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1 Attorney Docket No. 79944

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3 METHOD FOR OPTIMIZING VISUAL DISPLAY OF ENHANCED DIGITAL IMAGES

4
5 STATEMENT OF GOVERNMENT INTEREST

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10
11 BACKGROUND OF THE INVENTION

12 (1) Field Of The Invention

13 The present invention provides a method and system utilizing
14 the wavelet transform as a method of improving and optimizing the
15 visual display of image data at the time of viewing, to provide
16 enhanced information analysis capability for disease screening
17 and diagnosis, such as breast cancer. Through the use of an
18 interactive software tool, the user can display both unprocessed
19 and processed enhanced images simultaneously as well as control
20 higher enhanced image iterations to produce better image viewing
21 and therefore better diagnosing capability.

22 (2) Description Of The Prior Art

23 The historical method of conducting mass screening for
24 certain diseases, such as breast cancer, utilizes traditional
25 analog film mammograms produced from x-rays. Once the mammograms

1 are produced, the films are visually inspected by radiologists to
2 determine if any abnormalities exist. Should a suspicious area
3 be visually perceptible, various follow-on procedures are
4 conducted. This process is subjective and dependent upon the
5 level of expertise and thoroughness of the radiologist and the
6 quality of detail of suspicious features in the film mammogram.

7 For example, the presence of dense breast tissue can mask
8 subtle abnormal features in the mammogram. Cancer in the early
9 stages may go undetected for some period of time. Detection of
10 cancer during later stages of the disease results in more costly
11 invasive procedures at best and may result in loss of life for
12 severe cases.

13 With the recent advent of full-field, direct-digital
14 mammography, digital acquisition technology that results in
15 images most closely matching those of standard film screen
16 radiography is becoming the standard method for screening. The
17 advantage of digital mammography currently is that the image can
18 be generated with confidence that technical features and factors
19 will be satisfactory and the imaging will not need to be
20 repeated, thus maximizing efficiency for the facility and
21 minimizing x-ray dose exposure to the patient.

22 While such advantages are important, the opportunity exists
23 for software tools which allow the radiologist to visually
24 enhance features in digitally acquired images at the time of
25 viewing to yield more information than was ever available with

1 standard film screen radiography. With direct digital
2 acquisition, additional benefits for image optimization can be
3 realized through preprocessing and post-processing of image data.
4 Rather than printing digital images onto film for interpretation
5 by the radiologist, the same images can be available for viewing
6 directly on a monitor.

7 Various wavelet techniques are used to enhance the visual
8 and quantitative presentation of important image features. The
9 use of wavelet transformation for image enhancement is known in
10 the art of x-ray and ultrasonic imaging. Further the use of
11 multiple image display capability is also known. However, the
12 prior art does not demonstrate a unique system and method which
13 allows a physician or other image reader to acquire raw,
14 unprocessed data and interactively and iteratively perform image
15 processing operations to enhance the image while maintaining the
16 original unprocessed image for reference and comparison.

17

18 SUMMARY OF THE INVENTION

19 The present invention features an interactive method to
20 detect, isolate, and visually enhance features in digital images.

21 The wavelet transform accepts all of or a specific portion
22 of a digitized image, such as a mammogram, as the input image,
23 and using multi-spectral decomposition, produces a mathematical
24 model or algorithm representing the digital image across various
25 frequencies and spatial positions represented by the transform.

1 The resulting coefficient map is processed according to the
2 selected enhancement method. One dimensional, two dimensional
3 and three dimensional signal and image data may be enhanced, as
4 well as segments of the image.

5 Once the coefficient map has been processed, an inverse
6 transform is performed to reconstruct the image. The original
7 unprocessed image and the enhanced image are displayed at the
8 same time on the computer monitor. Since this is a variable
9 process which is influenced by size and geometry of the features
10 of interest and, in the case of a mammogram, density of breast
11 tissue, the current process has the capability for three separate
12 enhancement techniques as selected by the user.

13 The algorithms are parameterized and interactive such that
14 several enhanced images may be produced in real time and the
15 physician or the image reader may control tradeoffs among feature
16 contrast enhancement, background tissue contrast reduction and
17 spatial resolution. The system may also be adapted for use with
18 or by an automated detection algorithm.

19 The present invention is of special utility in the location
20 and enhancement of subtle abnormalities in breast images, to
21 increase the contrast of the features of interest while
22 simultaneously reducing the contrast of surrounding breast
23 tissue. Suspicious features which would have remained hidden by
24 conventional methods can be visualized in a manner that maintains
25 the highest visual spatial resolution possible while still

enhancing subtle features of interest to aid the radiologist to visually locate and interpret these suspicious features.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood in view of the following description of the invention taken together with the drawings wherein:

FIG. 1 is a system block diagram of the present invention;

FIG. 2 is a flow chart of the method of the present invention; and

FIG. 3 illustrates an alternative embodiment for performing enhancement on an image segment or full digital mammogram.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention comprises a method and system to detect, isolate, and visually enhance features in digital images. A data processing system 10, FIG. 1, such as a standalone workstation, personal computer (PC) or other processing system, is used to run the software system 12 which includes wavelet based software 14, enhancement routines 16 and a graphical user interface (GUI) 18 to guide the user through the received process. It is assumed that the image data 20 would be either received in digitized form or digitized external to the analysis system.

