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(54) **Method for rendering digital radiographic images for display based on independent control of fundamental image quality parameters**

Auf unabhängiger Kontrolle grundlegender Bildqualitätsparameter basierendes Verfahren zur Aufbereitung digitaler radiologischer Bilder zur Anzeige

Procédé de rendu d'images radiographiques numériques pour affichage, basé sur la commande indépendante de paramètres fondamentaux de la qualité d'image

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EP 1 501 049 B1

Description

[0001] This invention relates in general to image enhancement in digital image processing and in particular, to a method of image enhancement to be used in a medical radiographic imaging system, such as a computed radiography system.

[0002] It is a common desire to enhance images acquired from imaging devices to improve their image quality. There are fundamental attributes that govern the image quality of a grayscale image. These attributes are the brightness of an image, the dynamic range of an image, the contrast of detail in an image (or detail contrast), the sharpness of edges in an image, and the appearance of noise in an image. It is beneficial to provide a system that enables direct and independent control of these attributes of image quality. Further a system, which enables the control of the detail contrast, sharpness, and noise appearance in a density dependent fashion is also beneficial.

[0003] U.S. Patent No. 5,805,721, inventors P. Vuylsteke and E. Schoeters, entitled "Method and Apparatus for Contrast Enhancement", issued Sept. 8, 1998 describes a multi-resolution method for enhancing contrast with increased sharpness that includes dynamic range compression, and enhancing contrast without remarkably boosting the noise component. The described invention enhances detail contrast and sharpness via a multi-resolution method and controls dynamic range compression with a gradation curve to map the processed image into the appropriate dynamic range for the display. Application of the gradation curve will impact both the apparent detail contrast and dynamic range of the displayed image. Hence, both the modifying functions of the multi-resolution processing and the shape of the gradation curve affect the detail contrast in the image. This requires that both be adjusted when setting the detail contrast in the image.

[0004] U.S. Patent No. 5,978,518, inventors Oliyide et al., entitled "Image Enhancement in Digital Image Processing", issued Nov. 2, 1999 and U.S. Patent No. 6,069,979 (continuation-in-part of U.S. Patent No. 5,978,518), inventor Van-Metter, entitled "Method for Compressing the Dynamic Range of Digital Projection Radiographic Images", issued May 30, 2000, describe a multi-resolution method for performing dynamic range modification and high-frequency enhancement (including detail contrast). The methods include a tone scale look-up-table that is used to map the image for display rendering. A tone scale look-up-table impacts the dynamic range and contrast of detail in an image. Hence, in this method, the dynamic range and detail contrast of the image depends on both the settings of the frequency modification and the parameters of the tone scale look-up table. It is desirable, instead to have a single set of parameters that control these attributes independently.

[0005] U.S. Patent No. 6,072,913, inventor M. Yamada, entitled "Image Processing Method and Apparatus", issued June 6, 2000, describes a multi-resolution method for enhancing frequencies with dynamic range compression. The described invention requires the definition of many functions to control the performance of the algorithm. It does not disclose a set of parameters that directly and independently control all of the fundamental attributes of image quality.

[0006] Mary Couwenhoven et al., "Enhancement method that provides direct and independent control of fundamental attributes of image quality for radiographic imagery, Medical Imaging 2004-SPIE: vol. 5367, pp. 474-481, describes a rendering algorithm that provides orthogonal control, to the first order, of five fundamental attributes of perceived image quality. These attributes are brightness, latitude, detail contrast, sharpness, and appearance of noise. The detail contrast and sharpness can be controlled in a density-dependent manner. The algorithm uses a multifrequency-band decomposition wherein the bands of the decomposition are manipulated, and the reconstructed image is passed through a tone-scale process that prepares the image for display. The rendering method is implemented in software on a workstation that enables interactive control of these image quality attributes in order to facilitate the determination of rendering aims for different exam types.

[0007] Thus, there is a need for a method that can be applied to an image, the parameters of which provide direct and independent control of the above stated fundamental attributes of image quality.

[0008] According to the present invention, there is provided a solution to the problems and fulfillment of the needs discussed above by means of a method of digital image enhancement as set forth in claim 1, especially image enhancement of medical diagnostic (radiographic) digital images.

[0009] Further embodiments of the invention are defined in the dependent claims.

[0010] The invention has the following advantages.

1. A method for independently controlling fundamental attributes of image quality of a digital image.
2. A method for controlling detail contrast, sharpness, and noise appearance as a function of log exposure of a digital image is provided.
3. A method for density-dependent control of detail contrast, sharpness and noise appearance of a digital image is provided.

Fig. 1 is a flow diagram of an embodiment of the present invention.

Fig. 2 is a graphical view showing an example of tone scale function and parameters useful in explaining the present

invention.

Fig. 3 is a diagrammatic view illustrating the brightness control used in the present invention.

Fig. 4 is a diagrammatic view illustrating the effect of increasing the slope of the tone scale useful in explaining the present invention.

5 Fig. 5 is a diagrammatic view illustrating the independent control of detail contrast vs. dynamic range in the present invention.

Figs. 6a-6c are graphical views of functions to control detail, contrast, sharpness, and fine detail, respectively according to the present invention.

10 Figs. 7a-7c are graphical views of log exposure dependent functions to control detail contrast, sharpness, and fine detail, according to the present invention respectively.

Fig. 8 is a graphical view showing the mapping of density breakpoints to log exposure break points according to the present invention.

Fig. 9 is a diagrammatic view of density dependent control of the detail contrast according to the present invention.

Fig. 10 is a flow diagram of another embodiment of the present invention.

15 Fig. 11 is a block diagram of a digital image enhancement system for carrying out the present invention.

[0011] Referring now to Fig. 1, there is shown a block diagram of the present invention. A digital image in which code value is linearly related to log exposure is captured with an image acquisition unit **10**. Unit **10** can be for example, a medical image acquisition unit such as, a diagnostic image unit (MRI, CT, PET, US, etc.), a computed radiography or direct digital radiography unit, an x-ray film digitizer, or the like. Any other digital image acquisition unit can also be used). The present invention processes the log exposure code value data, as shown in Fig. 1, accordingly, the digital image data is split into four frequency bands $B_0(i,j)$, $B_1(i,j)$, $B_2(i,j)$, and $B_3(i,j)$. The log exposure code value data $I(i,j)$ of the input digital input digital image is first processed by three different low-pass filter operators **20**, **30**, **40**. Each operator uses a square-wave filter. It will be evident to those skilled in the art that other low-pass filter shapes such as a triangle-filter can be used. The filter kernel sizes are chosen to manipulate different sized features (or different frequency ranges) in the image. The first low-pass filter operator **20** uses kernel K_0 . This operator uses the largest kernel size and it passes only the lowest frequencies. It generates the low-pass image $I_0(i,j)$. The next low-pass operator **30** uses kernel K_1 . This operator uses the next largest kernel size and it passes the low to mid frequencies. It generates the low-pass image $I_1(i,j)$. The final low-pass operator **40** uses kernel K_2 . This operator uses the smallest kernel size and it passes all frequencies except for the very highest. It generates the low-pass image $I_2(i,j)$. The low-pass images are used to generate the frequency bands. The lowest frequency band image is $B_0(i,j)$ and is equal to $I_0(i,j)$. This band represents large-sized features in the image (and contains the lowest frequencies). Manipulation of this band produces a change in dynamic range or latitude. The next frequency band $B_1(i,j) = I_1(i,j) - I_0(i,j)$ is generated by subtractor **60**. This band contains the low-to-mid frequencies and represents mid-sized features in the image. Manipulation of this band produces a contrast effect without affecting the overall dynamic range. The next frequency band $B_2(i,j) = I_2(i,j) - I_1(i,j)$ is generated by subtractor **70**. This band contains the mid-to-high frequencies and represents the small-sized features in the image. Manipulation of this band produces a sharpness or blurring effect of the small-sized features. The next frequency band $B_3(i,j) = I(i,j) - I_2(i,j)$ is generated by subtractor **80**. This band contains the highest frequencies in the image and represents very fine detail in the image. Manipulation of this band produces a sharpness or blurring effect of very fine detail in the image.

40 **[0012]** As shown further in Fig. 1, the higher frequency bands $B_1(i,j)$, $B_2(i,j)$, and $B_3(i,j)$ are multiplied by respective gain terms **91**, **92**, **93** by respective multipliers **61**, **71**, **81** and summed together with the lowest frequency band image $B_0(i,j)$ to generate the reconstructed image using I' . The reconstructed image I' is defined as

$$45 \quad I'(i, j) = B_0(i, j) + g_1(B_0(i, j)) * B_1(i, j) + g_2(B_0(i, j)) * B_2(i, j) + g_3(B_0(i, j)) * B_3(i, j)$$

[0013] If the bands are not manipulated, that is if $g_1(B_0(i, j)) = g_2(B_0(i, j)) = g_3(B_0(i, j)) = 1.0$, the reconstructed image I' is equal to the original image I , i.e., $I'(i, j) = I(i, j)$.

50 **[0014]** As shown in Fig. 1 the reconstructed image I' is mapped through a tone scale (**TS**) process **90** which maps the values into the desired display range. The output image is represented as $I''(i, j) = TS(I'(i, j))$.

[0015] Fig. 2 shows an example of a tone scale function **100** used to map log exposure (x-axis) to optical density (y-axis). It is a sigmoid shape and is parameterized by the minimum density and maximum density, the reference density (or pivot point), the brightness (or shift of tone scale along the log exposure axis relative to the pivot point), and the

55 slope, $\frac{dD}{dx}$, about the reference density. The reference density maps the log exposure value that will remain invariant when the slope of the tone scale is varied. The brightness control is used to shift the mean density of the image. The brightness control defines the log exposure code value that is mapped via the tone scale to the reference density.

