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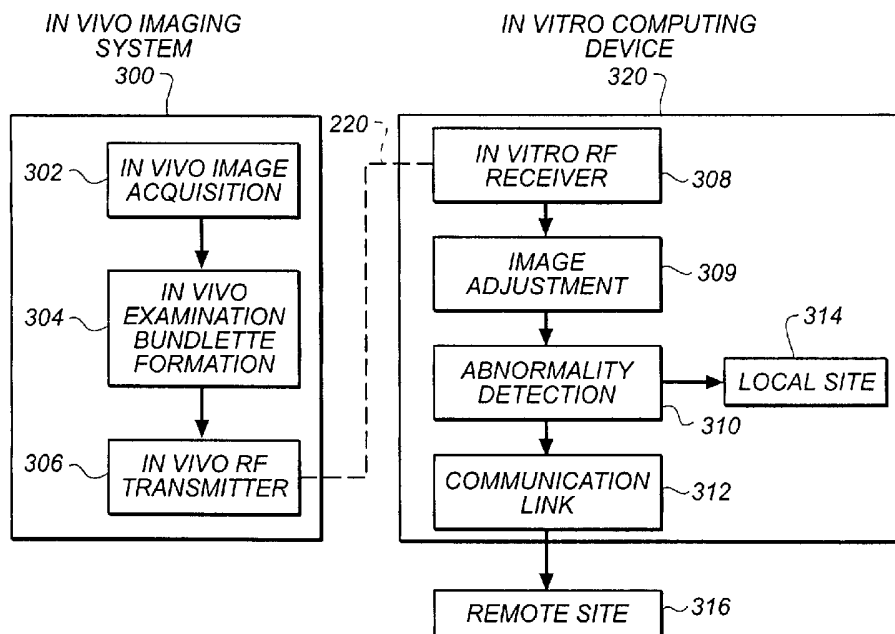
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(54) Title: AUTOMATIC IN VIVO IMAGE ADJUSTMENT



(57) Abstract: A digital image processing method for exposure adjustment of in vivo images that includes the steps of acquiring in vivo images; detecting any crease feature found in the in vivo images; preserving the detected crease feature; and adjusting exposure of the in vivo images with the detected crease feature preserved.



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AUTOMATIC IN VIVO IMAGE ADJUSTMENT

FIELD OF THE INVENTION

The present invention relates generally to an endoscopic imaging system and, in particular, to image exposure adjustment of in vivo images.

BACKGROUND OF THE INVENTION

Several in vivo measurement systems are known in the art. They include swallowed electronic capsules which collect data and which transmit the data to an external receiver system. These capsules, which are moved through the digestive system by the action of peristalsis, are used to measure pH ("Heidelberg" capsules), temperature ("CoreTemp" capsules) and pressure throughout the gastrointestinal (GI) tract. They have also been used to measure gastric residence time, which is the time it takes for food to pass through the stomach and intestines. These capsules typically include a measuring system and a transmission system, wherein the measured data is transmitted at radio frequencies to a receiver system.

U.S. Patent No. 5,604,531, assigned to the State of Israel, Ministry of Defense, Armament Development Authority, and incorporated herein by reference, teaches an in vivo measurement system, in particular an in vivo camera system, which is carried by a swallowed capsule. In addition to the camera system there is an optical system for imaging an area of the GI tract onto the imager and a transmitter for transmitting the video output of the camera system. The capsule is equipped with a number of LEDs (light emitting diodes) as the lighting source for the imaging system. The overall system, including a capsule that can pass through the entire digestive tract, operates as an autonomous video endoscope. It images even the difficult to reach areas of the small intestine.

U.S. Patent Application No. 2003/0023150 A1, assigned to Olympus Optical Co., LTD., and incorporated herein by reference, teaches a design of a swallowed capsule-type medical device which is advanced through the inside of the somatic cavities and lumens of human beings or animals for conducting examination, therapy, or treatment. Signals including images captured

by the capsule-type medical device are transmitted to an external receiver and recorded on a recording unit. The images recorded are retrieved in a retrieving unit, displayed on the liquid crystal monitor and to be compared by an endoscopic examination crew with past endoscopic disease images that are stored in a disease image database.

One problem associated with the capsule imaging system is a non-uniform lighting over the imaging area due to the nature of this miniature device. Especially, when the capsule travels along a tube-like anatomical structure, the field of view of the camera system covers a section of the anatomical structure inner wall which is nearly parallel with the camera optical axis. Obviously, in this field of view, part of the anatomical structure inner wall away from the capsule receives less photon flux than that of the anatomical structure inner wall close to the capsule. The resultant is a non-uniform photon flux field. In return, part of the image produced by the camera image sensor is either under exposure or over exposure depends on how the camera is calibrated. Therefore, details of texture and color will be lost, which not only affects physicians' ability of abnormality diagnosis using these in vivo images, but also reduces the effectiveness of neighboring in vivo image stitching in applications such image mosiacing.

In general, in order to maximize the use of photon flux, the in vivo camera is calibrated such that there will be no over exposure in the captured images. Thus the non-uniform photon flux distribution results in under exposure in various areas of certain in vivo images. This under exposure of in vivo image is similar to the light falloff in regular photographic images.

U.S. Patent Application No. 2003/0007707 A1, assigned to Eastman Kodak Company, and incorporated herein by reference, teaches a method for compensating for light falloff caused by the non-uniform exposure which is produced by lenses at their focal plane when imaging a uniformly lit surface. For instance, the light from a uniformly gray wall perpendicular to the camera optical axis will pass through a lens and form an image that is brightest at the center and dims radially. When the lens is an ideal thin lens, the intensity of light in the image will form an intensity pattern described by $\cos^4$ of the angle between the

optical axis of the lens and the point in the image plane. The visible effect of this phenomenon is referred to as falloff. The light compensating method taught in 0007707 describes a compensation function that relies on the value of the distance from a pixel location to the center of the image. Such a method is particularly useful for falloffs caused by lenses distortions. Invention 0007707 teaches a compensation equation: $fc_m(x, y) = \frac{4 * cvs}{\log 2} \log(\cos(\tan^{-1}(\frac{dd}{f})))$. Where dd is the distance in pixels from the (x, y) position to the center of the digital image and cvs is the number of code value per stop of exposure (cvs indicates scaling of the log exposure metric). The parameter f represents the focal length of a lens (in pixels) for which the falloff compensator will correct the falloff. This method is however less desirable for problems caused by non-uniform photon flux field when the endoscopic capsule traveling alone the GI tract, because regions with inadequate exposure do not have the geometric properties stated in the aforementioned equation.

Also the principal advantage of the invention described in 0007707 is that a falloff compensation may be applied to a digital image in such a manner that the balance of the compensated digital image is similar to that of the original digital image, which results in a much more pleasing effect that sometimes may causing problems such as blurring boundaries.

There is a need therefore for an improved endoscopic imaging system that overcomes the problems set forth above.

These and other aspects, objects, features and advantages of the present invention will be more clearly understood and appreciated from a review of the following detailed description of the preferred embodiments and appended claims, and by reference to the accompanying drawings.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a digital image processing method for exposure adjustment of in vivo images that includes the steps of acquiring in vivo images; detecting any crease feature found

in the in vivo images; preserving the detected crease feature; and adjusting exposure of the in vivo images with the detected crease feature preserved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 (PRIOR ART) is a block diagram illustration of an in vivo camera system.

FIG. 2A is an illustration of the concept of an examination bundle of the present invention.

FIG. 2B is an illustration of the concept of an examination bundlette of the present invention.

FIG. 3A is a flowchart illustrating information flow of the real-time abnormality detection method in the copending application.

FIG. 3B is a flowchart illustrating information flow of the in vivo image adjustment for diagnosis of the present invention.

FIG. 4 is a schematic diagram of an examination bundlette processing hardware system useful in practicing the present invention.

FIG. 5 is a flowchart illustrating the in vivo image adjustment method of the present invention.

FIG. 6 is a flowchart illustrating the exposure correction and cross boundary smoothing method of the present invention.

FIG. 7A is a schematic diagram of a binary image.

FIG. 7B is a schematic diagram of a mask image.

FIG. 7C is a schematic diagram of a skeleton image.

FIG. 7D is a schematic diagram of a binary image.

FIG. 8 is a collection of patterns.

FIG. 9A is a schematic diagram of an intermediate mask image.

FIG. 9B is a schematic diagram of a mask image.

FIG. 10A is a schematic diagram of a smoothing band image.