1 The raw image 15 is displayed proximate the processed,
2 enhanced image(s) or image segment(s) 17a-17c on a monitor or
3 other display device 26 connected to the data processing system
4 10. The user interfaces with the data processing system 10
5 through user interface devices, such as keyboard 30 and mouse 32.

6 Optional and external to this system could be a computer
7 aided detection system 22 that automatically analyzes and
8 highlights suspicious regions of either the raw or processed
9 image for further inspection by the user, such as a radiologist,
10 physician, or other image reader. Also external to this analysis
11 system could optionally be a commercial storage device 24
12 containing a database 25 of digital images, such as mammograms,
13 or other digitized images accessible via the Internet or local
14 area network. Therefore, comparison with historical image data
15 from previous years would be possible.

16 The analysis system of the present invention is driven by a
17 graphical user interface (GUI) 18. The GUI allows the physician
18 to select the enhancement method and processing tradeoffs,
19 including the selection of either full image or image segments
20 for further interactive wavelet enhancement. The GUI also
21 incorporates zoom-in and zoom-out features for original and
22 enhanced images as well as standard window and level image
23 processing techniques. Higher detail iterative image segment
24 analysis is possible for suspicious regions that are subtle in
25 nature or for areas containing dense tissue where the features

1 are difficult to visualize in either an original image or a
2 baseline enhanced image.

3 The GUI allows the user to select the wavelet basis
4 function(s), enhancement method and algorithm parameters
5 constrained within an acceptable level. The GUI can have default
6 settings which provide the user with initial images and
7 predefined sets of settings facilitating enhancement selection.

8 The physician or user interactively controls the processing
9 tradeoffs among contrast enhancement for features of interest,
10 contrast reduction for surrounding tissue and spatial resolution
11 for clarity of detail in real time. This is a variable process
12 which is influenced by size and geometry of the features of
13 interest and, in the case of a mammogram, density of breast
14 tissue. Because of this variability, the current process has the
15 capability for multiple separate enhancement techniques as
16 selected by the user and discussed below.

17 FIG. 2 illustrates the method of the present invention.
18 Image file identification data is entered by the user through the
19 GUI 18 to acquire or retrieve the original series of images as
20 indicated in act 110. The unprocessed image(s) is displayed on
21 the computer monitor, act 120. The user selects the processing
22 mode for either full image, act 125, or image segment, act 130.
23 If image segment is selected, the user guides the process at act
24 140 and selects a specific area of interest in the raw image for
25 further processing. A specific enhancement method may be

1 selected or, by default, three separate enhancement techniques
2 may be applied, act 150. The user may control the level of image
3 enhancement and the specific technique utilized for enhancement,
4 termed "Gentle", "Moderate", or "Aggressive". The selected
5 enhancement is performed by the wavelet transform. A dyadic
6 wavelet transform is performed on all the rows and columns of the
7 image data, for a two dimensional example. For a general
8 discussion of the use of wavelets, consult "Wavelets and Filter
9 Banks" by Gilbert Strang and Truong Nguyen.

10 The transform first produces the multi-spectral image
11 decomposition across the various frequencies and spatial
12 positions represented by the transform at act 160. A specific
13 wavelet basis function with various filter lengths may be
14 selected by the user such as Daubechies, Coiflet, Symmlet, Harr,
15 Morlet or the like. The system default utilizes the Daubechies
16 basis function. The coefficient map is next processed at act 170
17 according to the selected enhancement method as further explained
18 below under "Gentle Enhancement", "Moderate Enhancement", or
19 "Aggressive Enhancement".

20 Once the coefficient map has been processed, an inverse
21 wavelet transform is performed to reconstruct the image at act
22 180, now enhanced. The original unprocessed mammogram and
23 several enhanced baseline full breast images or image segments
24 are displayed simultaneously on the computer monitor at act 190.

1 The algorithms may be used with either digitized film
2 mammograms or with digitally acquired data from next generation
3 digital x-ray devices. The algorithms have been parameterized to
4 allow the physician to interactively control the processing
5 tradeoffs among contrast enhancement for features of interest,
6 contrast reduction for surrounding tissue and spatial resolution
7 for clarity of detail in real time.

