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(54) VOXEL MATCHING TECHNIQUE FOR REMOVAL OF ARTIFACTS IN MEDICAL SUBTRACTION IMAGES

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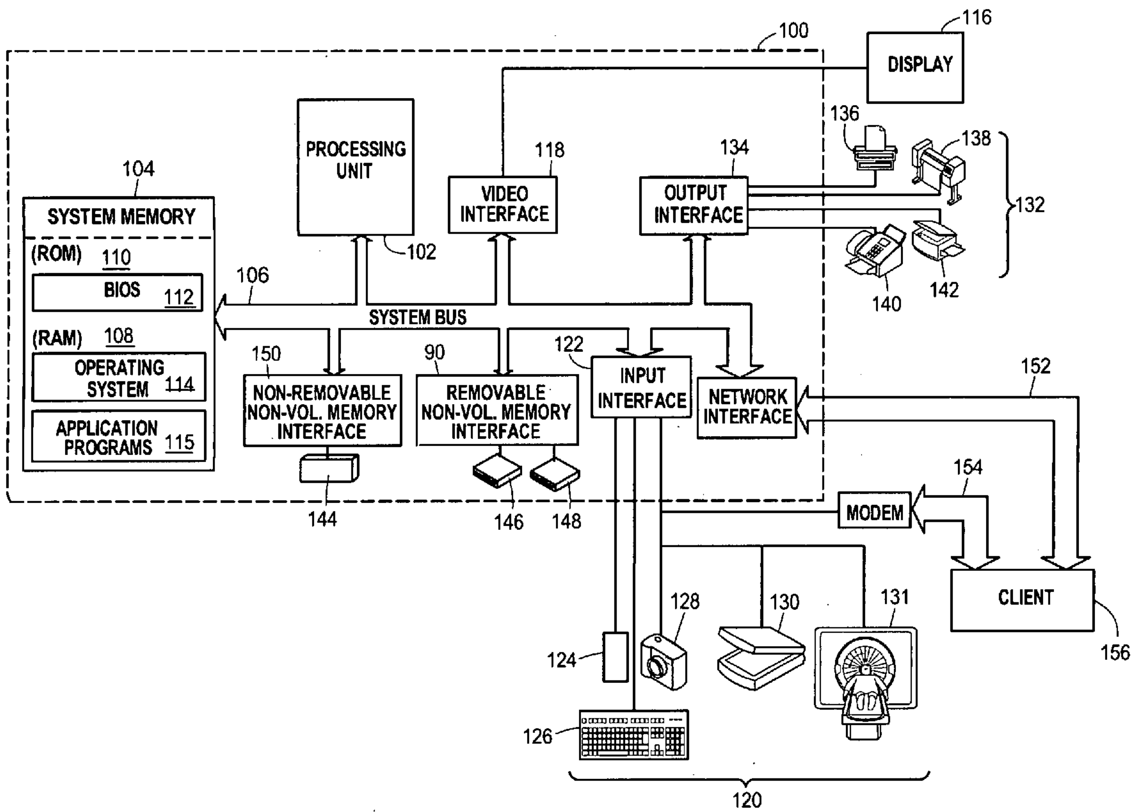
(57) ABSTRACT

A method for improving the alignment accuracy between different medical images may be disclosed. A warped or non-warped previous image and a warped or non-warped current image may include a plurality of respective previous and current basic units, for example, pixels in a 2-dimensional image or voxels in a 3-dimensional image. To ensure accurate registration between the previous and current images, a first basic unit from the previous image may be replaced by a second basic unit from the current image if the value of the first and second basic units are identical or nearly identical. The first and second basic units may be selected from a nearly-identical region or "kernel" within the previous and current images.