FIG. 10B is a schematic diagram of a one dimensional line in the smoothing band.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well-known features may be omitted or simplified in order not to obscure the present invention.

During a typical examination of a body lumen, the in vivo camera system captures a large number of images. The images can be analyzed individually, or sequentially, as frames of a video sequence. An individual image or frame without context has limited value. Some contextual information is frequently available prior to or during the image collection process; other contextual information can be gathered or generated as the images are processed after data collection. Any contextual information will be referred to as metadata. Metadata is analogous to the image header data that accompanies many digital image files.

FIG. 1 shows a block diagram of the in vivo video camera system described in U.S. Patent No. 5,604,531. The system captures and transmits images of the GI tract while passing through the gastro-intestinal lumen. The system contains a storage unit **100**, a data processor **102**, a camera **104**, an image transmitter **106**, an image receiver **108**, which usually includes an antenna array, and an image monitor **110**. Storage unit **100**, data processor **102**, image monitor **110**, and image receiver **108** are located outside the patient's body. Camera **104**, as it transits the GI tract, is in communication with image transmitter **106** located in capsule **112** and image receiver **108** located outside the body. Data processor **102** transfers frame data to and from storage unit **100** while the former analyzes the data. Processor **102** also transmits the analyzed data to image monitor **110** where a physician views it. The data can be viewed in real time or at some later date.

Referring to Figure 2A, the complete set of all images captured during the examination, along with any corresponding metadata, will be referred to as an examination bundle **200**. The examination bundle **200** consists of a collection of image packets **202** and a section containing general metadata **204**.

An image packet **206** comprises two sections: the pixel data **208** of an image that has been captured by the in vivo camera system, and image specific metadata **210**. The image specific metadata **210** can be further refined into image specific collection data **212**, image specific physical data **214** and inferred image specific data **216**. Image specific collection data **212** contains information such as the frame index number, frame capture rate, frame capture time, and frame exposure level. Image specific physical data **214** contains information such as the relative position of the capsule when the image was captured, the distance traveled from the position of initial image capture, the instantaneous velocity of the capsule, capsule orientation, and non-image sensed characteristics such as pH, pressure, temperature, and impedance. Inferred image specific data **216** includes location and description of detected abnormalities within the image, and any pathologies that have been identified. This data can be obtained either from a physician or by automated methods.

The general metadata **204** contains such information as the date of the examination, the patient identification, the name or identification of the referring physician, the purpose of the examination, suspected abnormalities and/or detection, and any information pertinent to the examination bundle **200**. It can also include general image information such as image storage format (e.g., TIFF or JPEG), number of lines, and number of pixels per line.

Referring to Fig. 2B, the image packet **206** and the general metadata **204** are combined to form an examination bundle **220** suitable for real-time abnormality detection.

It will be understood and appreciated that the order and specific contents of the general metadata or image specific metadata may vary without changing the functionality of the examination bundle.

Referring now to Fig. 3A, an exemplary application of the capsule in vivo imaging system is described. Fig. 3 is a flowchart illustrating a real-time automatic abnormality detection method of the present invention. In Fig. 3A, an in vivo imaging system **300** can be realized by using systems such as the swallowed capsule described in U.S. Patent No. 5,604,531 for the present invention. An in vivo image **208** is captured in an in vivo image acquisition step **302**. In a step of In Vivo Examination Bundlette Formation **304**, the image **208** is combined with image specific data **210** to form an image packet **206**. The image packet **206** is further combined with general metadata **204** and compressed to become an examination bundlette **220**. The examination bundlette **220** is transmitted to a proximal in vitro computing device through radio frequency in a step of RF transmission **306**. An in vitro computing device **320** is either a portable computer system attached to a belt worn by the patient or in near proximity. Alternatively, it is a system such as shown in Fig.4 and will be described in detail later. The transmitted examination bundlette **220** is received in the proximal in vitro computing device in a step of In Vivo RF Receiver **308**.

Data received in the in vitro computing device is examined for any sign of disease in a step of Abnormality detection **310**. Details of the step of abnormality detection can be found in commonly assigned, co-pending U.S. Patent Application Serial No. 10/679,711, entitled "Method And System For Real-Time Automatic Abnormality Detection For In Vivo Images" and filed on 06 October 2003 in the names of Shoupu Chen, Lawrence A. Ray, Nathan D. Cahill and Marvin M. Goodgame, and which is incorporated herein by reference.

Note that unlike taking photographic images in natural scenes (indoor or outdoor), in vivo imaging takes place inside the GI tract which is a controlled environment and in general is an open space within the field of the view of the camera. A controlled environment means that there are no sources of lighting other than that from the LEDs of the capsule. An open space implies that there should be no occlusions that cause shadows (under exposure). Also, the reflectance should be the same locally along the GI tract inner wall in general, at least with the same order of magnitude. (This is not the case in real world where

the reflectance of photographic objects could vary dramatically causing darker or brighter areas in the resultant images.) Thus, in an ideal case, an in vivo image should not present significant brightness differences in different areas. In reality, because of the uneven photon flux field generated by the limited lighting source, under exposure areas (low brightness areas) exist. Those low brightness areas need to be corrected to become brighter. While in photographic images of natural scenes (indoor or outdoor), low brightness areas could be a result of low reflection of a dark object surface which should not be corrected in an image.

Fig. 3B shows a diagram of information flow of the present invention. To ensure an effective detection and diagnosis of abnormality, images from RF Receiver 308 are exposure adjusted in a step of Image adjusting 309 before the abnormality detection 310 takes place (see Fig. 3B).

The step of Image adjusting 309 is detailed in Fig. 5. Denote image 501 received from RF receiver 308 by I and its pixel by $I(m, n)$, where $m = 0, \dots, M-1$, $n = 0, \dots, N-1$, M is the number of rows, and N is the number of columns. To automatically find if an image has under exposure regions, a step of image thresholding 502 is utilized. A threshold T (505) is established through a supervised learning. A supervised learning here means learning in vivo image characteristics by applying statistical analysis to a large number of in vivo images. Statistical analysis includes mean or median intensity analysis, and intensity deviation *etc.* An exemplary threshold value could be $T = \text{mean}(I) - K * \text{std}(I)$ where $\text{mean}(I)$ returns mean brightness value of the image, $\text{std}(I)$ returns the standard deviation value of the image, and K is a coefficient. An exemplary value of K is 3. The output of step 502 is a threshold image I_B and its pixel is expressed as $I_B(m, n)$. If a pixel value at location (m, n) is less than T (505), then $I_B(m, n) = 1$, otherwise, $I_B(m, n) = 0$.

Fig. 7A shows an exemplary threshold image I_B (702). The value of pixels $I_B(m, n)$ in regions 704, and 706 are one indicating that corresponding pixels, $I(m, n)$, in image I have lower brightness value than T (505). Note that image I_B 702 displays exemplary one-valued regions 706 indicating the

corresponding low brightness areas in image **I (501)** caused by crease features where light rays are unable to reach directly in certain anatomical structures of the GI tract. Image **I_B 702** also displays exemplary one-valued region **704** indicating a low brightness area in image **I (501)** caused mainly by the non-uniform photon flux field. The low brightness area in image **I (501)** corresponding to region **704** is subject to image adjustment to lift the brightness level for better diagnosis.

There are variety methods could be used to lift the brightness of an under exposure area in image **I (501)**. A preferred algorithm is described below.

Referring back to Fig. 5, in a step of Forming mask A (**506**), the threshold image **I_B (702)** undergoes a morphological opening process to close holes and gaps. The resultant image is named as mask A (**712**) shown in Fig. 7B, and denoted by **I_{MA}** and its pixel by **I_{MA}(m,n)**. In a step of Image statistics gathering **508**, the following equation is used to get **statsA (503)**:

$$statsA = F(I \cap \bar{I}_{MA}) \quad (1)$$

where $I \cap \bar{I}_{MA}$ is a logical AND operation, $\bar{I}_{MA}$ is the logical inverse of **I_{MA}**, $F(\bullet)$ is a statistical analysis operation, and **statsA (503)** is a **structure** containing mean, median and other statistical quantities of the operand which is the result of the logical AND operation, $I \cap \bar{I}_{MA}$. The **structure** is a C language like data type and **statsA (503)** is defined as

```

structure stats
{
    mean;
    median;
    minimum;
    maximum;
} statsA

```

where **stats** is the **structure** name and **statsA.mean** is the mean intensity of $I \cap \bar{I}_{MA}$, **statsA.median** is the median intensity of $I \cap \bar{I}_{MA}$, **statsA.minimum** is the minimal intensity of $I \cap \bar{I}_{MA}$ and **statsA.maximum** is the maximal intensity of $I \cap \bar{I}_{MA}$.