8 The graphical user interface (GUI) provides the user with a
9 series of interactive tools to iteratively select higher or lower
10 levels of feature contrast enhancement and background tissue
11 reduction. The interactive tools interface with the selected
12 wavelet transform and enhancement function(s) to adjust in real-
13 time the wavelet coefficients across multiscale space. Each time
14 the interactive tools are invoked, the wavelet coefficient space
15 is adjusted to accomplish the stated goals above. The user
16 controls the image enhancement according to whether or not the
17 last iterative enhancement was visually better or worse than the
18 previous enhanced image. Interactively controlling the level of
19 image enhancement produces better visualization of certain types
20 of features and tissue density.

21 The method of the present invention increases the signal to
22 noise ratio (SNR) for the features of interest by both increasing
23 the signal component and decreasing the noise component. Because
24 the overall goal is to make suspicious features in digital images
25 more visually apparent, these techniques increase the contrast

1 for features of interest and reduce the contrast for surrounding
2 tissue. In this respect, the ratio of signal (features of
3 interest) to noise (surrounding tissue) is improved.

4 The algorithms also include quantitative techniques for
5 calculating improvement factors (IFs). Coordinates are defined
6 for features of interest and for background tissue in the raw
7 unprocessed image. Average feature contrast to background tissue
8 contrast ratios are calculated for both enhanced images (CBRe)
9 and original images (CBRo). Improvement factors are defined as
10 follows: $IF = CBRe/CBRo$.

11 The IF gain factor is similar to calculating a signal to
12 noise ratio gain factor. Calculating IFs in this manner can aid
13 in the testing of automated detection algorithms. This approach
14 can function as a preprocessor for automated detection
15 algorithms, since the approach improves the feature contrast to
16 the background tissue contrast ratio, similar to boosting the
17 signal to noise ratio in signal processing. Better detection of
18 subtle microcalcifications and other lesions contained in dense
19 breast tissue could result through the use of automated
20 techniques, complementing visual inspection by physicians.

21 The iterations of the wavelet transformation process of the
22 present invention are illustrated in FIG. 3 and are similar,
23 whether performing enhancement on an image segment or on the full
24 digital image. In FIG. 3, the best baseline image from act 190
25 is selected as the baseline image in act 210. Through act 220,

1 the physician selects the GUI tools and then further optimizes
2 the best enhanced baseline image by directing and controlling
3 multiscale wavelet space in act 230 to produce further enhanced
4 iterations with respect to feature contrast enhancement,
5 background tissue contrast reduction, and spatial resolution at
6 act 240, through the GUI 18. The best possible image is
7 displayed at act 250. In addition, conventional image processing
8 capabilities, such as segment magnification and window and level
9 processing may be utilized with the present invention as
10 illustrated at act 260.

11 A two-dimensional dyadic wavelet transform is conducted on
12 each row and each column of input image data. This produces a
13 wavelet coefficient map that is essentially a matrix which
14 illustrates how closely the wavelet function correlates with the
15 image data across all frequencies and spatial positions
16 represented by the transform. It is this coefficient matrix that
17 is then processed as further described below to produce a
18 processed enhanced image after inverse transformation.

19 In well known wavelet terminology, a received digital image
20 is represented by multiple wavelet scales. Each scale represents
21 a binary order of magnitude of number of pixels. For example, a
22 1024 x 1024 pixel image would have ten scales - 2^1 , 2^2 , ..., 2^{10} .
23 In the wavelet transform, scale is inversely related to
24 frequency. For example, small scales are related to the highest
25 frequencies while large scales are related to the lowest

1 frequencies. A practitioner may be concerned with features that
2 are best represented by certain scales but less obvious when
3 viewing the original image. Accordingly it is often desirable to
4 enhance features represented by certain scales while de-
5 emphasizing image information represented in other scales.

6 A default generic scaling function is utilized by all three
7 approaches for providing a gain to a wavelet coefficient matrix.
8 Prior to invoking this function, the absolute value of the
9 coefficient matrix is taken such that only the magnitude of the
10 coefficients is passed to this function independent of the sign
11 of the coefficients. The signs of the elements will be preserved
12 in later calculations.

13 The scaling function receives the wavelet coefficients from
14 the selected enhancement method (gentle, moderate, or aggressive)
15 and maximum and minimum gain factors, $G_{\max}$ and $G_{\min}$, provided
16 either initially by the system or interactively from the GUI.
17 The maximum and minimum wavelet coefficients, $W_{\max}$ and $W_{\min}$, are
18 obtained from the coefficient matrix. The ratio M is defined as
19 follows:

