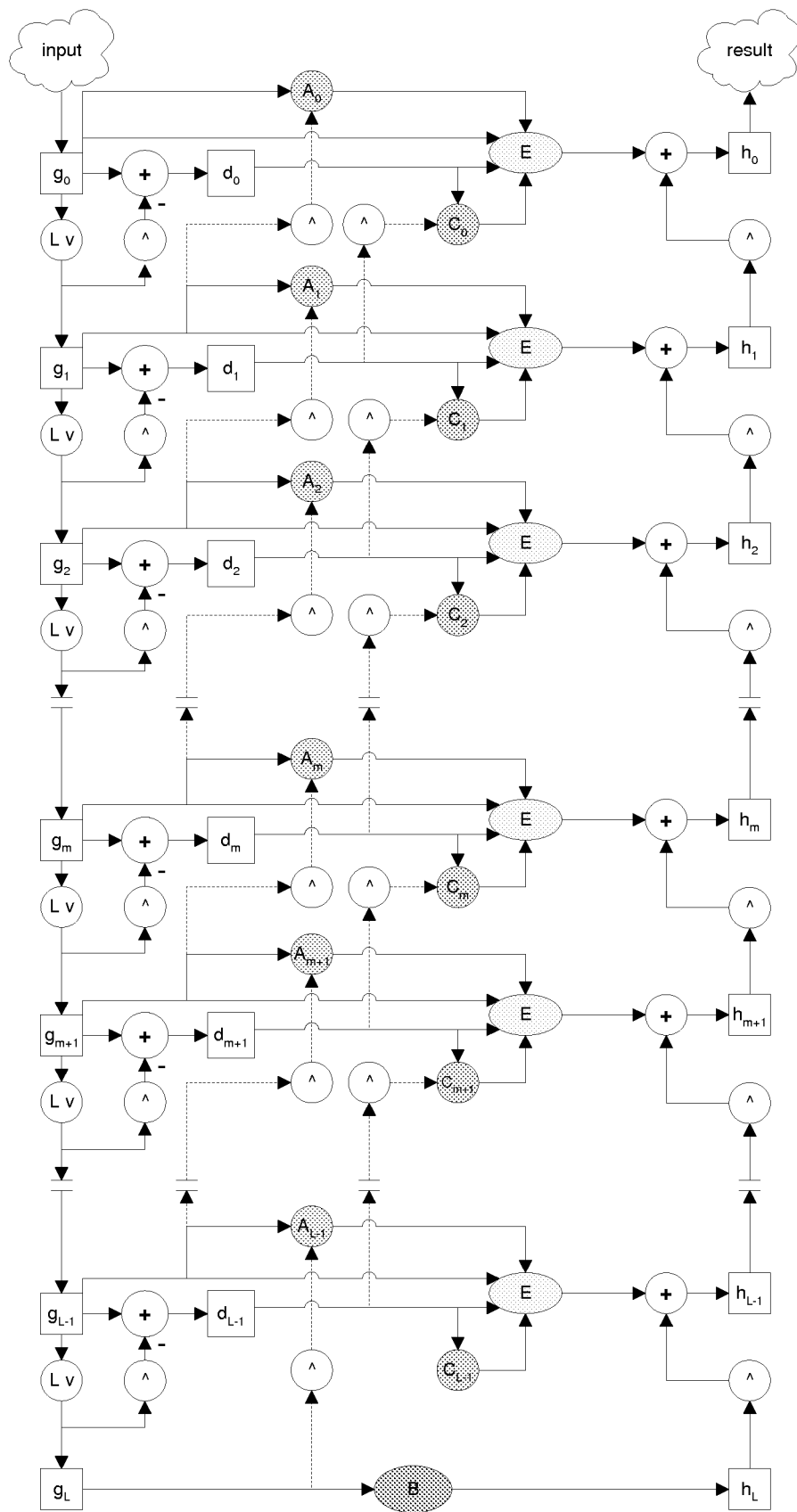


FIG. 1