Note that the logical AND operation, $I \cap \bar{I}_{MA}$, excludes under exposure pixels in the original image I (501) from the statistical analysis operation $F(\bullet)$. The purpose of this exclusion is to learn the statistics only in the normal exposure regions and the learned statistics will be used in a later procedure to lift the brightness level of under exposure regions so that the final image appears coherent.

Since the image adjustment operation is only applied to regions of under exposure (such as 704) caused by the non-uniform photon flux field, a second mask needs to be formed to exclude low brightness regions (such as 706) that belong to crease features. The second mask, mask B, is formed in a step of Forming mask B (504). The step of Forming mask B (504) is further detailed next.

A first operation of forming mask B (504) is a medial axis transformation that is applied to the threshold image I_B (702) (see “Algorithm for image processing and computer vision”, by J.R. Parker, Wiley Computer Publishing, John Wiley & Sons, Inc., 1997). A medial axis transformation defines a unique compressed geometrical representation of an object. The medial axis transformation is also referred to as morphological skeletonization. The morphological skeletonization uses erosion and opening as basic operations. The result of the morphological skeletonization is a skeleton image. Denote the skeleton image by I_S and its pixel by $I_S(m, n)$. Then $I_S(m, n) = S(I_B(m, n))$, where S is the medial axis transformation function. $I_S(m, n)$ (722), an exemplary result of applying the medial axis transformation to image I_B (702), is shown in Fig. 7C. Note that the thick lines 706 in Fig. 7A become one-valued thin lines 726 in Fig. 7C. The one-valued region 704 in Fig. 7A becomes a set of one-valued thin lines 724. Note also that lines 724, and 726 have a width of one pixel. Obviously, every pixel on lines 724, and 726 in image I_S must have a corresponding pixel on lines 704 and 706 in image I_B . For lines such as 706, their skeleton lines 726 are medial axes of their own. For regions such as 704, in general, they have a set of skeleton lines 724. The skeleton lines are used to detect crease features in the

threshold image. The skeleton lines also guide an erasing operation described below.

Denote the second mask, mask B, by I_{MB} and its pixel by $I_{MB}(m, n)$. First, initialize I_{MB} by letting $I_{MB}(m, n) = I_B(m, n) \forall m, \forall n$, where $\forall m, \forall n$ means all m and all n . Denote an eraser window 732 by W . Exemplary width and height of the eraser window W (732) are $3w$, where w is the average width of lines 706. To determine if a one-valued pixel at location (m, n) of the image I_{MB} belongs to crease features such as lines 706, center the eraser window W 732 at the location (m, n) 728 of I_S (in operation, the window W is also centered at the location (m, n) 728 of I_{MB}).

In general, there are various types of patterns of the geometry relationship between the window W (732) and the one-valued pixels that belong to crease features such as lines 706. Four exemplary representations of patterns are shown in Fig. 8 assuming window W 732 is centered at location (m, n) 728. The process of detecting crease features is to look for these patterns in the threshold image. In a north-south pattern 804, there are zero-valued pixels above and below line 706. In an east-west pattern 802, there are zero-valued pixels left and right to line 706. In a north west-south east pattern 806, there are zero-valued pixels in the upper left and lower right portions of window W (732). In a north east-south west pattern 808, there are zero-valued pixels in the lower left and upper right portions of window W (732).

When pattern 802 occurs, pixel $I_{MB}(m, n)$ and its associated east-west neighboring one-valued pixels are erased. When pattern 804 occurs, pixel $I_{MB}(m, n)$ and its associated north-south neighboring one-valued pixels are erased. When pattern 806 occurs, pixel $I_{MB}(m, n)$ and its associated north west-south east neighboring one-valued pixels are erased. When pattern 808 occurs, pixel $I_{MB}(m, n)$ and its associated north east-south west neighboring one-valued pixels are erased.

The operation of erosion can be described by the following code:

```
for m = 0; m < M; m++
```

```

for n = 0; n < N; n++
  if ( $I_S(m, n) = 1$ )
    center  $W$  at  $I_{MB}(m, n)$ 
    if (any one of the patterns (802, 804, 806, 808) occurs)

      erase  $I_{MB}(m, n)$  and its associated neighboring pixels;
    end
  end
end
end
end

```

Note that the above erosion operation produces an intermediate mask B image, I_{MB} , 902 shown in Fig 9A. There may exist residual elements such as tiny regions 906 in Fig. 9A. They can be further eliminated by checking the sizes after clustering the one-valued pixels in I_{MB} .

Those skilled in the art should understand that alternative erasing methods exist. For example, erasing operation can be implemented without performing medial axis transformation by checking more pixels.

Now referring to Fig. 6, there is a flow chart illustrating the steps of image adjustment. One-valued pixels in the mask B image I_{MB} are referred to as foreground pixels. Foreground pixels are grouped to form clusters. A cluster is a non-empty set of one-valued pixels with the property that any pixel within the cluster is also within a predefined distance to another one-valued pixel in the cluster. The present invention groups binary pixels into clusters based upon this definition of a cluster. However, it will be understood that pixels may be clustered on the basis of other criteria.

A cluster may be eliminated if it contains too few one-valued pixels no matter it is a cluster of pixels of crease features or a cluster of pixels of an under exposure region. A cluster contains too few one-valued pixels suggests that the cluster does not have much influence on diagnosis. For example, if the number of pixels in a cluster is less than V , then this cluster is erased from I_{MB} .

Example V value could be 10. The above operations are done in a step of Mask property check **602**. A query step **604** branches the process to stop **606** if there are no qualified clusters in mask B I_{MB} , or to step **610** if there is at least on qualified cluster. An exemplary qualified mask B I_{MB} **912** is shown in Fig. 9B.

Mask B I_{MB} **912** is now ready to assist applying image adjustment to image **I(501)** in step **510**. Image adjustment is further detailed by steps **610** and **612**.

The exposure correction is accomplished in step **610**. First, denote an image adjustment process by $\Phi(\bullet)$. Denote an adjusted image by I_{adj} . The adjusted image by I_{adj} can be obtained by the following equation:

$$I_{adj} = (I \cap \bar{I}_{MB}) \cup \Phi(I \cap I_{MB}) \quad (2)$$

where $\bar{I}_{MB}$ is the logical inverse of I_{MB} , symbol $\cup$ is a logic OR operator, and symbol $\cap$ is a logic AND operator. The operation $(I \cap I_{MB})$ signifies that the adjustment process $\Phi(\bullet)$ applies to pixels within region **704** in image **I(501)**. On the other hand, the operation $(I \cap \bar{I}_{MB})$ signifies that the pixels outside the region **704** in image **I(501)** keep their original value in this stage.

An exemplary of a preferred algorithm of the present invention for the adjustment process $\Phi(\bullet)$ is described below:

```

structure stats statsB
statsB = F( $I \cap I_{MB}$ )
cf = statsA.median/statsB.median;
for (m = 0; m < M; m++)
{
    for (n = 0; n < N; n++)
    {
        if ( $I_{MB}(m, n) = 1$ )
        {
             $\tilde{I}_{adj}(m, n) = cf \cdot I(m, n)$ ;
            if ( $\tilde{I}_{adj}(m, n) > \mathbf{statsA}.maximum$ )

```

```

        {
             $\tilde{\mathbf{I}}_{adj}(m, n) = \mathbf{statsA}.maximum;$ 
        }
    }
}
 $\mathbf{I}_{adj} = (\mathbf{I} \cap \bar{\mathbf{I}}_{MB}) \cup \tilde{\mathbf{I}}_{adj}.$ 

```

Note that in the above implementation, the adjustment coefficient cf is guaranteed to be greater than or equal to one since $\mathbf{statsA} = F(\mathbf{I} \cap \bar{\mathbf{I}}_{MA})$ and $(\mathbf{I} \cap \bar{\mathbf{I}}_{MA})$ contains pixels having intensity greater than or equal to T (505), where $T = \text{mean}(\mathbf{I}) - K * \text{std}(\mathbf{I})$. On the other hand, $\mathbf{statsB} = F(\mathbf{I} \cap \mathbf{I}_{MB})$ and $(\mathbf{I} \cap \mathbf{I}_{MB})$ contains pixels having intensity less than (505).