$$20 \quad M = \frac{G_{\max} - G_{\min}}{W_{\max} - W_{\min}} \quad (1)$$

21 The scaling function is provided as follows:

$$22 \quad [Y] = M * ([X] - W_{\min}) + G_{\min} \quad (2)$$

23 where X is the absolute value of the wavelet coefficient

24 matrix which may be either the entire matrix across all

1 scales and spatial positions or a partial coefficient
2 matrix which only represents specific scales and
3 spatial positions depending on the technique invoked;
4 $G_{\max}$ is the upper boundary of the range of the gain factors
5 to be applied to the wavelet coefficient matrix;
6 $G_{\min}$ is the lower boundary of the range of the gain factors
7 to be applied to the wavelet coefficient matrix;
8 $W_{\max}$ is the maximum magnitude of the wavelet coefficient
9 matrix; and
10 $W_{\min}$ is the minimum magnitude of the wavelet coefficient
11 matrix.
12 Y represents a scaled coefficient matrix, ranging between
13 the upper boundary value of $G_{\max}$ and the lower boundary
14 value of $G_{\min}$.
15 While the scaling function above is preferred, the system
16 may also utilize other functions to modify wavelet coefficients
17 which include but are not limited to piecewise linear functions,
18 square functions and cubic functions. For example, the piecewise
19 linear function is the implementation of three linear functions
20 for a user selected threshold and for a specified wavelet matrix.
21 If the wavelet coefficient is greater than the threshold, the
22 first linear function is implemented. If the wavelet coefficient
23 is less than the threshold, the second linear function is
24 implemented. If the absolute value of the wavelet coefficient is
25 less than the threshold, the third linear function is

1 implemented. The user controls the slope of the linear function
2 by passing parameters to the function.

3 As a second example, the square function takes the wavelet
4 coefficient as the input and squares the coefficient as the
5 output while preserving the sign of the coefficient. The cubic
6 function simply takes the wavelet coefficient as the input and
7 cubes the coefficient as the output.

8 The overall goal of the following techniques is to improve
9 the detection of breast cancer whether the approach is visually
10 inspecting an enhanced image or utilizing an automated detection
11 algorithm to highlight a suspicious region of an image. The
12 techniques concern three main functions: enhancement of features
13 of interest such as clustered calcifications, contrast reduction
14 of surrounding tissue, especially dense tissue, and maintenance
15 of high spatial resolution for diagnostic quality. These
16 functions may be addressed either simultaneously or individually.
17 For example, an image produced from fatty breast tissue that is
18 already very clear could require only enhancement of an extremely
19 subtle calcification that is not visually perceptible, rather
20 than reduction of contrast on uninteresting background tissue.

21 22 GENTLE ENHANCEMENT

23 In the gentle enhancement method, single scales or
24 frequencies of the wavelet transform are processed. The GUI
25 allows the user to select a single scale of the wavelet transform

1 that the user believes will map well with the size and shape of
2 the particular feature of interest.

3 Two closely related wavelet basis functions are selected for
4 representing the features of interest at a corresponding scale.
5 These wavelet basis functions have the same parent function but
6 different filter lengths. Previous work has shown the benefit of
7 using two closely related wavelet basis functions for improving
8 image enhancement using the ("gentle" and "moderate") techniques.

9 Two separate sets of gain factors are used to calculate two
10 separate gain factor matrices using the scaling function. The
11 first set of gain factors enhances desirable details in the
12 image. This set of gain factors is larger in magnitude and is
13 used to modify the higher frequency coefficients at a given
14 scale. The second set of gain factors de-emphasizes background
15 details in the image. This set is more modest in magnitude and
16 is used to modify the wavelet coefficients corresponding to the
17 lowest frequencies in the coefficient matrix at a given scale.
18 These sets of gain factors are empirically defined and specific
19 to a particular application. For example, digital mammography
20 would have a different set of gain factors than would digital
21 chest x-rays or bone and joint analysis. The transform
22 coefficients from the first wavelet basis function are used for
23 separate calculation of two gain factor matrices. The first
24 transform wavelet coefficients corresponding to the highest
25 frequencies of the decomposition based on the chosen scale of the

1 wavelet basis function are used to calculate the first gain
2 factor matrix as previously described.

3 The first transform wavelet coefficients corresponding to
4 the lowest frequencies of the decomposition based on the chosen
5 scale of the wavelet basis function are used to calculate the
6 second gain factor matrix as previously described. These
7 coefficients are excessively larger than the coefficients
8 corresponding to higher frequencies, and if left in the
9 calculation of the gain factor matrix for single scale
10 resolution, the data would be badly skewed towards the few large
11 coefficients of the lowest frequency.

12 The second wavelet transform coefficient matrix from the
13 second basis function is modified by the two gain factor
14 matrices. The modification of the wavelet space occurs as an
15 element by element matrix multiplication of the wavelet
16 coefficient matrix from the second transform with the two
17 calculated gain factor matrices from the first transform.

18 The gain factor matrix calculated with the lower magnitude
19 gain factors modifies the lower frequency coefficients. The gain
20 factor matrix calculated with the higher magnitude gain factors
21 modifies the remaining coefficients. The inverse wavelet
22 transform is performed on this modified coefficient matrix from
23 the second basis function to produce an enhanced image.