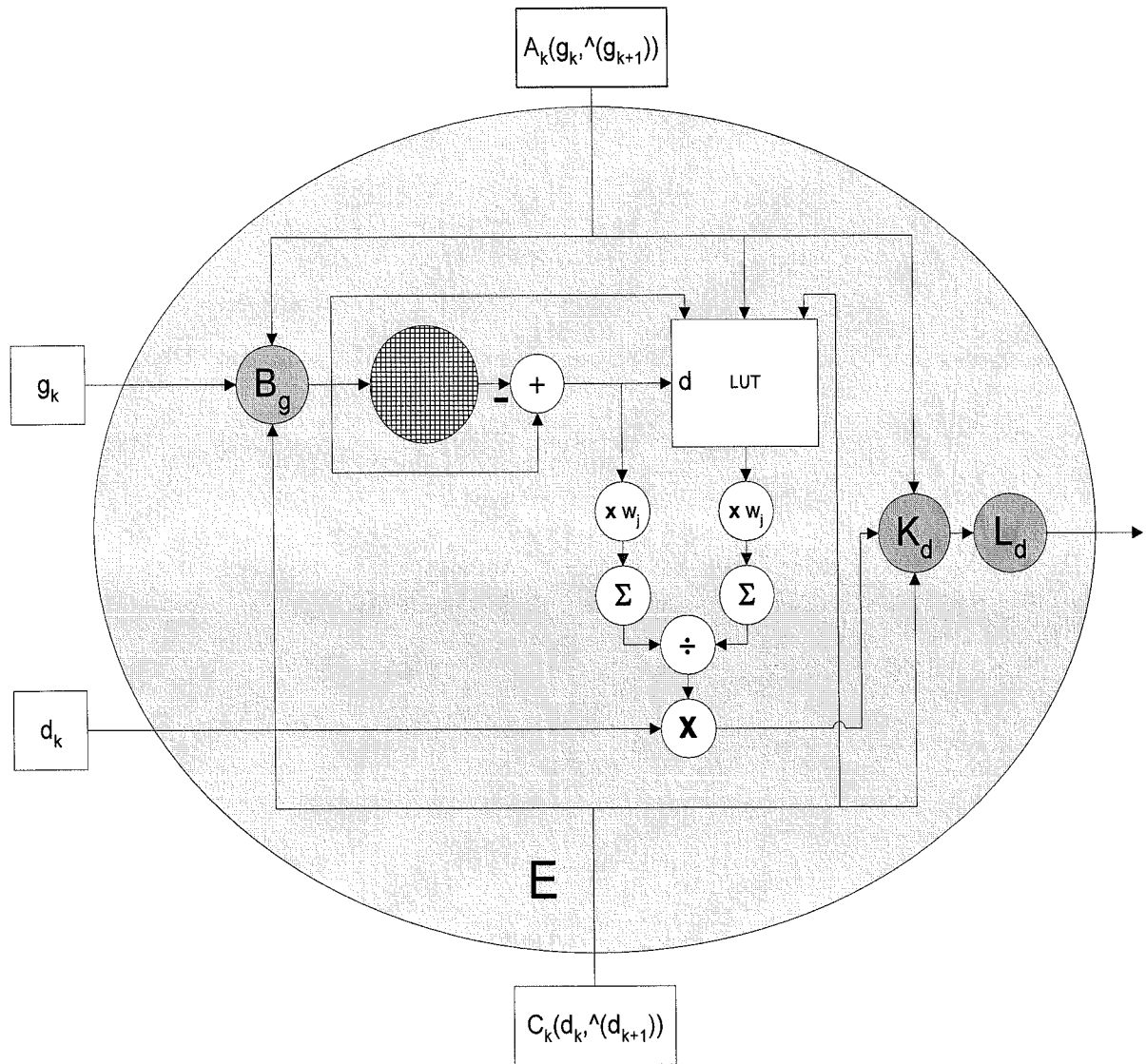


FIG. 2