[0016] Fig. 3 shows the effect of the brightness control (Image A to Image C). Increasing the brightness control lowers the mean density of the image (Image C is lower in mean density than Image A) (or increases the brightness of the image), while decreasing the brightness control raises the mean density of the image (or darkens the image). In a preferred embodiment, the tone scale function is further mapped to a standard gray scale display function (as specified by the Medical Image Standard format DICOM PART 10) for monochrome image presentation. This facilitates the same gray scale rendering between softcopy (video monitor) systems and between softcopy and hardcopy (film, paper) systems.

[0017] The amount of contrast in which the mid size detail in an image is rendered is defined as the detail contrast. In traditional screen film radiographic imaging systems, there is an inherent tradeoff between detail contrast and latitude (or range of log exposure that are rendered to unique densities). In these systems, if the contrast is increased, the latitude is decreased (or image dynamic range is increased). Likewise, if the latitude is increased, (or image dynamic range decreased) the detail contrast is decreased. The same is true if the image dynamic range and detail-contrast are controlled via a digital enhancement process (e.g., multi-resolution decomposition) in which the output of the process is mapped through a tone scale to render it to the display. Inherently, the tone scale also modifies both the dynamic range and detail contrast of an image. As shown in Fig. 4, from image A to image C as the slope of the tone scale increases both the image dynamic range and detail-contrast are increased and the latitude is decreased. Unless the digital enhancement process accounts for the tone scale effects both the dynamic range and detail-contrast of the image will be affected upon display.

[0018] In the embodiment of the present invention, shown in Fig. 1, the lowest frequency band of the multi-resolution decomposition is $B_0(i,j)$. If this band is manipulated it affects the dynamic range of the image. As previously discussed,

the slope of the tone scale, $\frac{dD}{dx}$, also affects the dynamic range. According to the present invention, the lowest band is not manipulated for dynamic range control; instead, the slope of the tone scale is used. The dynamic range control is defined as the slope of the tone scale, $dynamicRange = dD / dx$ at the reference density. Increasing the dynamic range reduces the latitude while decreasing the dynamic range increases the latitude.

[0019] Manipulation of band $B_1(i,j)$ affects the detail contrast of the image. According to the present invention, band $B_1(i,j)$ is multiplied by the gain term $g_1(B_0(i,j))$ at multiplier 61. As previously discussed, the slope of the tone scale also

affects the detail contrast of the image. To account for the fact that both the slope of the tone scale $\frac{dD}{dx}$ and the gain term $g_1(B_0(i,j))$ affect the detail contrast, a detail contrast control is defined as a

$$detailContrast(B_0(i, j)) = g_1(B_0(i, j)) * (dD / dx).$$

[0020] By defining the dynamic range and detail contrast parameters in this way independent control of these attributes can be achieved. This is illustrated by Fig. 5. It shows a 3x3 matrix of images (i.e., IA, IB, IC, IIA, IIB, IIC, IIIA, IIIB, IIIC) processed using these controls. By moving from left to right (Image A and Image C) across a row (I, II, III) in the matrix, the dynamic range increases as the value of the dynamic range control is increased, while the detail contrast is held constant at a particular level. By moving from the bottom to top of the matrix along a column (A, B, C) the detail contrast increases as the value of the detail contrast control is increased while the dynamic range is held constant at a particular level. The image 200 (IA) in the bottom left corner has wide latitude and low detail contrast, while the image 201 (IIIC) in the upper right corner has narrow latitude and high detail contrast.

[0021] The controls for the sharpness of small features, $sharpness(B_0(i,j))$, and very fine features, $fineDetail(B_0(i,j))$, are defined as follows

$$sharpness(B_0(i, j)) = \frac{g_2(B_0(i, j))}{g_1(B_0(i, j))}$$

$$fineDetail(B_0(i, j)) = \frac{g_3(B_0(i, j))}{g_2(B_0(i, j))}$$

[0022] To achieve the independent control of sharpness/blurring, it is found that controlling the gain ratio between the frequency bands is important. The *sharpness*($B_0(i,j)$) parameter provides control of the sharpness of small detail in an image, and the *fineDetail*($B_0(i,j)$) parameter provides an extra level of control over the sharpness of very fine detail in an image.

[0023] The gain terms that are used to manipulated the frequency bands, B_1 , B_2 , and B_3 are derived from detail contrast, sharpness and fine detail controls respectively as follows

$$g_1(B_0(i, j)) = detailContrast(B_0(i, j)) / dD / dx$$

$$g_2(B_0(i, j)) = sharpness(B_0(i, j)) * g_1(B_0(i, j))$$

$$g_3(B_0(i, j)) = fineDetail(B_0(i, j)) * g_2(B_0(i, j))$$

[0024] The present invention enables exposure dependent control of the *detailContrast*($B_0(i,j)$), *sharpness*($B_0(i,j)$), and *fineDetail*($B_0(i,j)$). The low band image $B_0(i,j)$ represents the average log exposure and serves as a map of exposure regions in an image. To achieve exposure dependent control of the image enhancement, the parameters are defined as a function of that band. Areas of the low band image where the code values are low correspond to the low exposure regions in the image (that is the low density or bright areas in the image). Areas where the code values are high correspond to high exposure regions in the image (that is the high density or dark areas in the image). This information can be used to provide exposure dependent control of detail contrast, sharpness of edges, and sharpness of fine detail and to improve the enhancement of the image.

[0025] Figs. 6a-6c show examples of a functional form of the detail contrast (Fig. 6a), sharpness (Fig. 6b), and fine detail (Fig. 6c) controls, respectively. In this example the function is constant across all exposure regions (exposure independent). When a control is set to a value of 1.0 there is no enhancement of features in the image. While a control value greater than 1.0 result in the enhancement of features in the image. Both the sharpness and the fine detail controls can have values less than 1.0 (but not negative). If these controls are set to a value less than 1.0, the corresponding features are blurred (the gain of these bands are decreased relative to the lower bands). Setting the *fineDetail*($B_0(i,j)$) control to a value less than 1.0 is used to reduce the appearance of high frequency noise in an image.

[0026] Figs. 7a-7c shows an example of an exposure dependent functional form that can be used for detail contrast, sharpness and fine detail controls, respectively. The functional form is a piecewise linear curve in which two breakpoints are used. The function is parameterized by setting a left and right log exposure break point, and a left function value (for $B_0(i,j) \leq$ left break point) and a right function value (for $B_0(i,j) \geq$ right break point). The functional form between the breakpoints is linear.

[0027] As shown in Fig. 8, breakpoints can be first assigned in density and then mapped to log exposure breakpoints via the tone scale curve. The high-density breakpoint is mapped to the right log exposure breakpoint and the low-density breakpoint is mapped to the left log exposure breakpoint. Once the brightness and dynamic range of the image are set, via the tone scale, then the log exposure breakpoint are defined. Setting the breakpoint in density provides a mechanism to achieve a preferred rendering of density regions. Often they correspond directly to important anatomical structures in a radiographic image of an individual. For example, on a chest image the lung field is a higher density (darker) region and can be rendered differently from the diaphragm, which is in a lower density (brighter) region. As illustrated in Fig. 9, a user or image analysis algorithm can independently control the detail contrast (as well as sharpness of small and fine detail (or noise suppression)) in low and high-density areas of an image. For example the detail contrast can be set higher in the lung field areas 300 and lower in the lower density diaphragm area 301.

[0028] It will be evident to those skilled in the art that there are other useful functional forms that can be generated for the *detailContrast*($B_0(i,j)$), *sharpness*($B_0(i,j)$), and *fineDetail*($B_0(i,j)$) controls.

[0029] Another embodiment of the present invention is shown in Fig. 10. In this embodiment, the original image $I(i, j)$ from *Image acquisition unit 10* and the low-pass images (and not the frequency band images) (from low pass filter operators 20, 30, 40) are directly manipulated at multipliers 400, 401, 402, and 403, and the results are summed together at adders 501, 502, and 503 to generated the reconstructed image $I'(i,j)$ which is expressed as

$$I'(i, j) = g_3(I_0(i, j))I(i, j) + (1 - g_1(I_0(i, j)))I_0(i, j) + (g_1(I_0(i, j)) - g_2(I_0(i, j)))I_1(i, j) + (g_2(I_0(i, j)) - g_3(I_0(i, j)))I_2(i, j)$$

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[0030] This embodiment produces the same result as the method shown in FIG. 1 but does not require the calculation of the frequency band images and may be advantageous in some implementations.

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[0031] It is a preferred embodiment of this invention that the brightness and dynamic range parameters and the parameters for the *detailContrast*($B_0(i,j)$), *sharpness*($B_0(i,j)$), and *fineDetail*($B_0(i,j)$) functions be either entered directly at a user interface to the algorithm or automatically determined via an image analysis method.

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[0032] Referring now to Fig. 11, there is shown a digital computer 600 for carrying out the present invention. As shown, digital computer 600 includes memory 601 for storing digital images, application programs, operating systems, etc. Memory 601 can include mass memory (such as hard magnetic disc or CD ROM), and fast access memory (such as RAM). Computer 600 also includes input devices 602 (such as keyboard, mouse, touch screen) display 603 (CRT, Flat Panel Display), central processing unit 604, output device 605 (thermal printer, laser printer, etc.). Components 601, 602, 603, 604, and 605 are connected together by control/data bus 606. Computer 600 can include a transportable storage medium drive 607 for reading from and/or writing to transportable storage media 608, such as DVD or CD.