24 For the gain factors for the lowest frequencies in this
25 technique, $G_{\max}$ has varied between 0.9 and 1.2 and $G_{\min}$ has varied

from 0.9 to 1.0. For the set of gain factors for the highest frequencies in this technique, $G_{\max}$ has varied between 1.0 to 8.0 and $G_{\min}$ has varied from 0.5 to 1.0. These factors have been found to enhance the image while maintaining good spatial quality.

MODERATE ENHANCEMENT

Moderate enhancement relies on a multi-step process for conducting image enhancement. Generally, this is similar to the gentle enhancement technique except a range of feature characteristics is specified, and this range of feature characteristics involves multiple scales of the wavelet transform. After transforming, rescaling is utilized to take full advantage of the entire dynamic range of the color map.

The user selects the specific features of interest and resolutions desired for image enhancement. Scales of the wavelet transform are selected that map well with the features of interest. These features may span a range of size and shape characteristics. As discussed above, two wavelet basis functions are provided and gain factor matrices are calculated for each scale. Transformation, enhancement, and inverse transformation is performed as above for each scale.

The rescaling function works best when the image segment to be enhanced is fairly homogeneous in structure, i.e. the data exists in a narrow band of the entire dynamic range for the

1 image. In that case it is beneficial to rescale the image data.
2 For example, if an image segment is selected for magnification
3 and has a dynamic range between 124 and 182 out of 256 grayscale,
4 there would be a visual benefit to rescaling the data to take
5 advantage of stretching the segment dynamic range over the entire
6 256 grayscale.

7 If the image segment to be enhanced already significantly
8 represents the dynamic range of the color map, this technique
9 would utilize enhancement from two or three frequency/spatial
10 resolutions and not attempt to rescale the image data. For the
11 set of gain factors for the lowest frequencies in this technique
12 $G_{\max}$ has varied between 0.7 to 1.6 and $G_{\min}$ has varied from 0.5 to
13 1. For the set of gain factors for the highest frequencies in
14 this technique, $G_{\max}$ has varied between 1.0 to 12 and $G_{\min}$ has
15 varied from 0.5 to 1. In all other respects, the specific
16 technique followed for image enhancement is the same as the
17 approach discussed above for gentle enhancement except for the
18 fact that more than one scale of the wavelet transform is being
19 utilized.

20

21 AGGRESSIVE ENHANCEMENT

22 Unlike the previous techniques, the aggressive enhancement
23 utilizes a single wavelet transform from a single basis function
24 for both the calculation of the gain factor matrix and the
25 processing of the wavelet coefficient matrix. This technique

1 utilizes the entire frequency/spatial decomposition as produced
2 by the dyadic wavelet transform for image enhancement. The gain
3 factors are passed to the scaling function as the default or to
4 piece-wise linear, square or cubic functions for each unique
5 frequency/spatial resolution of the wavelet transform.

6 Given that the present invention is conducting a two-
7 dimensional wavelet transform on the image data, the number of
8 unique frequency/spatial resolution cells is determined by the
9 size of the input image data. The wavelet transform is conducted
10 on all of the rows and all of the columns of the input image
11 data. What may be varied with this technique is the choice of
12 the wavelet basis function and the gain factors passed to the
13 scaling function or other selected enhancement function for each
14 scale. For example, if $G_{\max}$ and $G_{\min}$ are both passed the values of
15 1, there is no modification in the wavelet coefficient for that
16 particular frequency/spatial resolution.

17 A unique gain factor matrix is calculated for each
18 individual scale. This gain factor matrix is then used to
19 perform an element by element matrix multiplication with the
20 original wavelet matrix for that specific resolution to create a
21 new modified wavelet matrix. When the process is completed for
22 all scales, an inverse wavelet transform is performed, and an
23 enhanced image is produced. Because this technique utilizes all
24 scales of the transform, it requires significantly more
25 computations than the other techniques.

1 There are some general rules defined by heuristic measures
2 that are followed in the selection of the magnitude of the gain
3 factors for all three methods of wavelet enhancement.

4 First, since it is not known apriori the exact size of the
5 features to be enhanced and in which directions the features are
6 more prominent, i.e., the horizontal or vertical direction,
7 consistency is kept in the selection of the gain factors for
8 related frequency/spatial resolutions. For example, gain factors
9 used for a level 3 scale in the horizontal direction and a level
10 4 scale in the vertical direction would be similar to gain
11 factors used for a level 4 scale in the horizontal direction and
12 a level 3 scale in the vertical direction.

13 Secondly, since the lowest frequency resolutions contain the
14 highest percentage of image energy, the magnitude of the gain
15 factors for the low frequency scale are significantly smaller
16 than the magnitude of the gain factors for the high frequency
17 scales.