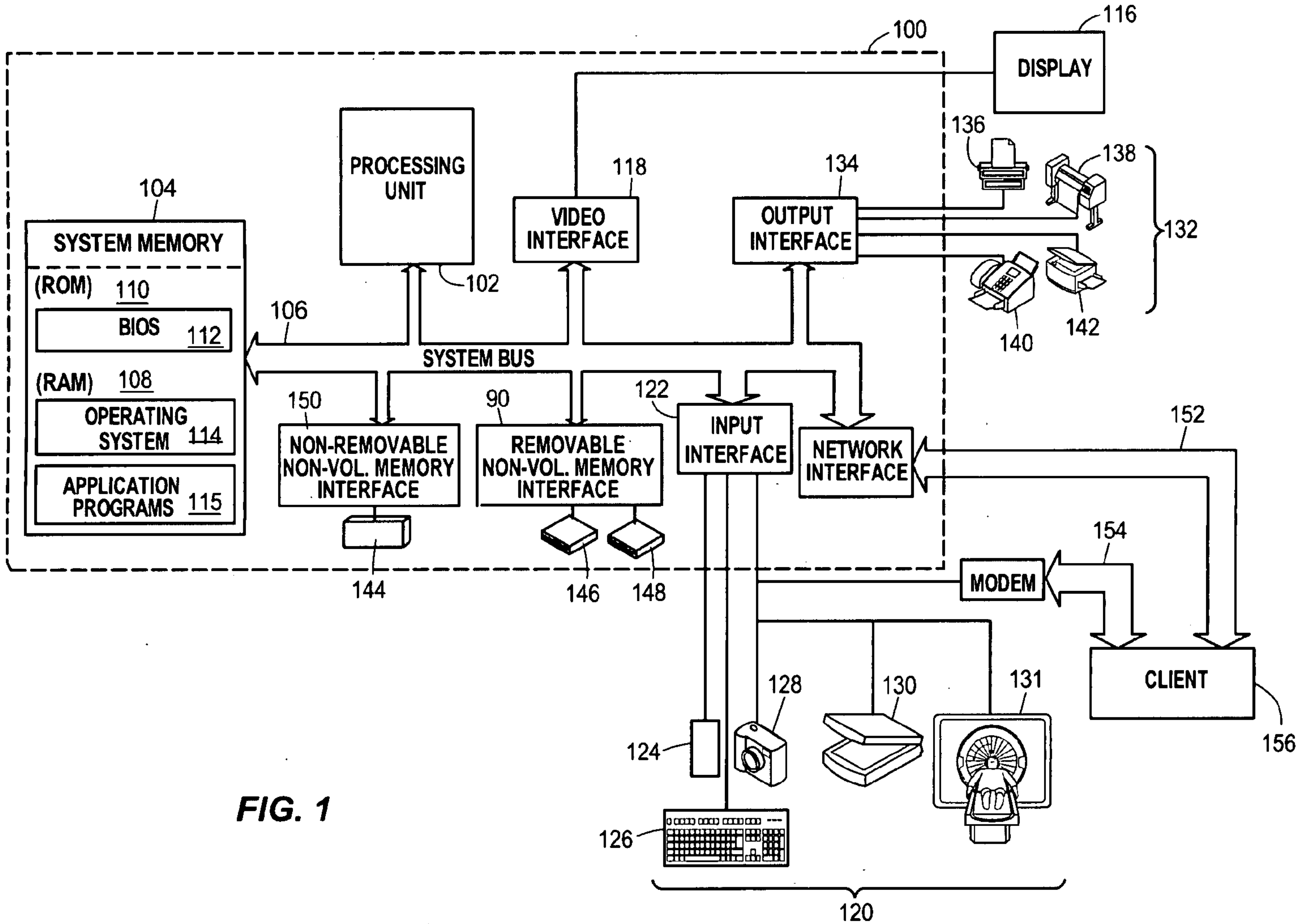

100
DISPLAY
116
PROCESSING UNIT
102
VIDEO INTERFACE
118
OUTPUT INTERFACE
134
136
138
132
140
142
104
SYSTEM MEMORY
(ROM) 110
BIOS 112
(RAM) 108
OPERATING SYSTEM 114
APPLICATION PROGRAMS 115
106
SYSTEM BUS
150
NON-REMOVABLE NON-VOL. MEMORY INTERFACE
90
REMOVABLE NON-VOL. MEMORY INTERFACE
122
INPUT INTERFACE
NETWORK INTERFACE
152
144
146
148
154
MODEM
CLIENT
156
124
128
130
131
126
120