20 **Claims**

1. A computer implemented method of enhancing a digital image comprising:

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providing a digital image (10);
 decomposing the provided digital image into a multi-frequency band representation including a low frequency band image and multiple different high frequency band images (20, 30, 40);
 multiplying (61, 71, 81) each of said high-frequency band images with a gain factor (91, 92, 93);
 summing together said unmodified low frequency band image and said modified high-frequency band images to produce a reconstructed digital image (62, 72, 82); and
 mapping said reconstructed digital image through a tone-scale look-up-table to map said reconstructed digital image to optical densities (90);

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wherein the gain factors (91, 92, 93) are derived from the slope of the tone-scale function and from parameters which independently control different visually discernible image attributes.

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2. The method of claim 1 wherein said providing provides a digital medical image.
3. The method of claim 1 wherein said providing provides a digital radiological image acquired by one of a medical diagnostic imaging unit, a computed radiography unit, a direct digital radiography unit, and an x-ray film digitizer.
4. The method of claim 1 wherein said decomposing is effected by processing said provided digital image with a plurality of different low pass filter operators which operate to pass different low-pass images, wherein said low-pass images are used to generate said low-frequency band image and said multiple different high-frequency band images.
5. The method of claim 4 wherein said plurality of low pass filter operators use square wave filters.
6. The method of claim 4 wherein said plurality of different low pass filter operators use different filter kernel sizes to pass said different low-pass images.
7. The method of claim 6 wherein said plurality of different low pass filter operators include first, second and third pass filter operators having respective first, second and third kernels.
8. The method of claim 1 wherein said decomposing decomposes the provided digital image into four frequency bands as follows:

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a lowest frequency band image which represents large-sized features in the digital image;
 a low-to-mid frequency band image which represents mid-sized features in the digital image;

a mid-to-high frequency band image which represents the small-sized features in the digital image; and
a highest frequency band image which represents very fine detail in the digital image.

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9. The method of claim 8 including manipulating said lowest frequency band image to produce a dynamic range or latitude in said digital image; wherein latitude is the range of log exposure that are rendered to unique densities
10. The method of claim 8 including manipulating said low-to-mid frequency band image to produce a contrast effect without affecting the overall dynamic range of said digital image.
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11. The method of claim 8 including manipulating said mid-to-high frequency band image to produce a sharpness or blurring effect of said small-sized features of said digital image.
12. The method of claim 8 including manipulating the highest frequency band image to produce a sharpness or blurring effect of very fine detail in said digital image.
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13. The method of claim 1 wherein said mapping includes a brightness control for shifting the mean density of the digital image.
14. The method of claim 1 wherein said mapping further includes mapping the tone scale function to a standard gray scale display function for monochrome image presentation.
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15. The method of claim 1 wherein in said mapping, said tone scale has slope at a reference density that defines dynamic range control and wherein increasing the dynamic range reduces latitude of said digital image, while increasing the dynamic range decreases the latitude to said digital image; wherein latitude is the range of log exposure that are rendered to unique densities
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16. The method of claim 8 wherein in said mapping, said tone scale has slope at a reference density that defines dynamic range control and wherein said gain factor which multiplies said low-to-mid frequency band image is derived from a detail contrast control and said dynamic range control.
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17. The method of claim 8 wherein said gain factor which multiplies said mid-to-high frequency band image is derived from a sharpness control and said gain factor which multiplies said low-to-mid frequency band image.
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18. The method of claim 8 wherein said gain factor which multiplies said highest frequency band image is derived from a fine detail control and said gain factor which multiplies the mid-to-high frequency band image.

Patentansprüche

- 40
1. Computer implementiertes Verfahren zum Verbessern eines digitalen Bildes, das Folgendes aufweist:
- Bereitstellen eines digitalen Bildes (10);
Zerlegen des bereitgestellten digitalen Bildes in eine Multi-Frequenzband Darstellung, die ein Niederfrequenzband-Bild und mehrere verschiedene Hochfrequenzband-Bilder (20, 30, 40) aufweist;
45 Multiplizieren (61, 71, 81) jedes der Hochfrequenzband-Bilder (20, 30, 40) mit einem Gewinn-Faktor (91, 92, 93);
Zusammenzählen der unmodifizierten Niederfrequenzband-Bilder und der modifizierten Hochfrequenzband-Bilder, um ein rekonstruiertes digitales Bild (62, 72, 82) zu erzeugen; und
Abbilden des rekonstruierten digitalen Bildes auf eine Tonskala-Nachschlagetabelle, um das rekonstruierte digitale Bild auf optische Dichten (90) abzubilden;
- 50
- wobei die Gewinn Faktoren (91, 92, 93) aus der Steigung der Tonskalenfunktion und von Parametern hergeleitet wird, die unabhängig verschiedene, visuell wahrnehmbare Bildattribute steuern.
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2. Verfahren nach Anspruch 1, wobei das Bereitstellen ein digitales medizinisches Bild bereitstellt.
3. Verfahren nach Anspruch 1, wobei das Bereitstellen ein digitales radiologisches Bild bereitstellt, welches entweder durch eine medizinisch diagnostische Abbildungseinheit, eine Computerradiografieeinheit, oder eine direkte digitale Radiografieeinheit und einem Röntgenfilmdigitalisierer erfasst wurde.

EP 1 501 049 B1

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4. Verfahren nach Anspruch 1, wobei das Zerlegen bewirkt wird durch das Verarbeiten des bereitgestellten digitalen Bildes mit einer Vielzahl von verschiedenen Tiefpassfilter-Operatoren die das Passieren verschiedener Tiefpass-Bilder bewirken, wobei die Tiefpass-Bilder benutzt werden, um die Niederfrequenzband-Bilder und die mehreren verschiedenen Hochfrequenzband-Bilder zu erzeugen.
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5. Verfahren nach Anspruch 4, wobei die Vielzahl der Tiefpassfilter-Operatoren Square-Wave Filter benutzen.
6. Verfahren nach Anspruch 4, wobei die Vielzahl der verschiedenen Tiefpassfilter-Operatoren verschiedene Filter-Kernel-Größen verwendet, um die verschiedenen Tiefpass-Bilder durch zu lassen.
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7. Verfahren nach Anspruch 6, wobei die Vielzahl der verschiedenen Tiefpassfilter-Operatoren erste, zweite und dritte Passierfilter-Operatoren mit entsprechenden ersten, zweiten und dritten Kernels aufweist.
8. Verfahren nach Anspruch 1, wobei das Zerlegen das bereitgestellte digitale Bild wie folgt in vier Frequenzbänder zerlegt:
- 20
- ein Niedrigstfrequenzband-Bild, welches großformatige Merkmale in dem digitalen Bild darstellt;
ein Niedrig - bis Mittelfrequenzband-Bild, welches mittelformatige Merkmale in dem digitalen Bild darstellt;
ein Mittel - bis Hochfrequenzband-Bild, welches kleinformatige Merkmale in dem digitalen Bild darstellt;
ein Höchsthochfrequenzband-Bild, welches sehr feine Details in dem digitalen Bild darstellt.
- 25
9. Verfahren nach Anspruch 8, weist ferner das Manipulieren des Niedrigstfrequenzband-Bildes auf, um einen dynamischen Bereich oder einen Belichtungsspielraum in den digitalen Bildern zu erzeugen, wobei der Belichtungsspielraum der Bereich der log Belichtung ist, der in eindeutige Dichten umgesetzt ist.
- 30
10. Verfahren nach Anspruch 8, weist ferner das Manipulieren des Niedrig - bis Mittelfrequenzband-Bildes auf um einen Kontrasteffekt zu erzeugen ohne den gesamten dynamischen Bereich des digitalen Bildes zu beeinflussen.
11. Verfahren nach Anspruch 8, weist ferner das Manipulieren des Mittel - bis Hochfrequenzband-Bildes auf, um einen Schärfe - oder Unschärfeeffekt der kleinformatigen Merkmale des digitalen Bildes zu erzeugen.
- 35
12. Verfahren nach Anspruch 8, weist ferner das Manipulieren des Höchsthochfrequenzband-Bildes auf, um einen Schärfe - oder Unschärfeeffekt der sehr feinen Details des digitalen Bildes zu erzeugen.
- 40
13. Verfahren nach Anspruch 1, wobei das Abbilden eine Helligkeitssteuerung zum Verschieben der mittleren Dichte des digitalen Bildes beinhaltet.
- 45
14. Verfahren nach Anspruch 1, wobei das Abbilden, weiterhin das Abbilden der Tonskalenfunktion auf eine Standard-Graustufenabbildungsfunktion zur Monochrombilddarstellung beinhaltet.
- 50
15. Verfahren nach Anspruch 1, wobei in dem Abbilden, die Farbtonskala eine Steigung bei einer Referenzdichte aufweist, die eine Steuerung für den dynamischen Bereich definiert und wobei das Erhöhen des dynamischen Bereichs den Belichtungsspielraum des digitalen Bildes reduziert, während das Erhöhen des dynamischen Bereichs den Belichtungsspielraum des digitalen Bildes verringert, wobei der Belichtungsspielraum der Bereich der log Belichtung ist, der in eindeutige Dichten umgesetzt ist.
- 55
16. Verfahren nach Anspruch 8, wobei in dem Abbilden, die Tonskala eine Steigung bei einer Referenzdichte aufweist, die eine Steuerung für den dynamischen Bereich definiert und wobei der Gewinn-Faktor, der das Niedrig - bis Mittelfrequenzband-Bild verstärkt, über eine Detail-Kontrast-Steuerung und die Steuerung für den dynamischen Bereich hergeleitet wird.
17. Verfahren nach Anspruch 8, wobei der Gewinn-Faktor, der das Mittel - bis Hochfrequenzband-Bild verstärkt, über eine Schärfe-Steuerung und den Gewinn-Faktor, der das Niedrig - bis Mittelfrequenzband-Bild verstärkt, hergeleitet wird.
18. Verfahren nach Anspruch 8, wobei der Gewinn-Faktor, der das Höchsthochfrequenzband-Bild verstärkt, über eine Fein-Detail-Steuerung und den Gewinn-Faktor, der das Mittel - bis Hochfrequenzband-Bild vervielfacht, hergeleitet wird.