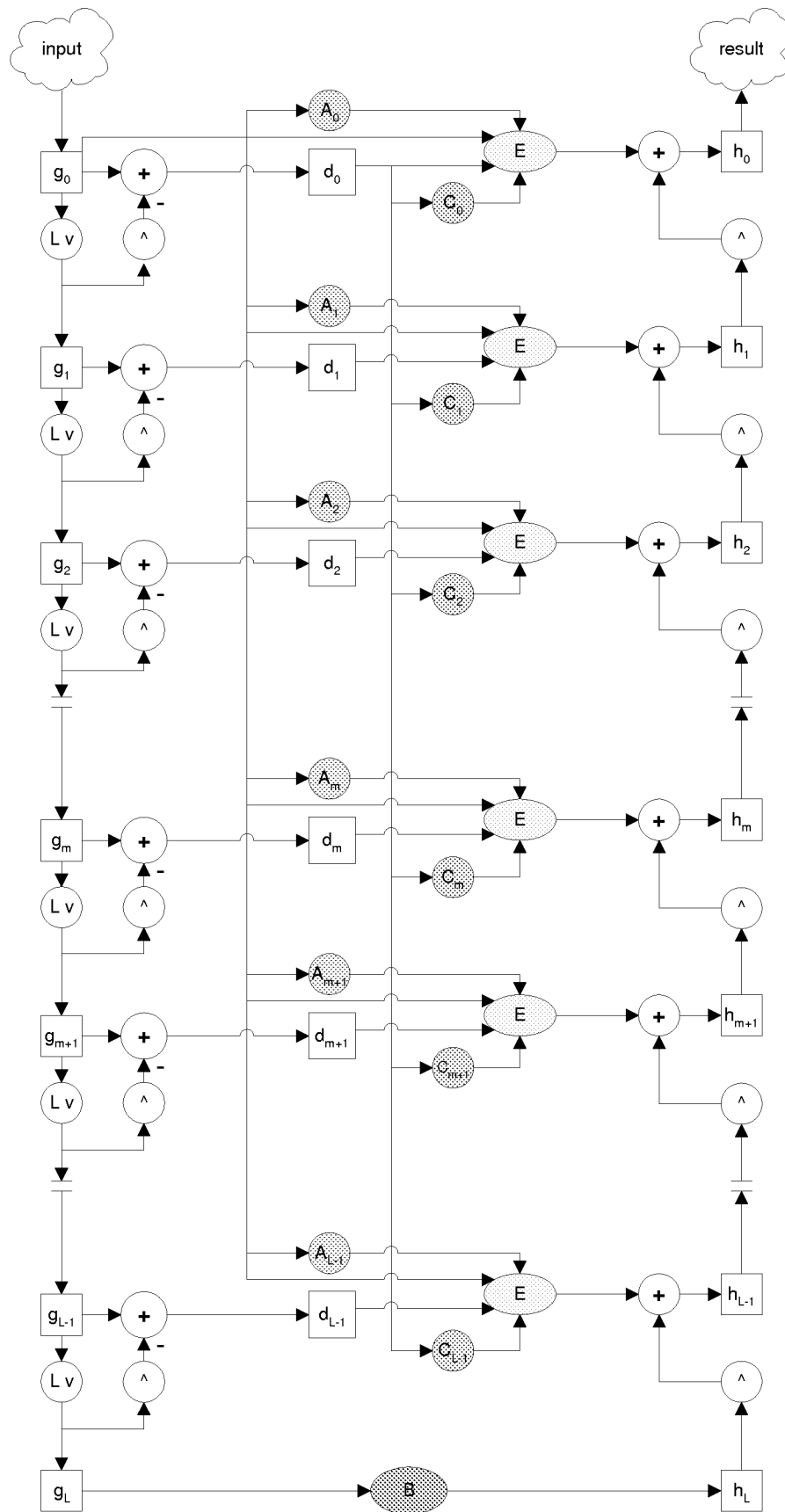


FIG. 3