Notice also that statistics other than median could be used to compute the adjustment coefficient cf , and the adjustment could be applied to individual color channels, (R, G and B), independently. The adjustment operation, $\tilde{\mathbf{I}}_{adj}(m, n) = cf \mathbf{I}(m, n)$, in this embodiment is a linear function. But other types of nonlinear functions such as log adjustment or LUT (look up table) also can be used.

Since the exposure correction is conducted only in areas such as 504 in image $\mathbf{I}$ (501), intensity discontinuity between the exposure corrected (adjustment) and uncorrected (non-adjustment) areas may exist along the boundary line such as 1004 in Fig. 10A. Line 1004 separates region 904 (same as 504) from the rest of the image. To smooth out intensity discontinuity, a step of Cross boundary smoothing 612 follows the step of Exposure correction in masked area(s) 610.

In Fig. 10A, two lines, two non-intersecting lines 1006 and 1008 define an intensity smoothing band. Lines 1006 and 1008 are on either side of a boundary line 1004 in relation to adjustment and non-adjustment areas for the in vivo image. Lines 1006 and 1008 are formed with respect to line 1004 with a

certain distance at each point to form the band width. An exemplary distance is a constant distance d (1012). An exemplary process of forming lines 1006 and 1008 is illustrated as follows. Select a point 1020 on line 1004. Find the tangent arrow 1014 of line 1004 at point 1020. Find a line 1019 that passes point 1020 and is perpendicular to arrow 1014. Find a point 1010 on line 1019 with a distance d (1012) away from point 1020 at one side of line 1004. Find a point 1018 on line 1019 with a distance d (1012) away from point 1020 at the other side of line 1004. Repeating this process for all other points on line 1004 forms two lines 1006 and 1008.

The cross boundary smoothing operation can be realized in one-dimensional space or two-dimensional space. Fig. 10B displays a one-dimensional realization. Denote point 1020 on line 1019 by $x(0)$, point 1018 by $x(-d)$, and point 1010 by $x(d)$. Other points on line 1019 will be named accordingly in the following code of implementation.

```

for (i = 0; i <= d; i++)
{

$$x(i) = \frac{1}{2D+1} \sum_{-D}^D x(i+j);$$

}
for (i = -1; i >= -d; i--)
{

$$x(i) = \frac{1}{2D+1} \sum_{-D}^D x(i+j);$$

}

```

D is less than or equal to d . Exemplary value for D is 1, and 10 for d .

From the above code, it can be seen that the new $x(0)$ is the moving average of pixels from both sides of the boundary line 1014. The influence of pixels from one side to the other side is propagated through newly updated $x(i)$. Starting the process from $x(0)$ helps the propagation of information across the boundary.

The operation described by the above discussion is assumed to be operated in an sRGB space (see Stokes, Anderson, Chandrasekar and Motta, "A Standard Default Color Space for the Internet – sRGB", <http://www.color.org/sRGB.html>).

Images in sRGB have already been optimally rendered for video display, typically by applying a 3x3 color transformation matrix and then a gamma compensation lookup table. Any adjustment to the brightness, contrast, and gamma characteristics of an sRGB image will degrade the optimal rendering. If a digital image contained pixel values representative of a linear or logarithmic space with respect to the original scene exposures, the pixel values could be adjusted without degrading any subsequent rendering steps. For those skilled in the art, the ideas and algorithms of the present invention can be applied to spaces such as de-rendered logarithmic space.

Fig. 4 shows an exemplary of an examination bundle processing hardware system useful in practicing the present invention including a template source **400** and an RF receiver **412** (also **308**). The template from the template source **400** is provided to an examination bundle processor **402**, such as a personal computer, or work station such as a Sun Sparc workstation, or a handheld device (e.g., personal digital assistant—PDA). The RF receiver passes the examination bundle to the examination bundle processor **402**. The examination bundle processor **402** preferably is connected to a CRT display **404** (which may be a touch-screen display), an operator interface such as a keyboard **406** and a mouse **408**. Examination bundle processor **402** is also connected to computer readable storage medium **407**. The examination bundle processor **402** transmits processed and adjusted digital images and metadata to an output device **409**. Output device **409** can comprise a hard copy printer, a long-term image storage device, and a connection to another processor. The examination bundle processor **402** is also linked to a communication link **414** (also **312**) or a telecommunication device connected, for example, to a broadband network.

It is well understood that the transmission of data over wireless links is more prone to requiring the retransmission of data packets than wired links. There is a myriad of reasons for this, a primary one in this situation is that the patient moves to a point in the environment where electromagnetic interference occurs. Consequently, it is preferable that all data from the Examination Bundle be transmitted to a local computer with a wired connection.

This has additional benefits, such as the processing requirements for image analysis are easily met, and the primary role of the data collection device on the patient's belt is not burdened with image analysis. It is reasonable to consider the system to operate as a standard local area network (LAN). The device on the patient's belt **100** is one node on the LAN. The transmission from the device on the patient's belt **100** is initially transmitted to a local node on the LAN enabled to communicate with the portable patient device **100** and a wired communication network. The wireless communication protocol IEEE-802.11, or one of its successors, is implemented for this application. This is the standard wireless communications protocol and is the preferred one here. It is clear that the Examination Bundle is stored locally within the data collection device on the patient's belt, as well at a device in wireless contact with the device on the patient's belt. However, while this is preferred, it will be appreciated that this is not a requirement for the present invention, only a preferred operating situation. The second node on the LAN has fewer limitations than the first node, as it has a virtually unlimited source of power, and weight and physical dimensions are not as restrictive as on the first node. Consequently, it is preferable for the image analysis to be conducted on the second node of the LAN. Another advantage of the second node is that it provides a "back-up" of the image data in case some malfunction occurs during the examination. When this node detects a condition that requires the attention of trained personnel, then this node system transmits to a remote site where trained personnel are present, a description of the condition identified, the patient identification, identifiers for images in the Examination Bundle, and a sequence of pertinent Examination Bundlettes. The trained personnel can request additional images to be transmitted, or for the image stream to be aborted if the alarm is declared a false alarm. Details of requesting and obtaining additional images for further diagnosis can be found in commonly assigned, co-pending U.S. Patent Application Serial No. (our docket 86570SHS), entitled "Method And System For Real-Time Remote Diagnosis Of In Vivo Images" and filed on 01 March 2004 in the names of Shoupu Chen, Lawrence A. Ray, Nathan D. Cahill, and Marvin M. Goodgame, and which is incorporated

herein by reference. To ensure diagnosis accuracy, images to be transmitted are those exposure adjusted in step 309.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100	Storage Unit
102	Data Processor
104	Camera
106	Image Transmitter
108	Image Receiver
110	Image Monitor
112	Capsule
200	Examination Bundle
202	Image Packets
204	General Metadata
206	Image Packet
208	Pixel Data
210	Image Specific Metadata
212	Image Specific Collection Data
214	Image Specific Physical Data
216	Inferred Image Specific Data
220	Examination Bundlette
300	In Vivo Imaging system
302	In Vivo Image Acquisition
304	Forming Examination Bundlette
306	RF Transmission
308	RF Receiver
309	Image adjustment
310	Abnormality Detection
312	Communication Connection
314	Local Site
316	Remote Site
320	In Vitro Computing Device
400	Template source
402	Examination Bundlette processor

404 Image display
406 Data and command entry device
407 Computer readable storage medium
408 Data and command control device
409 Output device
412 RF transmission
414 Communication link
501 An image
502 Image Thresholding
503 *Stats*
504 Forming mask B
505 Threshold
506 Forming mask A
508 Image statistics gathering
510 Image adjusting
602 Mask property check
604 A query
606 Stop
610 Exposure correction in masked area(s)
612 Cross boundary smoothing
702 Binary image
704 A region
706 Lines
712 Mask A
722 Skeleton image
724 Lines
726 Lines
728 A point
732 A window
802 A pattern
804 A pattern

806 A pattern
808 A pattern
816 A dark area
822 A generalized R image
902 An intermediate mask B
904 A region
906 Residuals
912 Mask B image
1002 A smoothing band graph
1004 A line
1006 A line
1008 A line
1010 A point
1012 A distance d
1014 An arrow
1018 A point
1019 A line
1020 A point

CLAIMS:

1. A digital image processing method for exposure adjustment of in vivo images, comprising the steps of:
 - a) acquiring in vivo images;
 - 5 b) detecting any crease feature found in the in vivo images;
 - c) preserving the detected crease feature; and
 - d) adjusting exposure of the in vivo images with the detected crease feature preserved.
- 10 2. The digital image processing method claimed in claim 1, wherein the step of adjusting exposure of the in vivo images includes the steps of:
 - d1) thresholding the in vivo images to form a threshold image;
 - d2) forming a first mask, A, from the threshold image;
 - d3) forming a second mask, B, from the threshold image;
 - 15 d4) gathering image statistics with mask A; and
 - d5) adjusting image exposure with mask B and the gathered statistics of mask A.
- 20 3. The digital image processing method claimed in claim 2, wherein the step of adjusting image exposure with mask B and the gathered statistics of mask A further includes the step of forming a smoothing band across an adjustment boundary, and smoothing image pixels in the smoothing band.
- 25 4. The digital image processing method claimed in claim 1, wherein detecting the crease feature, further includes the steps of:
 - b1) forming a skeleton image of the threshold image; and
 - b2) testing the skeleton image and the threshold image for one or more crease features.