18 Thirdly, the type of tissue structure encountered will
19 effect the level of the gain factors selected. For extremely
20 dense breast tissue, it is at least equally important to reduce
21 the contrast of the surrounding breast tissue as it is to
22 increase the contrast of features of interest. It is not
23 uncommon for both $G_{\max}$ and $G_{\min}$ to have values less than 1 for low
24 frequency resolutions for dense breast tissue. For fatty tissue
25 structure, $G_{\max}$ may vary from slightly greater than 1 to slightly

1 less than 1 and $G_{\min}$ may vary from 0 to 1 for low frequency
2 resolutions. For fatty-glandular tissue structure, the values of
3 the parameters fall in between the range of those mentioned above
4 for low frequency resolutions for this technique depending on
5 whether the tissue structure has a higher percentage of fatty or
6 glandular tissue density.

7 Fourthly, for higher frequency resolutions, $G_{\max}$ may vary
8 between 1.0 and 40.0 and $G_{\min}$ may vary between 0 and 1.0.

9 Although the present invention is described with regard to
10 an embodiment that relates to the use of the present invention in
11 the area of mammography, this is for exemplary purposes only.
12 The process of real time interactive visual enhancement is
13 relevant for all digital images independent of modality and
14 method of acquisition. The present invention could be utilized
15 in other applications in digital radiography as well, but is not
16 limited to, for example, x-ray examinations for chest, abdomen,
17 extremities, bone and joint, and general cancer x-ray
18 examinations for lung, prostate, and brain. The present
19 invention could also be utilized in other modalities, for
20 example, ultrasound, Magnetic Resonance Imaging (MRI), Computer
21 Tomography (CT), and nuclear radiology including single photon
22 emission tomography (SPECT) and positron emission tomography
23 (PET). The present invention would have application in digital
24 angiography, with or without subtraction, and in digital
25 techniques such as tomosynthesis and dual kilovolt (kv)

1 subtraction. Non-medical applications include, for example, x-
2 ray analysis for security applications including baggage and
3 cargo protection, manufacturing fault detection analysis,
4 inspection of electronic circuit boards, and enhancement of
5 satellite imagery.

6 In addressing workflow issues, system default selections may
7 be established by a specific physician based upon individual
8 desires such that baseline enhanced images are preprocessed and
9 available for review at the time of viewing for full digital
10 images. Additional image enhancement iterations may then be
11 produced in real time should a suspicious region require further
12 enhancement.

13 Should these techniques be utilized as an adjunct to
14 computer aided detection (CAD) algorithms, baseline enhanced
15 image segments may be produced and displayed at the time of
16 viewing. Multiple baseline enhanced image segments, each
17 segment produced for an individual CAD marked segment, would
18 provide the physician with a tool to visually inspect areas of
19 the image thought to be suspicious by the CAD algorithm. These
20 enhanced image segments would be available at the time of
21 viewing. Similarly for this process, the physician may desire to
22 produce additional enhanced image iterations for increased visual
23 diagnosis.

24 Various presets may be established to conduct specific and
25 focused screening and diagnosis for a particular feature type.

1 For example, a physician may select a preset where the technique
2 is optimized to conduct image enhancement for only calcifications
3 or only spiculated lesions. As previously described, additional
4 iterative image enhancements may be conducted.

5 In light of the above, it is therefore understood that
6 the invention may be
7 practiced otherwise than as specifically described.

1 Attorney Docket No. 79944

2

3 METHOD FOR OPTIMIZING VISUAL DISPLAY OF ENHANCED DIGITAL IMAGES

4

5 ABSTRACT OF THE DISCLOSURE

6 The present invention provides a method utilizing a wavelet
7 transform for improving and optimizing the visual display of
8 image data at the time of viewing to provide enhanced information
9 analysis capability for image analysis such as breast cancer
10 screening and diagnosis. Through the use of an interactive
11 software tool, the user displays both unprocessed and processed
12 images simultaneously. The method also allows additional
13 enhancement iterations resulting in better image reading and
14 interpretation. In the case of digital mammography images, this
15 technique allows suppression of background details and
16 enhancement of selected features allowing additional diagnostic
17 capability.