Revendications

1. Procédé d'amélioration d'image numérique, mis en oeuvre sur un ordinateur, comprenant :
 - 5 fournir une image numérique (10) ;
décomposer l'image numérique fournie en une représentation en bandes de fréquences multiples comprenant une image en bande de fréquence basse et plusieurs images en bandes de fréquence hautes (20, 30, 40) différentes ;
 - 10 multiplier (61, 71, 81) chacune des images en bandes de fréquence hautes par un facteur de gain (91, 92, 93) ;
additionner entre elles l'image en bande de fréquence basse non modifiée et les images en bandes de fréquence hautes modifiées pour produire une image numérique reconstruite (62, 72, 82) ; et
mapper l'image numérique reconstruite par l'intermédiaire d'une table de correspondance d'échelle de nuances pour mapper l'image numérique reconstruite en des densités optiques (90) ;
 - 15 dans lequel les facteurs de gain (91, 92, 93) sont obtenus à partir de la pente de la fonction d'échelle de nuances et à partir de paramètres qui contrôlent indépendamment différents attributs d'image discernables visuellement.
2. Procédé selon la revendication 1, dans lequel l'image fournie est une image médicale numérique.
- 20 3. Procédé selon la revendication 1, dans lequel l'image fournie est une image radiologique numérique acquise par un dispositif d'imagerie pour diagnostic médical, un dispositif de radiographie calculée, un dispositif de radiographie numérique directe, ou un numériseur de films pour rayons X.
- 25 4. Procédé selon la revendication 1, dans lequel la décomposition est effectuée par un traitement de l'image numérique fournie à l'aide d'une pluralité d'opérateurs différents de filtrage passe-bas, qui fonctionnent de façon à laisser passer différentes images filtrées passe-bas, et lesdites images filtrées passe-bas sont utilisées pour produire l'image en bande de fréquence basse et les multiples d'images en bandes de fréquence hautes différentes.
- 30 5. Procédé selon la revendication 4, dans lequel la pluralité d'opérateurs de filtrage passe-bas utilise des filtres d'onde carrée.
- 35 6. Procédé selon la revendication 4, dans lequel la pluralité d'opérateurs de filtrage passe-bas utilise différentes tailles de noyaux de filtrage pour laisser passer différentes images filtrées passe-bas.
- 40 7. Procédé selon la revendication 6, dans lequel la pluralité d'opérateurs de filtrage passe-bas différents comprend des premier, deuxième et troisième opérateurs de filtrage passe-bas ayant des premier, deuxième et troisième noyaux respectifs.
- 45 8. Procédé selon la revendication 1, dans lequel la décomposition décompose l'image numérique fournie en quatre bandes de fréquence de la façon suivante :
 - une image en bande de fréquence la plus basse, qui représente des caractéristiques de grande dimensions de l'image numérique ;
 - 45 une image en bande de fréquence basse-à-moyenne, qui représente des caractéristiques de taille moyenne de l'image numérique ;
 - une image en bande de fréquence moyenne-à-haute, qui représente des caractéristiques de petite taille de l'image numérique ; et
 - une image en bande de fréquence la plus élevée, qui représente des détails très fins de l'image numérique.
- 50 9. Procédé selon la revendication 8, comprenant la manipulation de l'image en bande de fréquence la plus basse pour produire une plage dynamique ou latitude dans l'image numérique ; la latitude étant la plage de l'exposant logarithmique qui est rendue en des densités uniques.
- 55 10. Procédé selon la revendication 8, comprenant une manipulation de l'image en bande de fréquence basse-à-moyenne pour produire un effet de contraste sans affecter la plage dynamique globale de l'image numérique.
11. Procédé selon la revendication 8, comprenant une manipulation de l'image en bande de fréquence moyenne-à-haute pour produire un effet de piqué ou de flou sur les caractéristiques de petite taille de l'image numérique.

EP 1 501 049 B1

12. Procédé selon la revendication 8, comprenant une manipulation de l'image en bande de fréquence la plus élevée pour produire un effet de piqué ou de flou sur des détails très fins de l'image numérique.

5 13. Procédé selon la revendication 1, dans lequel le mappage comprend un contrôle de luminosité pour décaler la densité moyenne de l'image numérique.

14. Procédé selon la revendication 1, dans lequel le mappage comprend en outre le mappage de la fonction d'échelle de nuances vers une fonction d'affichage en niveaux de gris standard pour une présentation en image monochrome.

10 15. Procédé selon la revendication 1, dans lequel dans le mappage, l'échelle de nuances a une pente au niveau d'une densité de référence qui définit un contrôle de plage dynamique, et dans lequel une augmentation de la plage dynamique réduit la latitude de l'image numérique, tandis qu'une augmentation de la plage dynamique diminue la latitude de l'image numérique ; dans lequel la latitude est la plage d'exposant logarithmique qui est rendue en des densités uniques.

15 16. Procédé selon la revendication 8, dans lequel dans le mappage, l'échelle de nuances a une pente au niveau d'une densité de référence qui définit un contrôle de plage dynamique et dans lequel le facteur de gain qui multiplie l'image en bande de fréquence basse-à-moyenne est obtenu à partir d'un contrôle de contraste de détails et dudit contrôle de plage dynamique.

20 17. Procédé selon la revendication 8, dans lequel le facteur de gain qui multiplie l'image en bande de fréquence moyenne-à-haute est obtenu à partir d'un contrôle de piqué et du facteur de gain qui multiplie l'image en bande de fréquence faible-à-moyenne.

25 18. Procédé selon la revendication 8, dans lequel le facteur de gain qui multiplie l'image en bande de fréquence la plus élevée est obtenu à partir d'un contrôle de détails fin et du facteur de gain qui multiplie l'image en bande de fréquence moyenne-à-haute.

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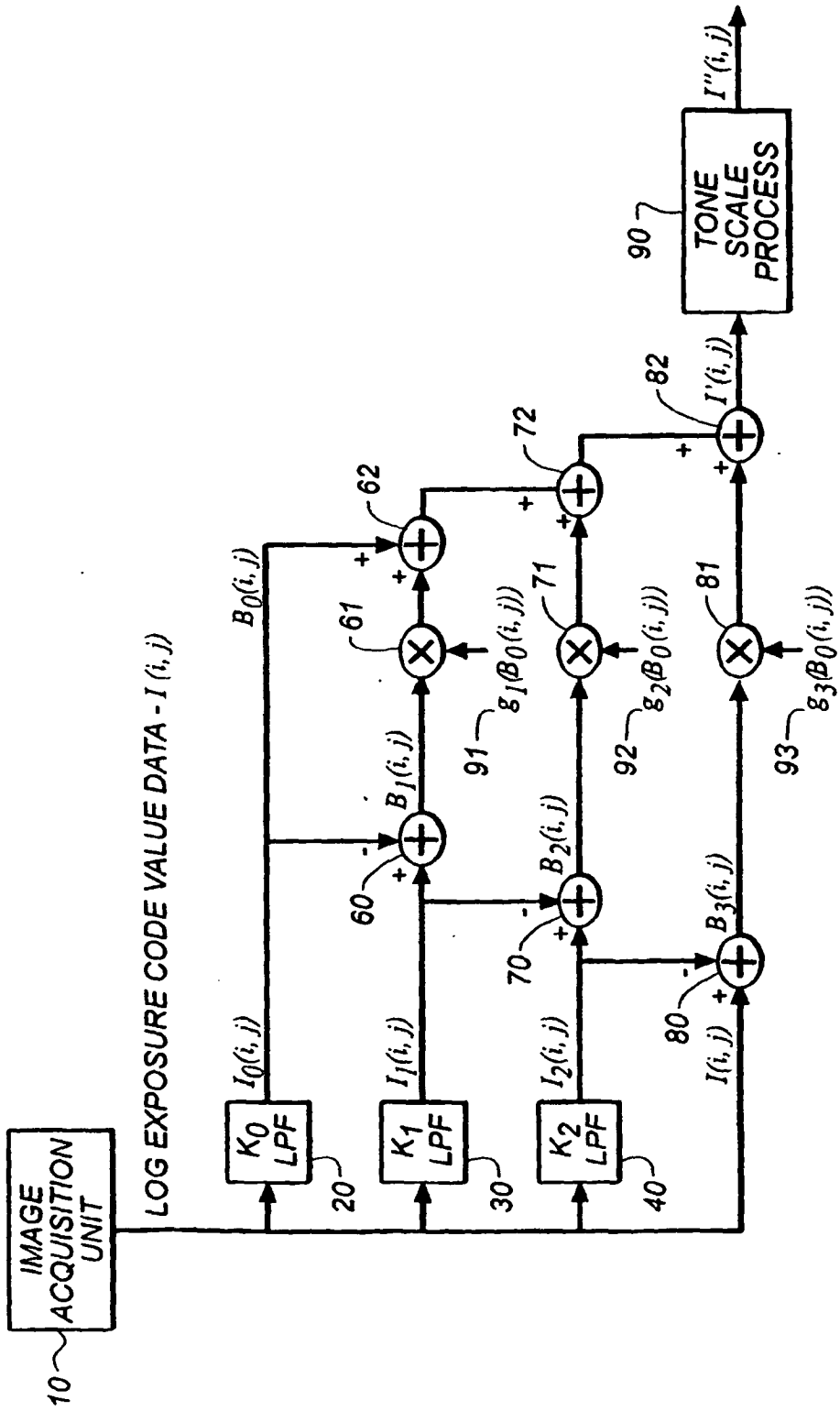