5. The digital image processing method claimed in claim 2, wherein forming a second mask, B, from the threshold image, further includes the steps of:

- 5 i.) erasing corresponding pixels of the detected crease feature in the threshold image; and
 ii.) erasing any remaining residual elements from the threshold image, wherein the residual elements are tiny regions.

6. The digital image processing method claimed in claim 1, wherein an image area indicated by mask B is intensified using an adjustment coefficient.

7. The digital image processing method claimed in claim 6, wherein the adjustment coefficient is determined by distinct statistics of intensity corresponding to masked areas and unmasked areas of an original image, respectively.

8. The digital image processing method claimed in claim 6, wherein the image area indicated by mask B is intensified using the adjustment coefficient, and said intensification is selected from the group consisting of a linear function, a non-linear function, and a look-up table.

9. The digital image processing method claimed in claim 6, wherein the image area indicated by mask B is monochrome or polychrome.

10. The digital image processing method claimed in claim 3, wherein forming a smoothing band further includes the steps of:
 i) forming two non-intersecting lines, one on either side of a boundary line in relation to adjustment and non-adjustment areas for the in vivo image;

ii) defining a width of the smoothing band from the two non-intersecting lines; and

iii) determining intensity of in vivo image pixels on the boundary in the smoothing band from a moving average of in vivo image pixels found on
5 both side of the boundary line;

iv) determining intensity of in vivo image pixels off the boundary in the smoothing band from a moving average of in vivo image pixels newly updated starting from the pixels on the boundary.

10 11. A digital image processing method for exposure adjustment of in vivo images, comprising the steps of:

a) acquiring the in vivo images using an in vivo video camera system;

b) forming an examination bundlette from the in vivo images
15 acquired with the in vivo video camera system;

c) transmitting the examination bundlette to proximal in vitro computing device(s);

d) processing the examination bundlette; and

e) adjusting exposure of the in vivo images transmitted in the
20 examination bundlette, while simultaneously preserving any crease feature found in the in vivo images.

12. The digital image processing method claimed in claim 11,
further comprising the step of notifying a remote site of suspected abnormalities
25 that have been identified in the in vivo images.

13. The digital image processing method claimed in claim 12,
wherein a communication channel is provided to the remote site.

14. The digital image processing method claimed in claim 11, wherein the in vivo video camera system comprises a camera having video capture capability; and an optical system for imaging an area of interest onto said camera.

5 15. The digital image processing method claimed in claim 11, wherein the step of forming an in vivo video camera system examination bundlette includes the steps of:

- i.) forming an image packet; and
- ii.) forming general metadata.

10

16. The digital image processing method claimed in claim 11, wherein the in vitro computing device comprises a radio receiver, an examination bundlette processor, and a wireless communication system.

15 17. The digital image processing method claimed in claim 11, wherein the step of processing the examination bundlette comprises the steps of:

- i) decomposing the examination bundlette; and
- ii) processing the in vivo images.

20 18. The digital image processing method claimed in claim 11, wherein the step of adjusting exposure of the in vivo images includes the steps of:

- d1) thresholding the in vivo images to form a threshold image;
- d2) forming a first mask, A, from the threshold image;
- d3) forming a second mask, B, from the threshold image;
- 25 d4) gathering image statistics with mask A; and
- d5) adjusting image exposure with mask B and the gathered statistics of mask A.

30 19. The digital image processing method claimed in claim 18, wherein the step of adjusting image exposure with mask B and the gathered

statistics of mask A further includes the step of forming a smoothing band across an adjustment boundary, and smoothing image pixels in the smoothing band.

20. The digital image processing method claimed in claim 11,
5 wherein detecting the crease feature, further includes the steps of:
b1) forming a skeleton image of the threshold image; and
b2) testing the skeleton image for one or more crease features.

21. The digital image processing method claimed in claim 18,
10 wherein forming a second mask, B, from the threshold image, further includes the steps of:
i.) erasing corresponding pixels of the detected crease feature in the threshold image; and
ii.) erasing any remaining residual elements from the threshold
15 image, wherein the residual elements are tiny regions.

22. The digital image processing method claimed in claim 11,
wherein an image area indicated by mask B is intensified using an adjustment
coefficient.

20

23. The digital image processing method claimed in claim 22,
wherein the adjustment coefficient is determined by distinct statistics of intensity
corresponding to masked areas and unmasked areas of an original image,
respectively.

25

24. The digital image processing method claimed in claim 22,
wherein mask B is intensified using the adjustment coefficient, and said
intensification is selected from the group consisting of a linear function, a non-
linear function, and a look-up table.

30

25. The digital image processing method claimed in claim 22, wherein mask B is intensified using the adjustment coefficient is applied to gray-scale or color images.

5

26. The digital image processing method claimed in claim 19, wherein forming a smoothing band further includes the steps of:

- i) forming two non-intersecting lines, one on either side of a boundary line in relation to adjustment and non-adjustment areas for the in vivo image;
10 image;
- ii) defining a width of the smoothing band from the two non-intersecting lines; and
- iii) determining intensity of in vivo image pixels on the boundary in the smoothing band from a moving average of in vivo image pixels found on
15 both side of the boundary line;
- iv) determining intensity of in vivo image pixels off the boundary in the smoothing band from a moving average of in vivo image pixels newly updated starting from the pixels on the boundary.

20

27. An examination bundle processing hardware system for in vivo imaging, comprising:

- a) an examination bundle processor for adjusting exposure of in vivo images while preserving any detected crease feature in the in vivo images;
- b) a radio frequency receiver/transmitter connected to the
25 examination bundle processor for transmitting data packets containing the in vivo images;
- c) a communication link connected to the examination bundle processor for establishing a network link for communication the data packets;
- d) a computer readable storage medium connected to the
30 examination bundle processor for storing the data packets;

e) a display device connected to the examination bundle processor for providing user interface via a keyboard and/or a mouse, or a touch screen; and

f) an output device connected to the examination bundle processor for transforming the data packets to another media, wherein the media includes print and storage.

28. The examination bundle processing hardware system claimed in claim 27, wherein said system is incorporated within a handheld personal digital assistant, (PDA).

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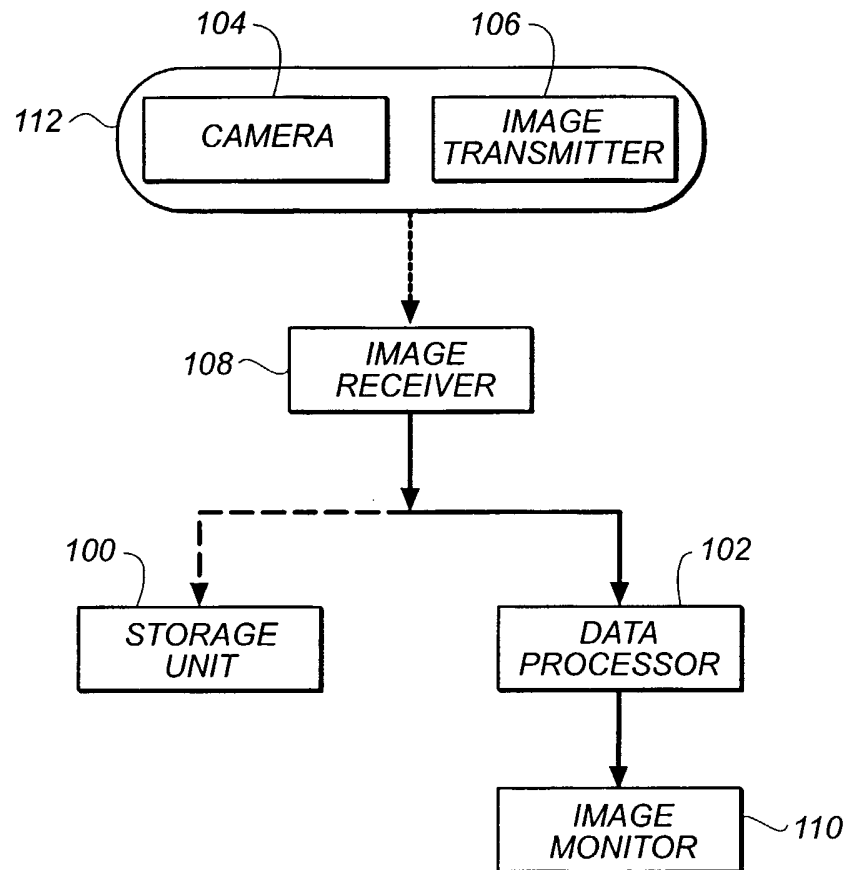