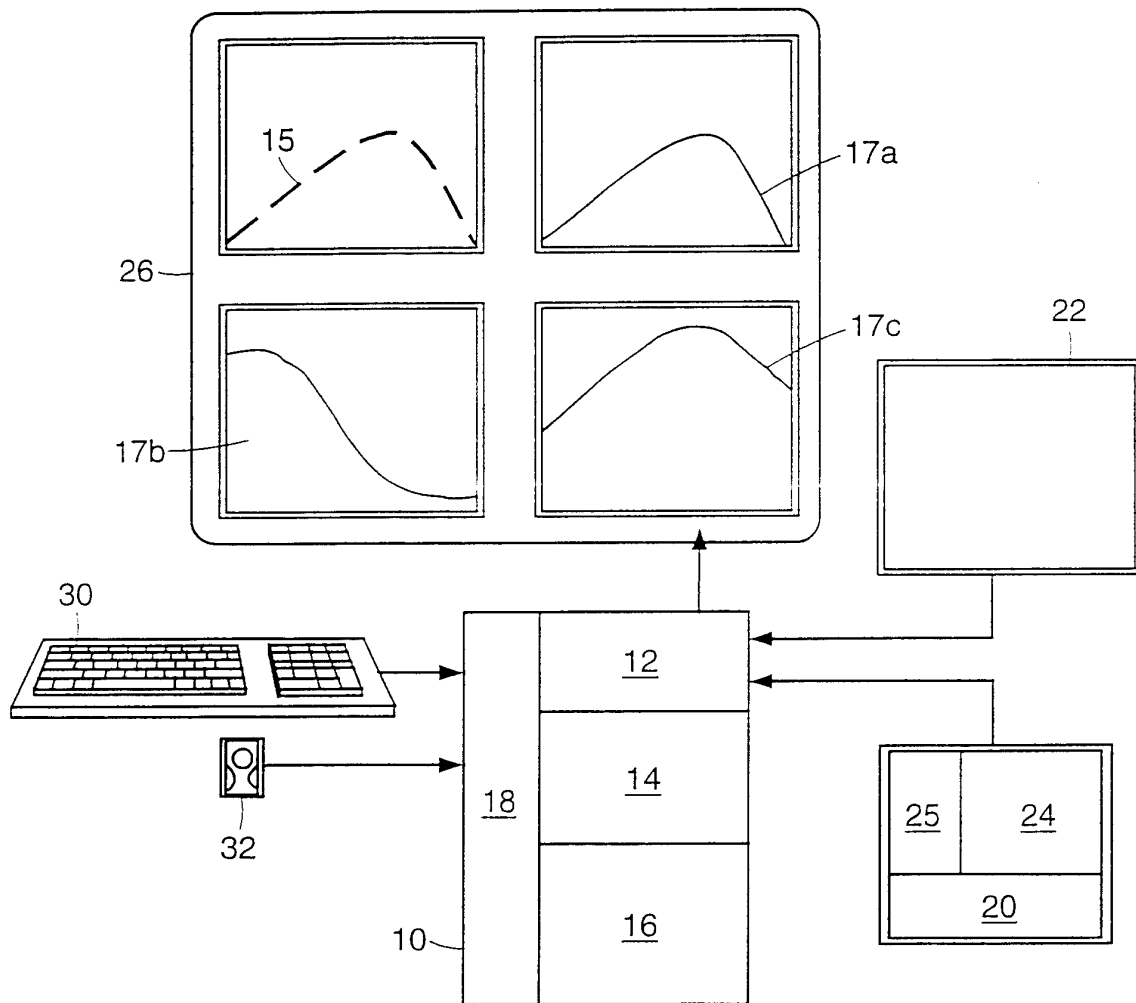


FIG. 1

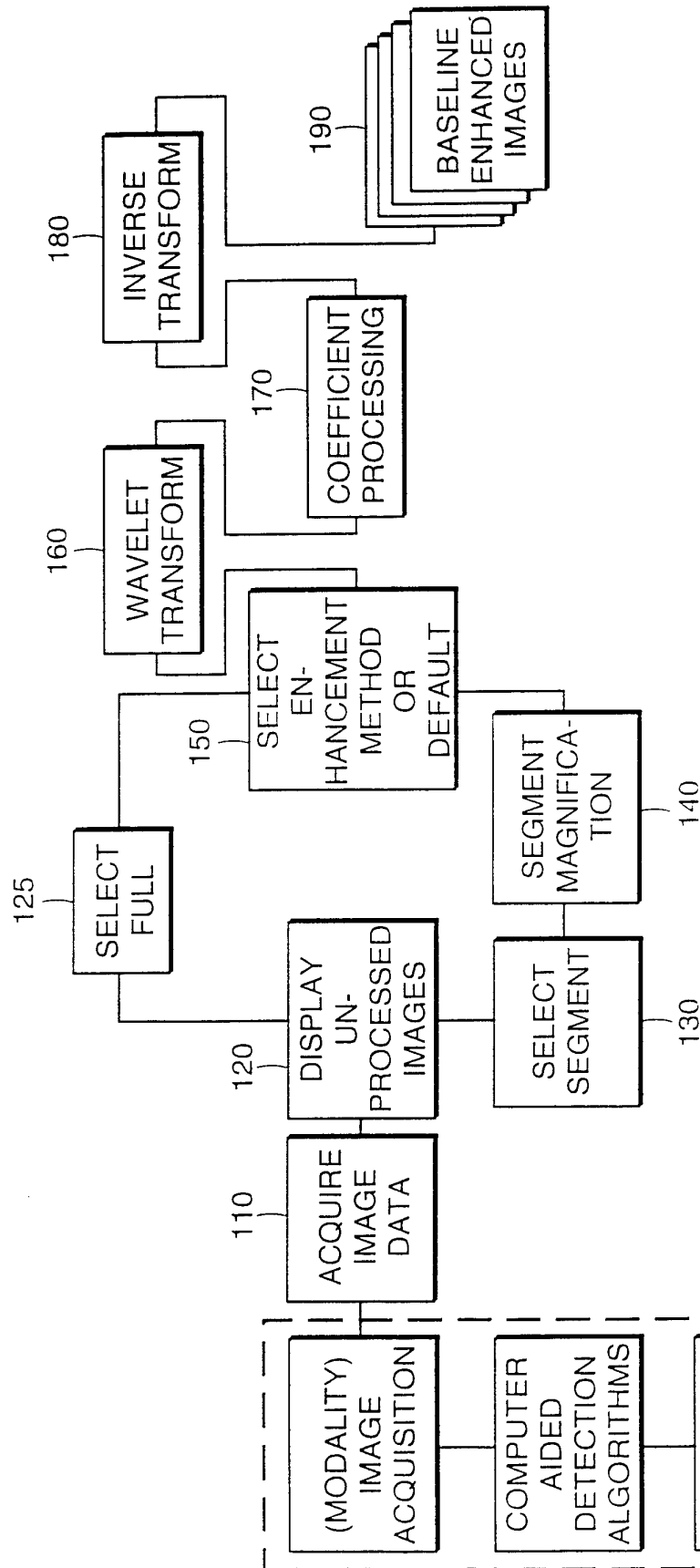