FIG. 1

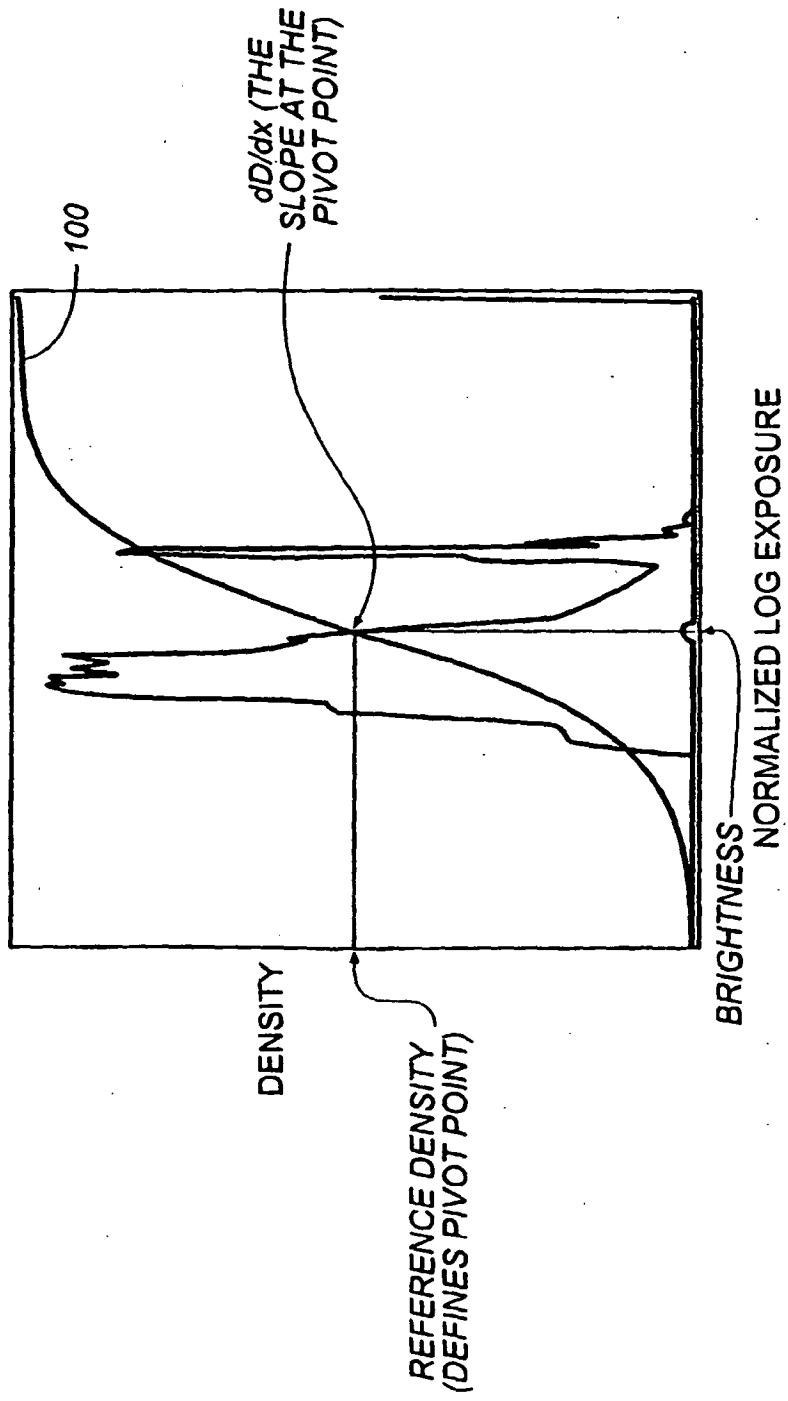


FIG. 2

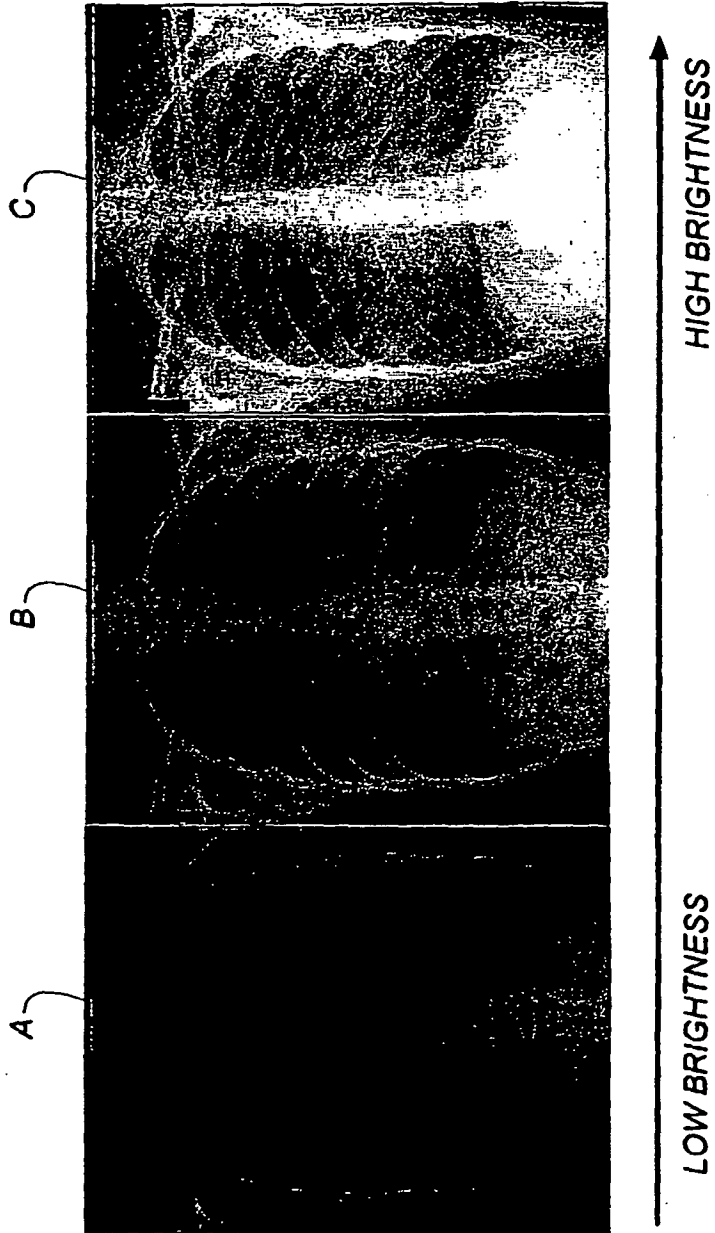


FIG. 3

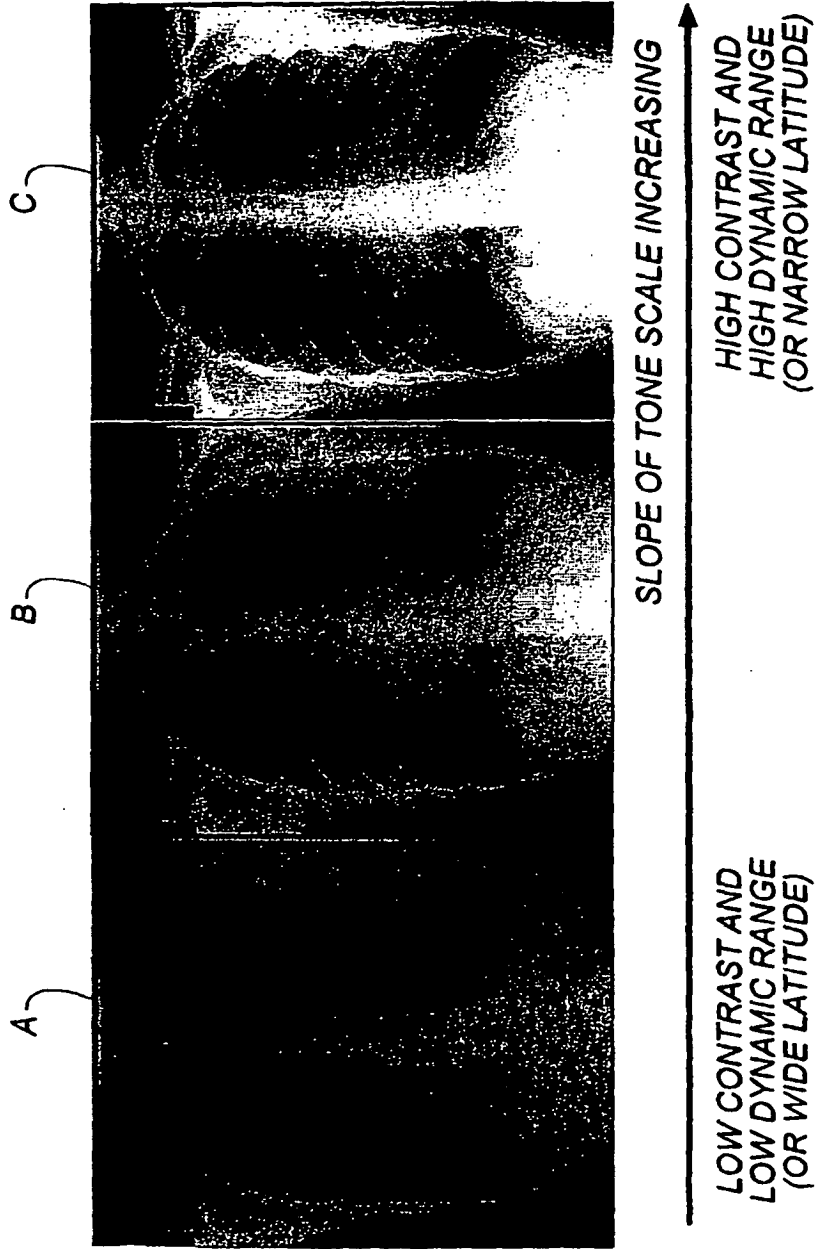


FIG. 4

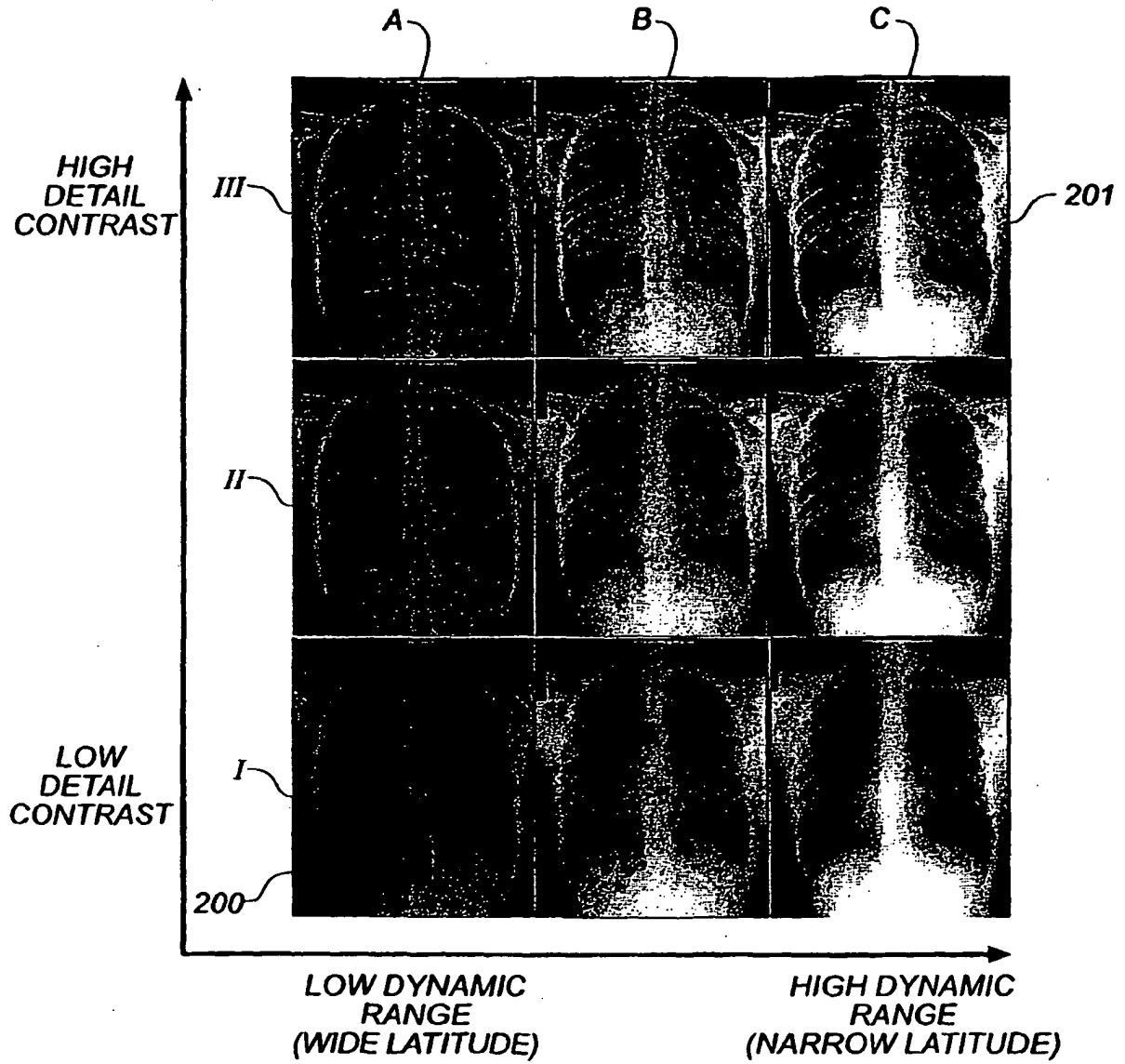


FIG. 5

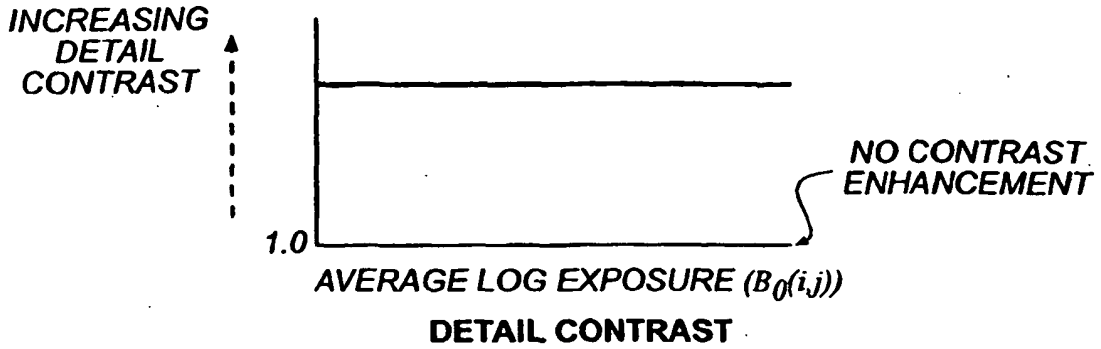


FIG. 6a

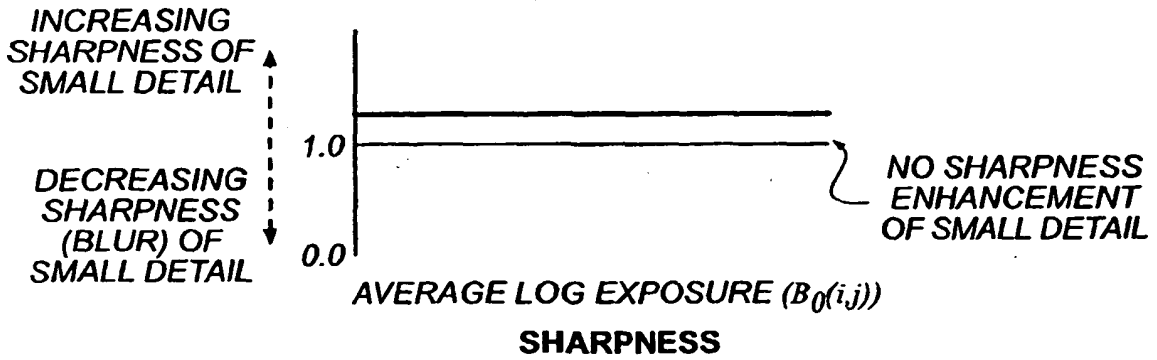


FIG. 6b

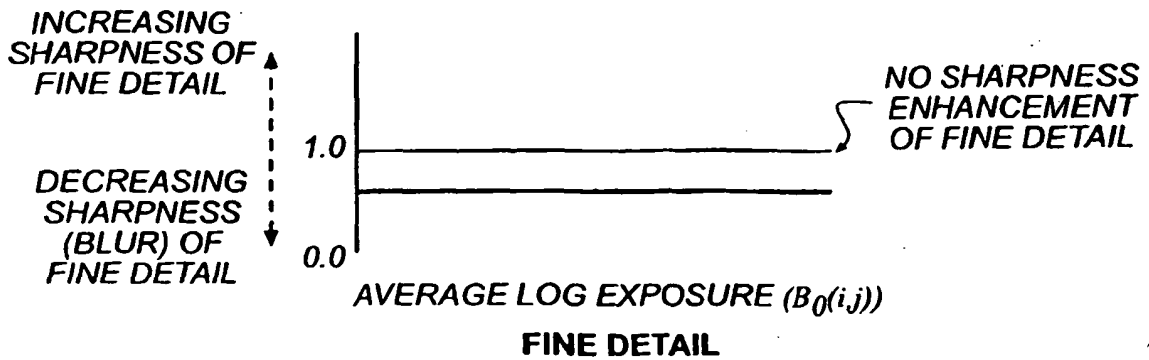


FIG. 6c

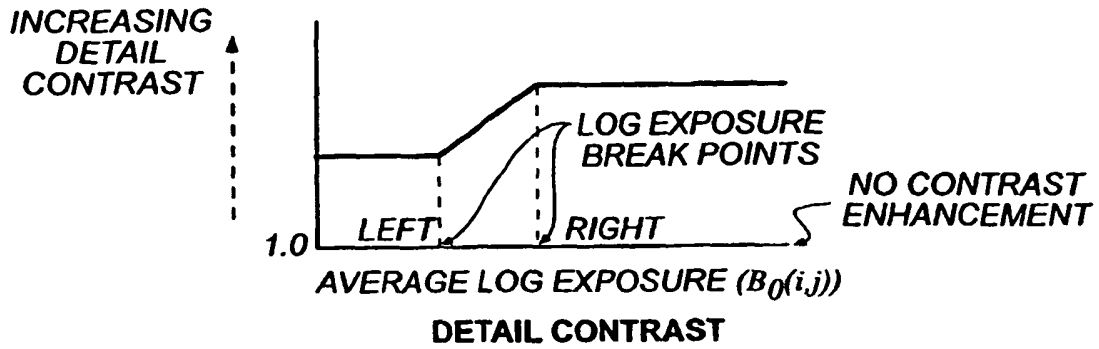