FIG. 1
(PRIOR ART)

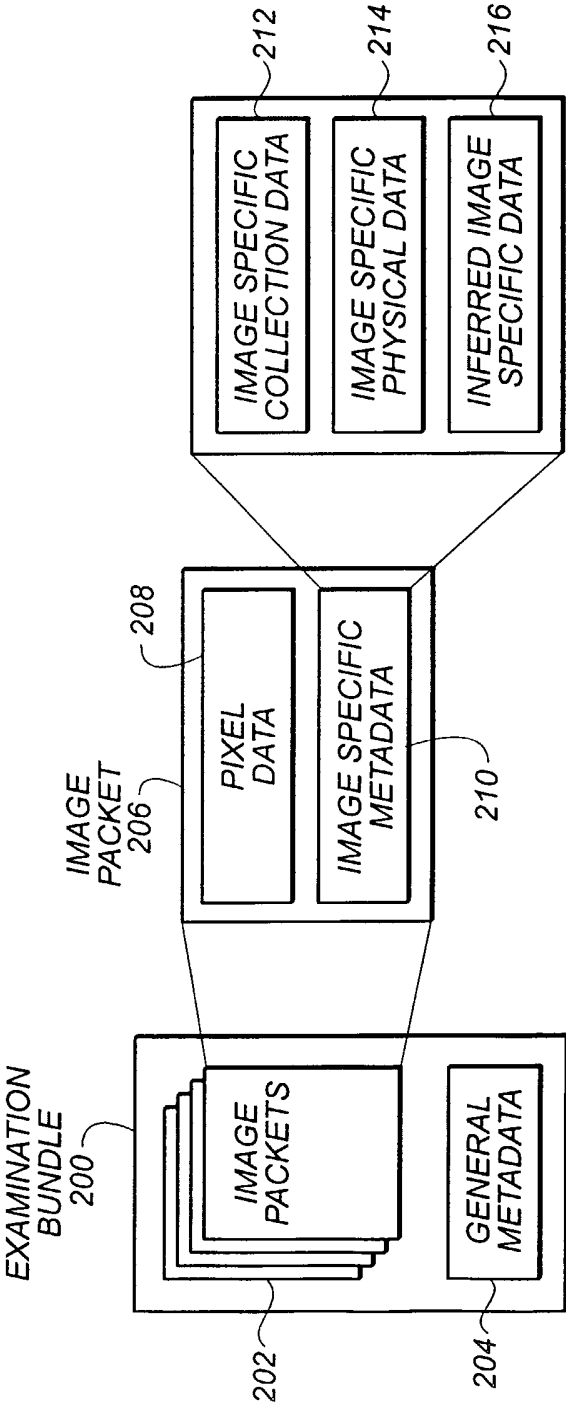


FIG. 2A

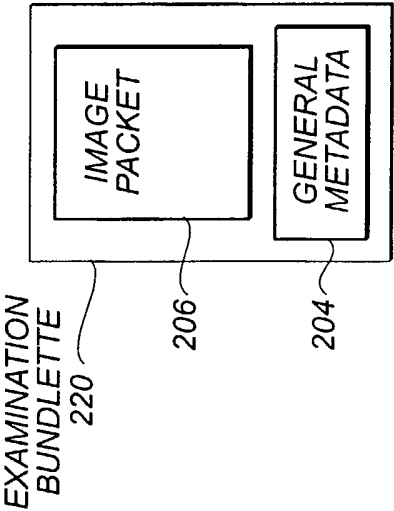


FIG. 2B

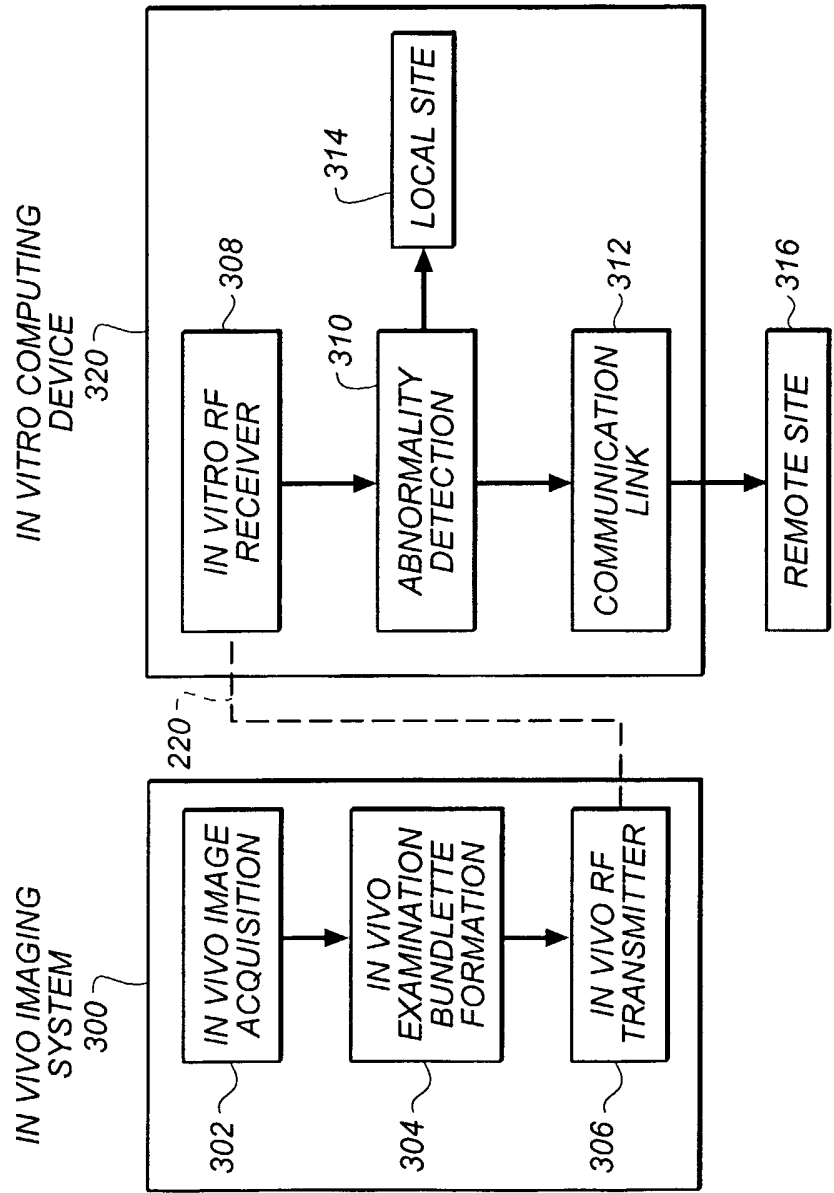


FIG. 3A