FIG. 2

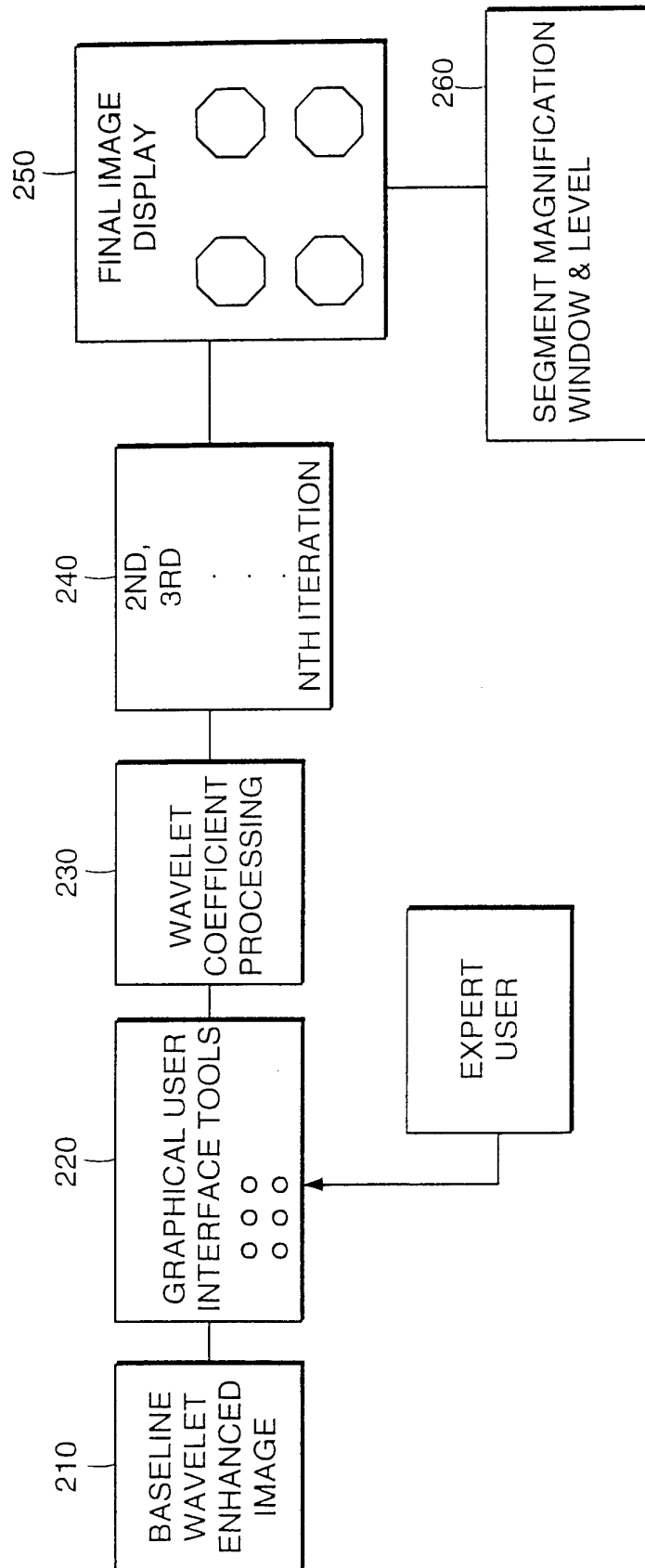


FIG. 3