FIG. 7a

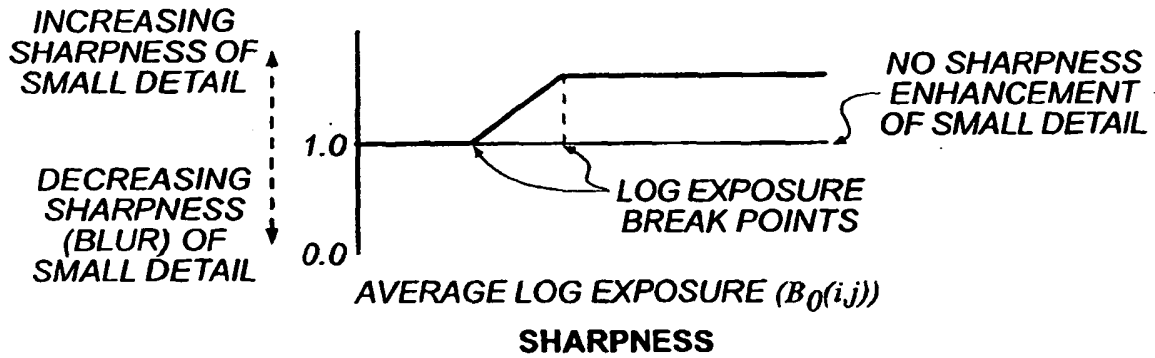


FIG. 7b

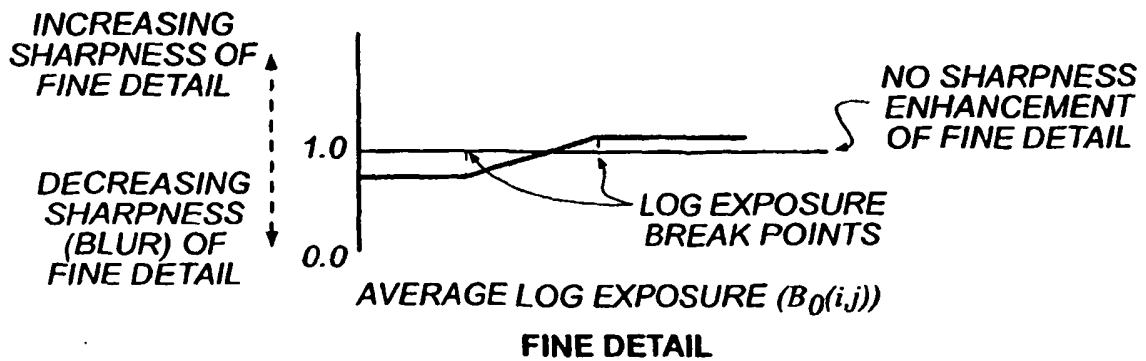


FIG. 7c

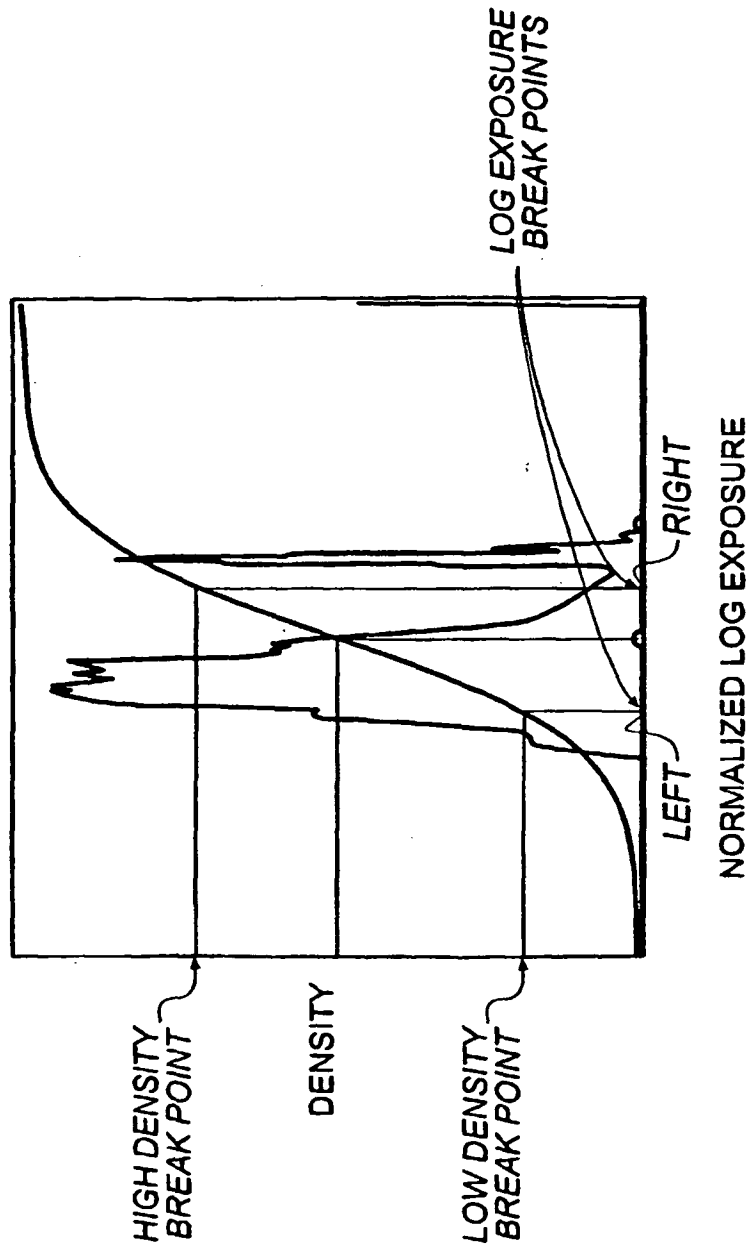


FIG. 8

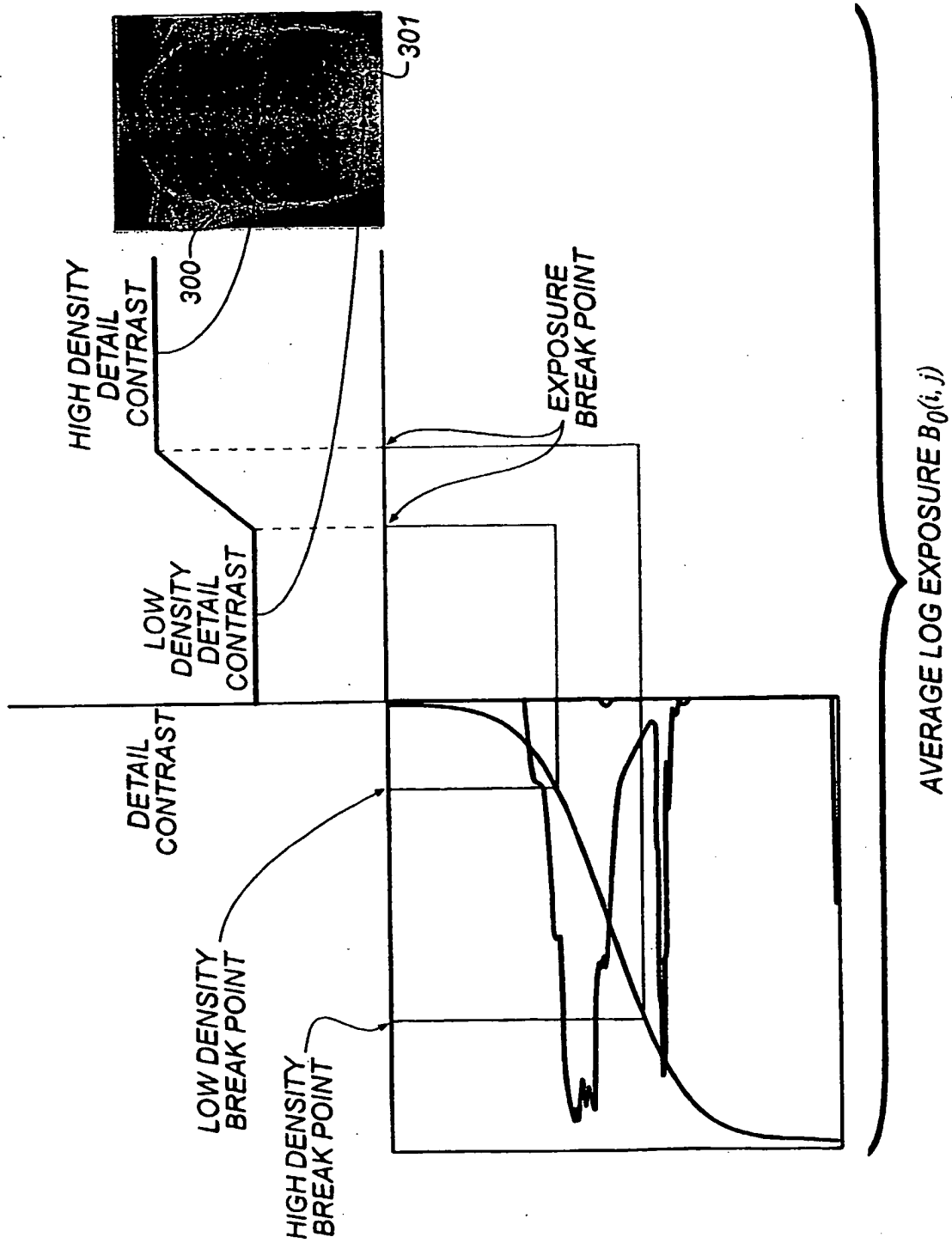


FIG. 9

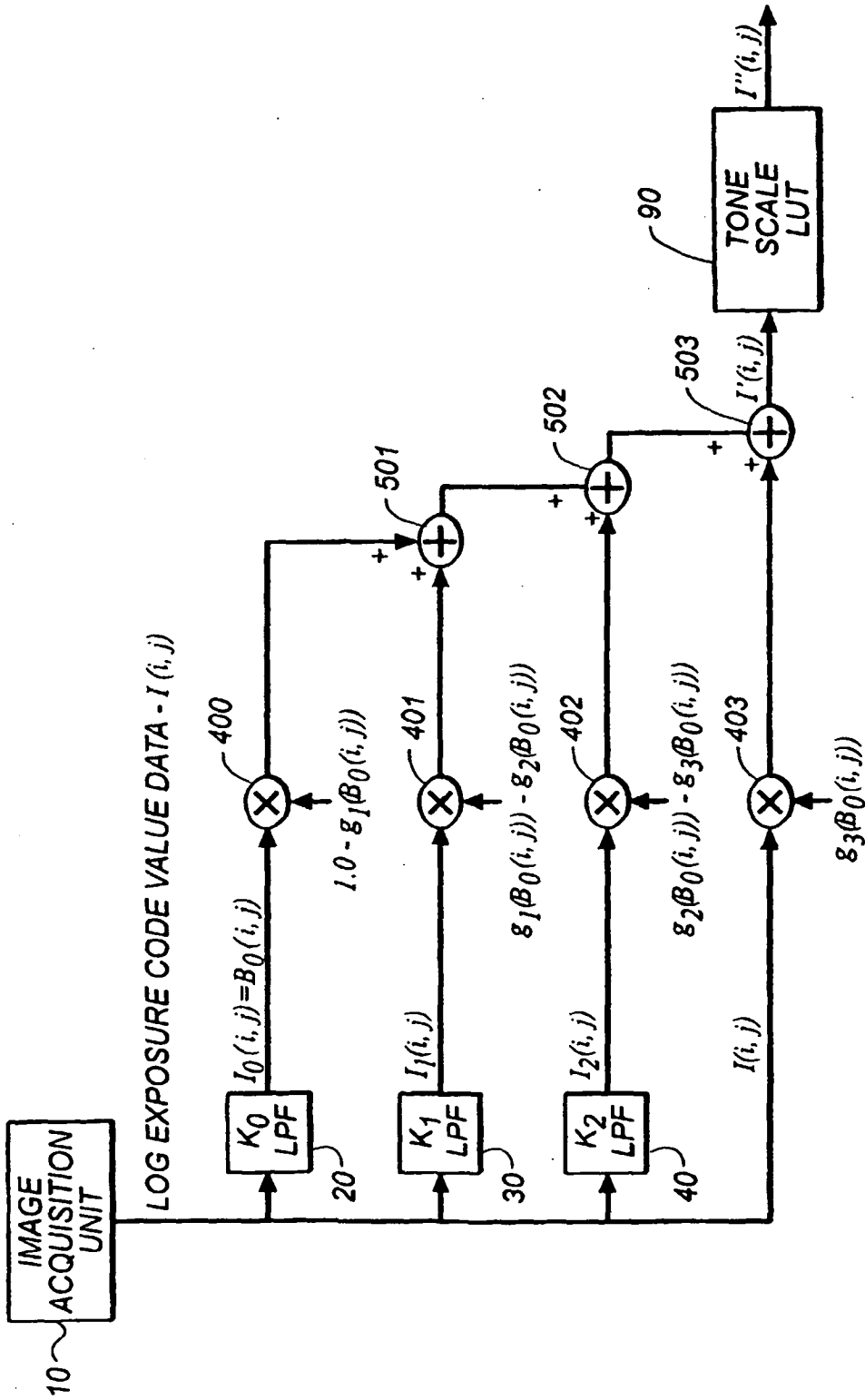


FIG. 10

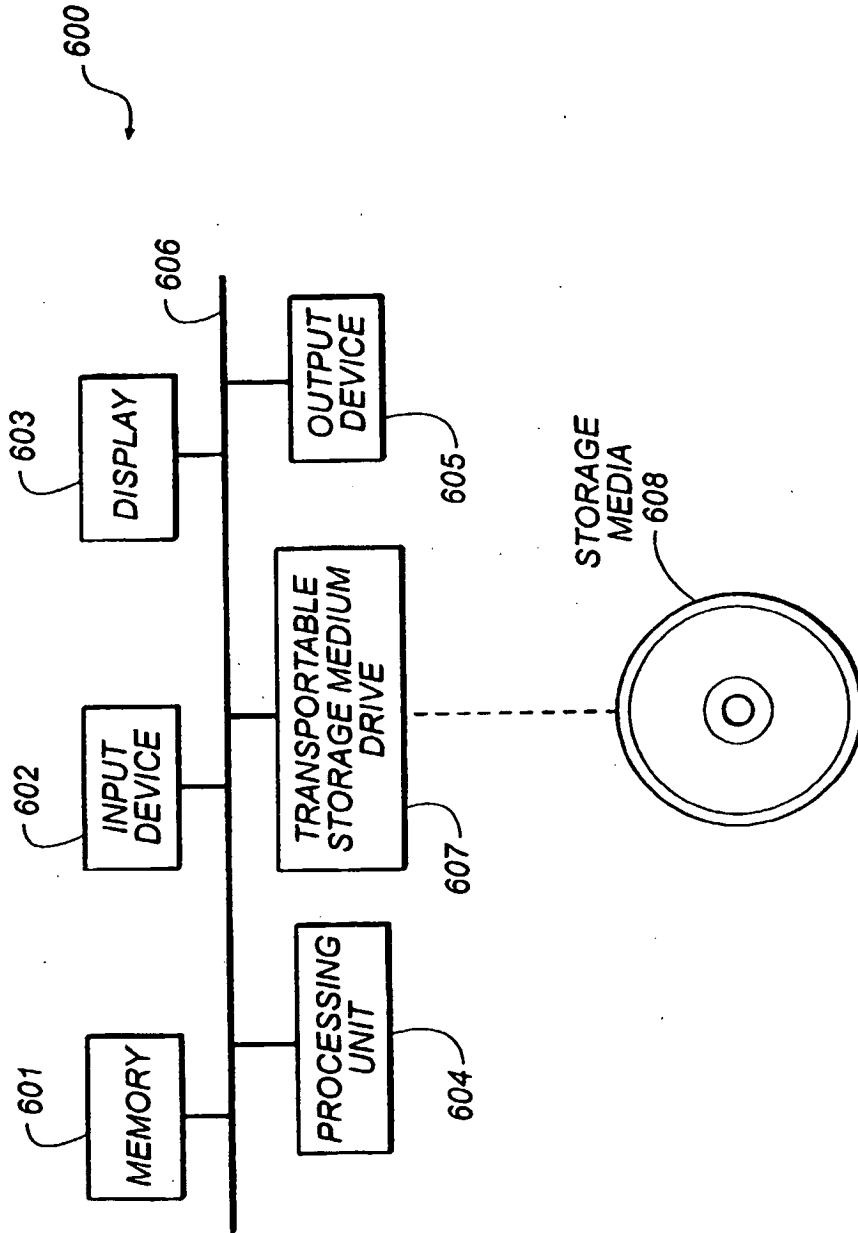


FIG. 11

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **Mary Couwenhoven et al.