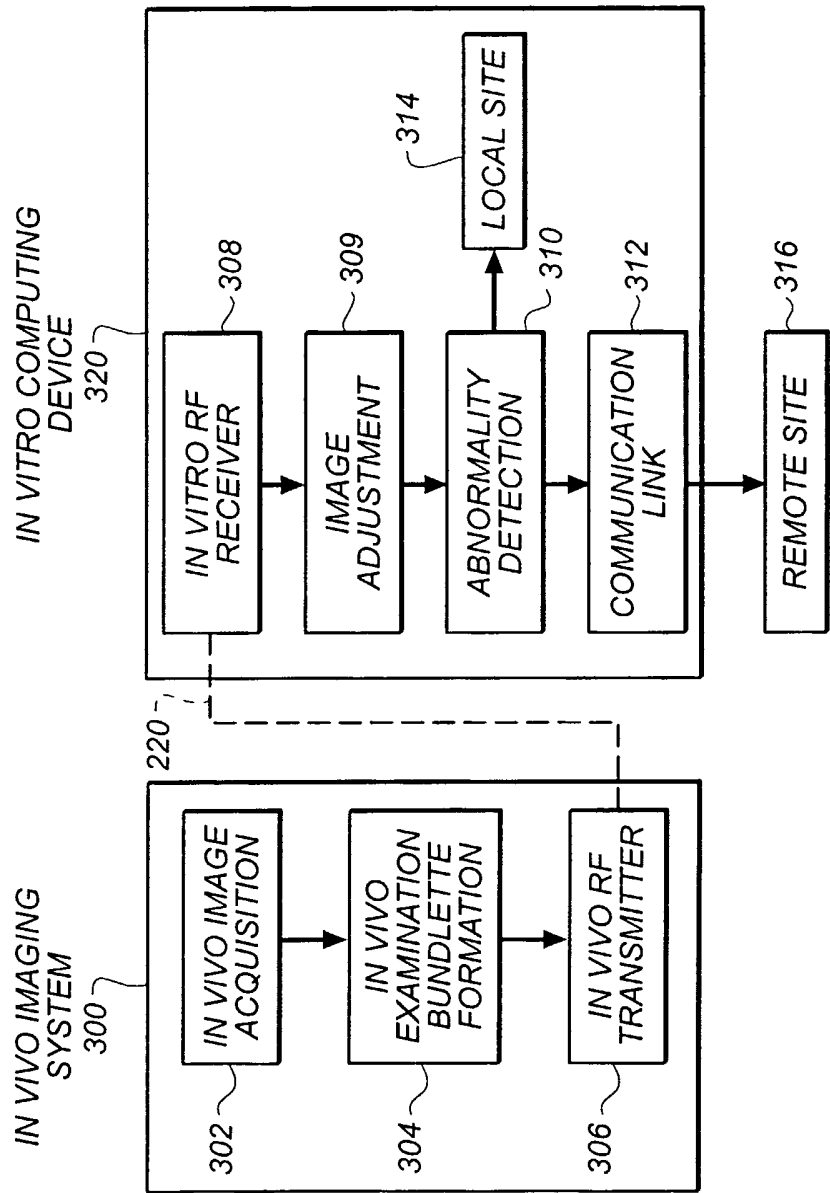


FIG. 3B

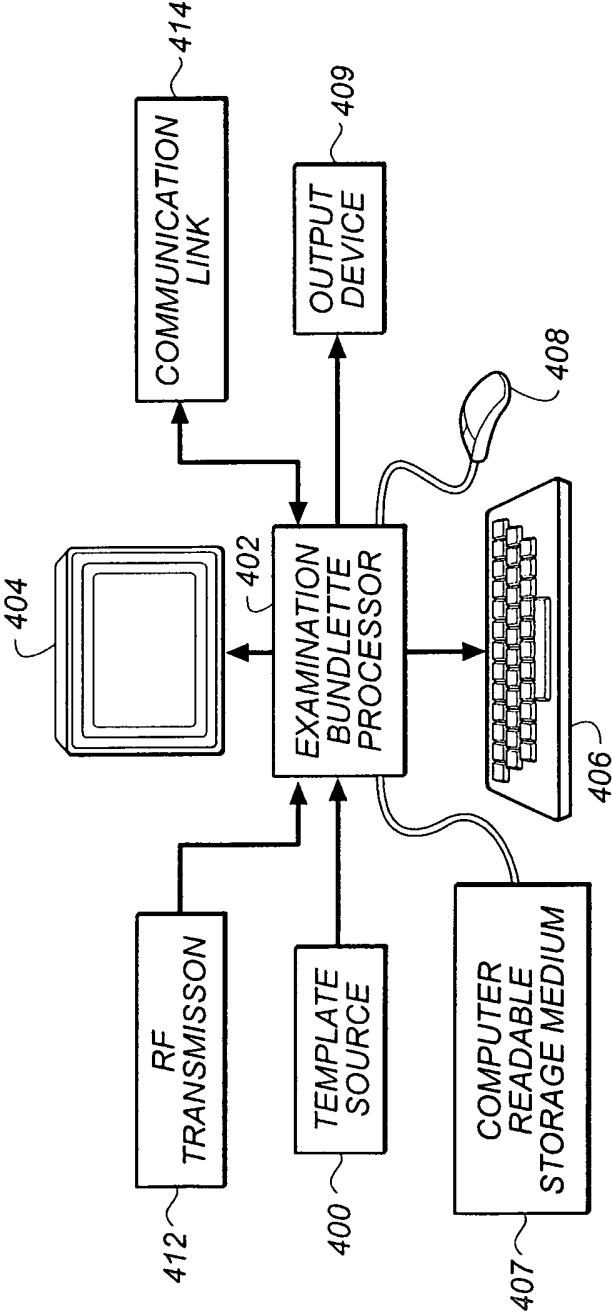
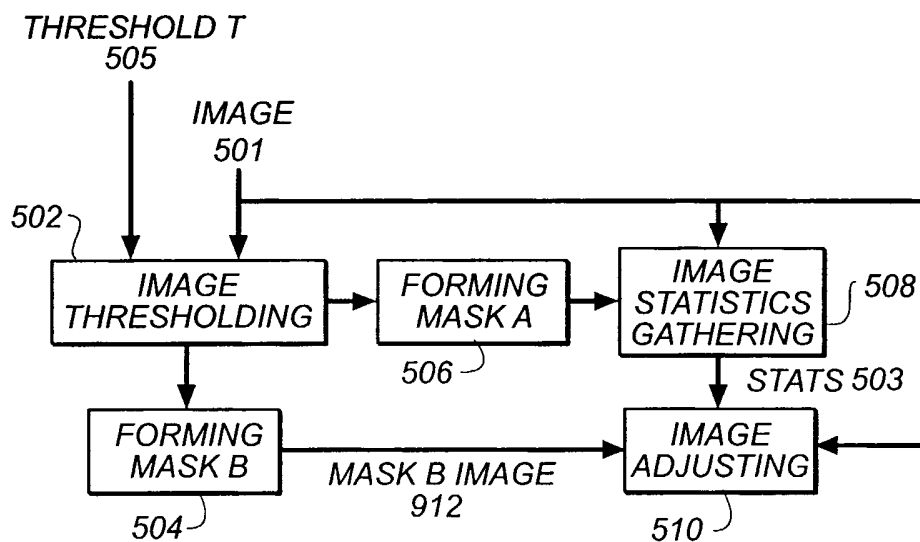
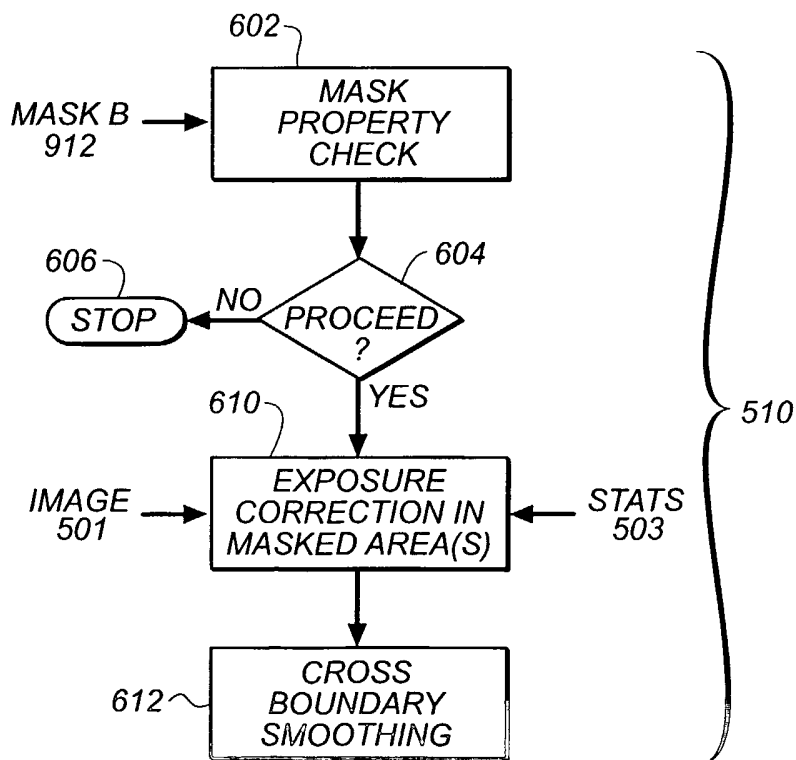