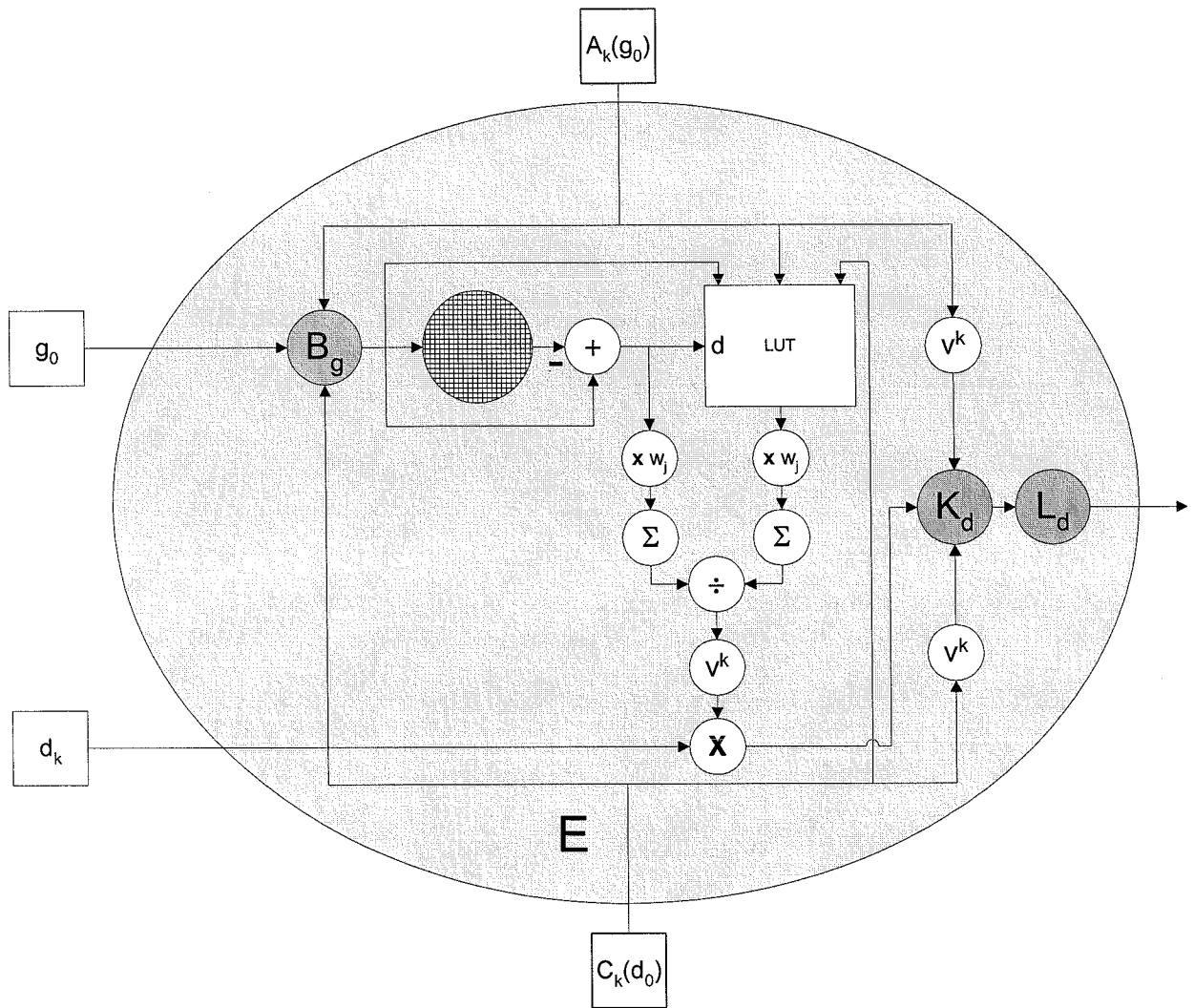


FIG.