** Enhancement method that provides direct and independent control of fundamental attributes of image quality for radiographic imagery. *Medical Imaging 2004-SPIE*, vol. 5367, 474-481 [0006]

专利名称(译)	基于对基本图像质量参数的独立控制来渲染用于显示的数字射线照相图像的方法		
公开(公告)号	EP1501049B1	公开(公告)日	2009-12-30
申请号	EP2004077018	申请日	2004-07-12
[标]申请(专利权)人(译)	伊斯曼柯达公司		
申请(专利权)人(译)	伊士曼柯达公司		
当前申请(专利权)人(译)	锐珂医疗, INC.		
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IPC分类号	G06T5/00 A61B5/00 A61B6/03 G06K9/00 G06K9/40 G06T1/00 G06T5/20 H04N1/409		
CPC分类号	G06T5/004 G06T2207/20016		
优先权	10/625964 2003-07-24 US		
其他公开文献	EP1501049A1		
外部链接	Espacenet		

摘要(译)

一种增强数字图像的方法, 包括: 提供数字图像; 将所提供的数字图像分解成包括低频带图像和多个不同高频带图像的多频带表示; 将每个高频带图像乘以增益因子; 将未修正的低频带图像和修正的高频带图像相加在一起以产生重建的数字图像; 以及通过色调比例查找表映射重建的数字图像以将重建的数字图像映射到光密度。