FIG. 4

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**FIG. 5****FIG. 6**

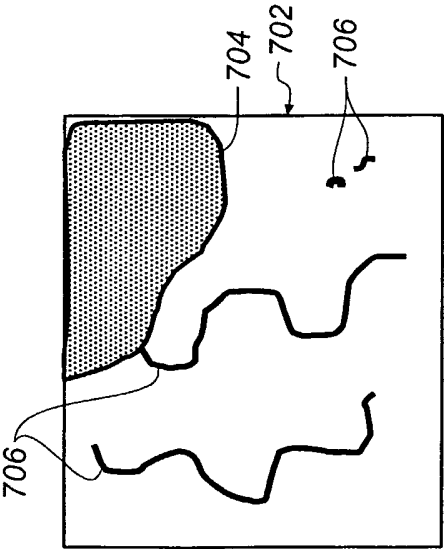


FIG. 7A

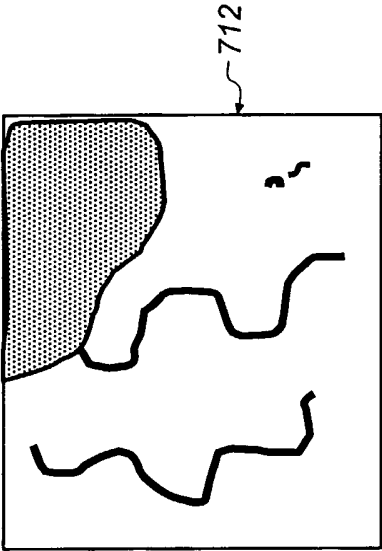


FIG. 7B

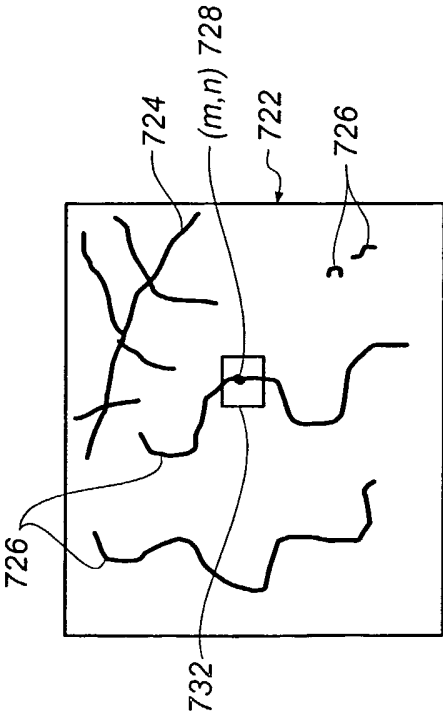


FIG. 7C

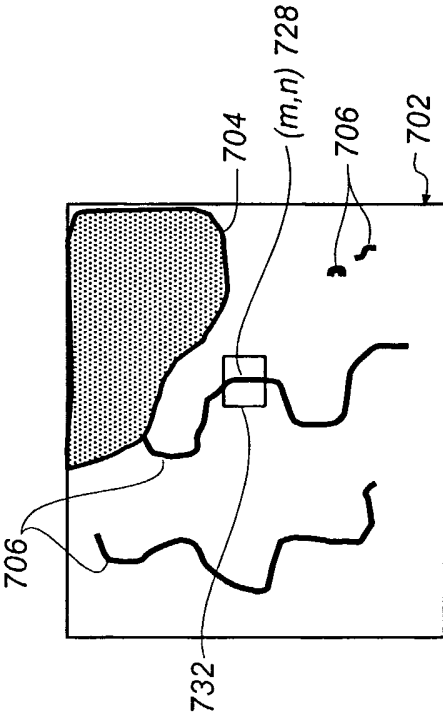
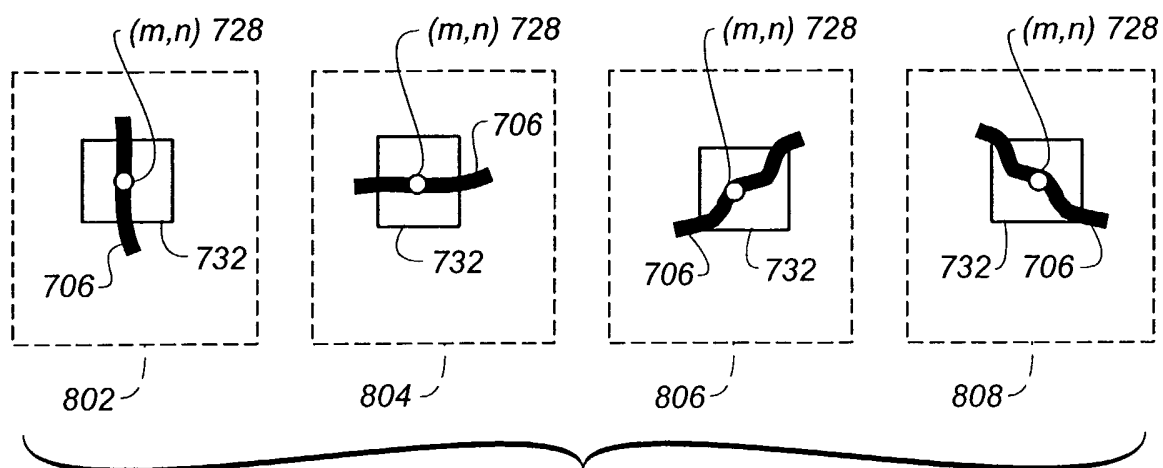
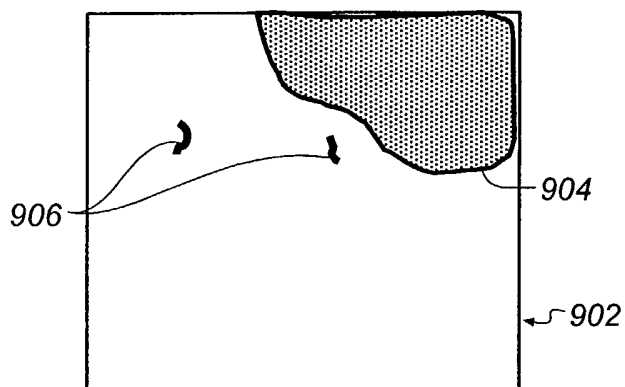
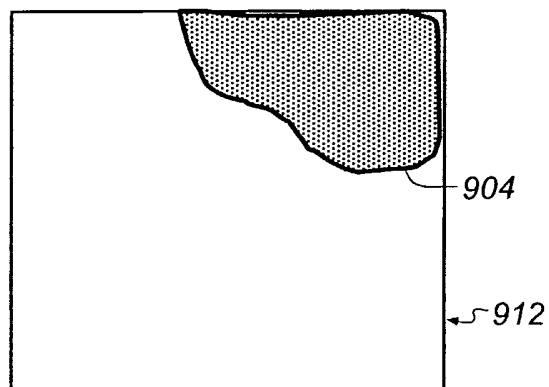


FIG. 7D

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**FIG. 8****FIG. 9A****FIG. 9B**

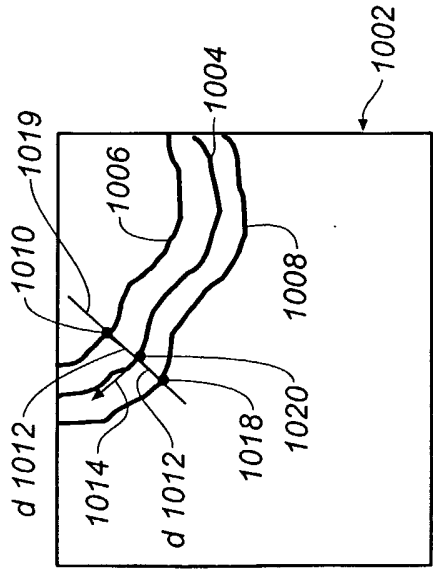


FIG. 10A

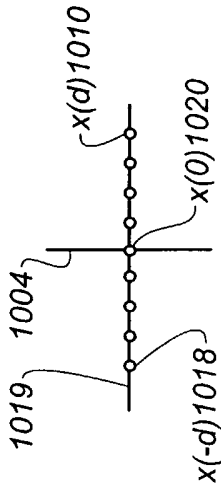


FIG. 10B