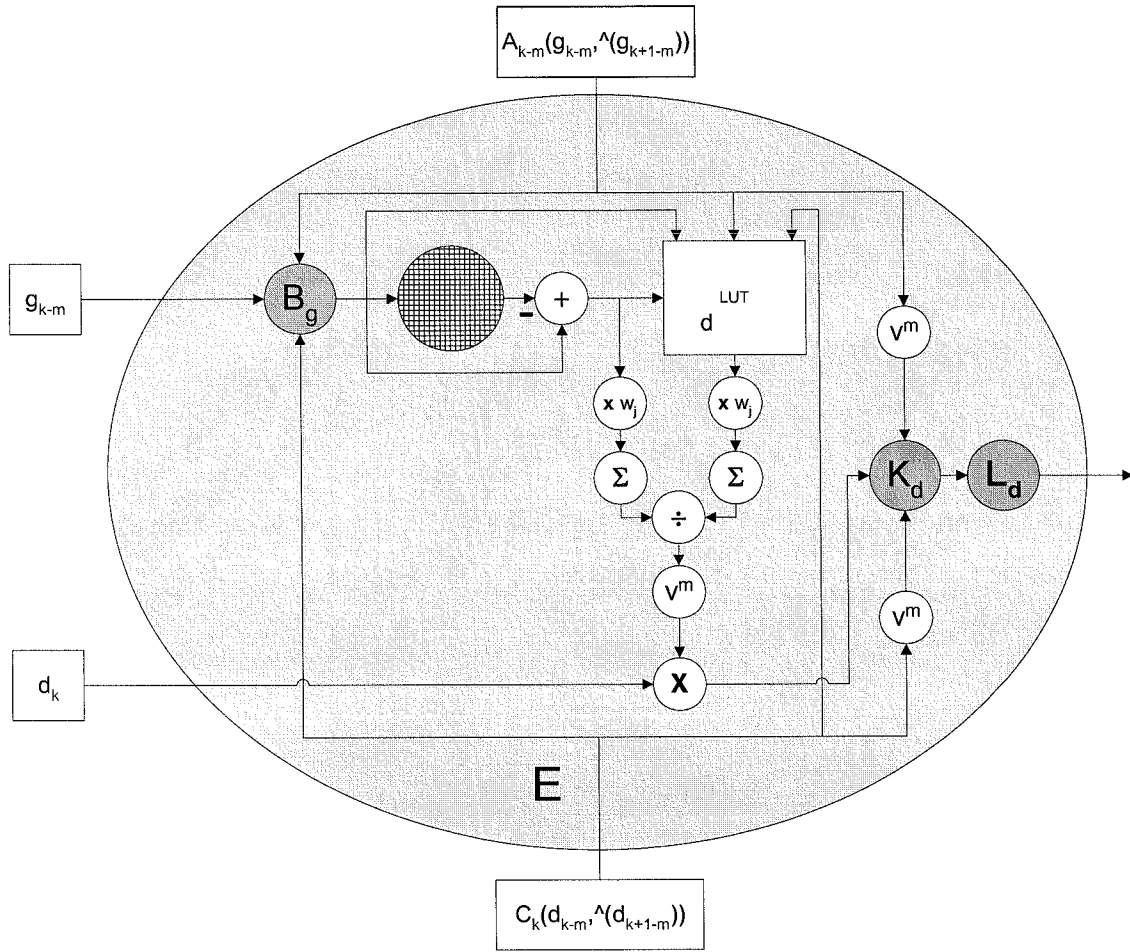


FIG. 6

**Legenda**


Symbol	
$g_k$	Approximation image at scale k
$d_k$	Detail image at scale k
$h_k$	Contrast enhanced approximation image at scale k
$L_v$	Low-pass filtering of input image, followed by subsampling
$v^m$	Subsampling m consecutive times
$\wedge$	Upsampling
$+$	Addition
$\times$	Multiplication
$\Sigma$	Summation
$\div$	Division
	Moving neighborhood operator (used to compute the translation differences)
$\times w_l$	Weighing operator
LUT	Conversion operator
$A_k$	Optional transform applied to the approximation images to obtain useful steering characteristics
$C_k$	Optional transform applied to the detail images to obtain useful steering characteristics
$B_k$	Optional adaptive filter applied to the approximation images
$K_k$	Optional adaptive filter applied to the enhanced detail images
$L_k$	Optional transform applied to the enhanced detail images (e.g. normalization)
$R$	Optional transform of the residual image.

FIG. 7

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2008/060058

A. CLASSIFICATION OF SUBJECT MATTER  
 INV. G06T5/20 G06T5/00

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)  
 G06T

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

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

EPO-Internal, INSPEC

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Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 788 826 B1 (VAN DE VELDE KOEN [BE] ET AL) 7 September 2004 (2004-09-07)	1,9-16
Y	column 2 - column 6; figures 1-6	2-8
Y	US 6 252 931 B1 (AACH TIL [DE] ET AL) 26 June 2001 (2001-06-26) figures 2-7 column 7, line 41 - line 67 column 8, line 1 - line 6 column 9, line 1 - line 40	2-4
Y	EP 0 574 969 A (AGFA GEVAERT NV [BE] AGFA GEVAERT NV [US] AGFA GEVAERT [BE]) 22 December 1993 (1993-12-22) page 7, line 17 - line 58 page 8, line 1 - line 32	5
	-/--	

 Further documents are listed in the continuation of Box C. See patent family annex.

## \* Special categories of cited documents:

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\*Z\* document member of the same patent family

Date of the actual completion of the international search

16 September 2008

Date of mailing of the international search report

30/09/2008

Name and mailing address of the ISA/

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2008/060058

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 98/55916 A (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS PATENTVERWALTUNG [DE]; PH) 10 December 1998 (1998-12-10) page 4, line 9 - line 25 figures 1-4 -----	7
A	US 2005/259889 A1 (FERRARI RICARDO J [CA] ET AL) 24 November 2005 (2005-11-24) paragraph [0048] - paragraph [0049] -----	1
A	US 7 239 424 B1 (BERKNER KATHRIN [US] ET AL) 3 July 2007 (2007-07-03) the whole document -----	1-4
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Information on patent family members

International application No

PCT/EP2008/060058

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