FIG. 1

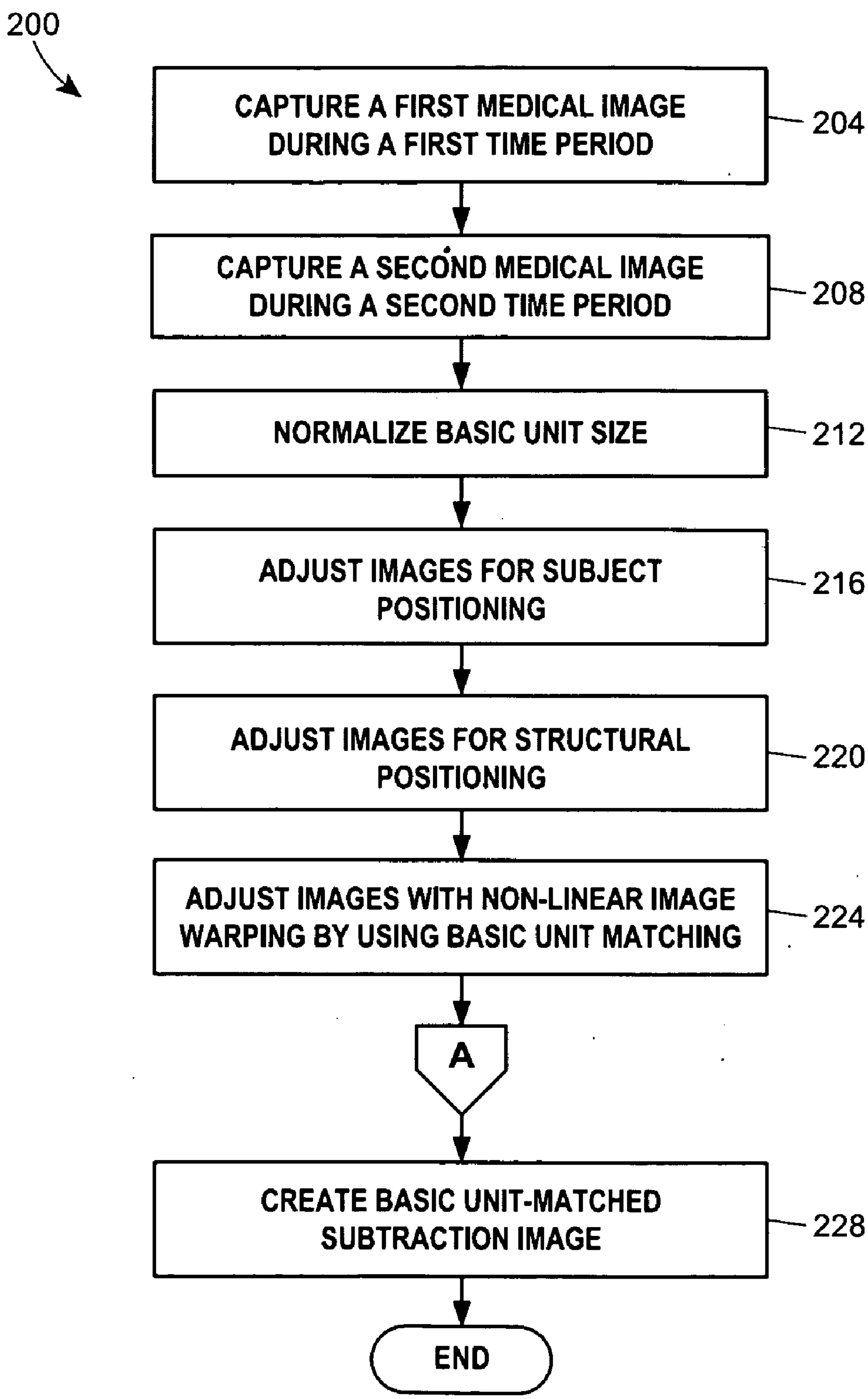

200
CAPTURE A FIRST MEDICAL IMAGE DURING A FIRST TIME PERIOD
204
CAPTURE A SECOND MEDICAL IMAGE DURING A SECOND TIME PERIOD
208
NORMALIZE BASIC UNIT SIZE
212
ADJUST IMAGES FOR SUBJECT POSITIONING
216
ADJUST IMAGES FOR STRUCTURAL POSITIONING
220
ADJUST IMAGES WITH NON-LINEAR IMAGE WARPING BY USING BASIC UNIT MATCHING
224
A
CREATE BASIC UNIT-MATCHED SUBTRACTION IMAGE
228
END

FIG. 2

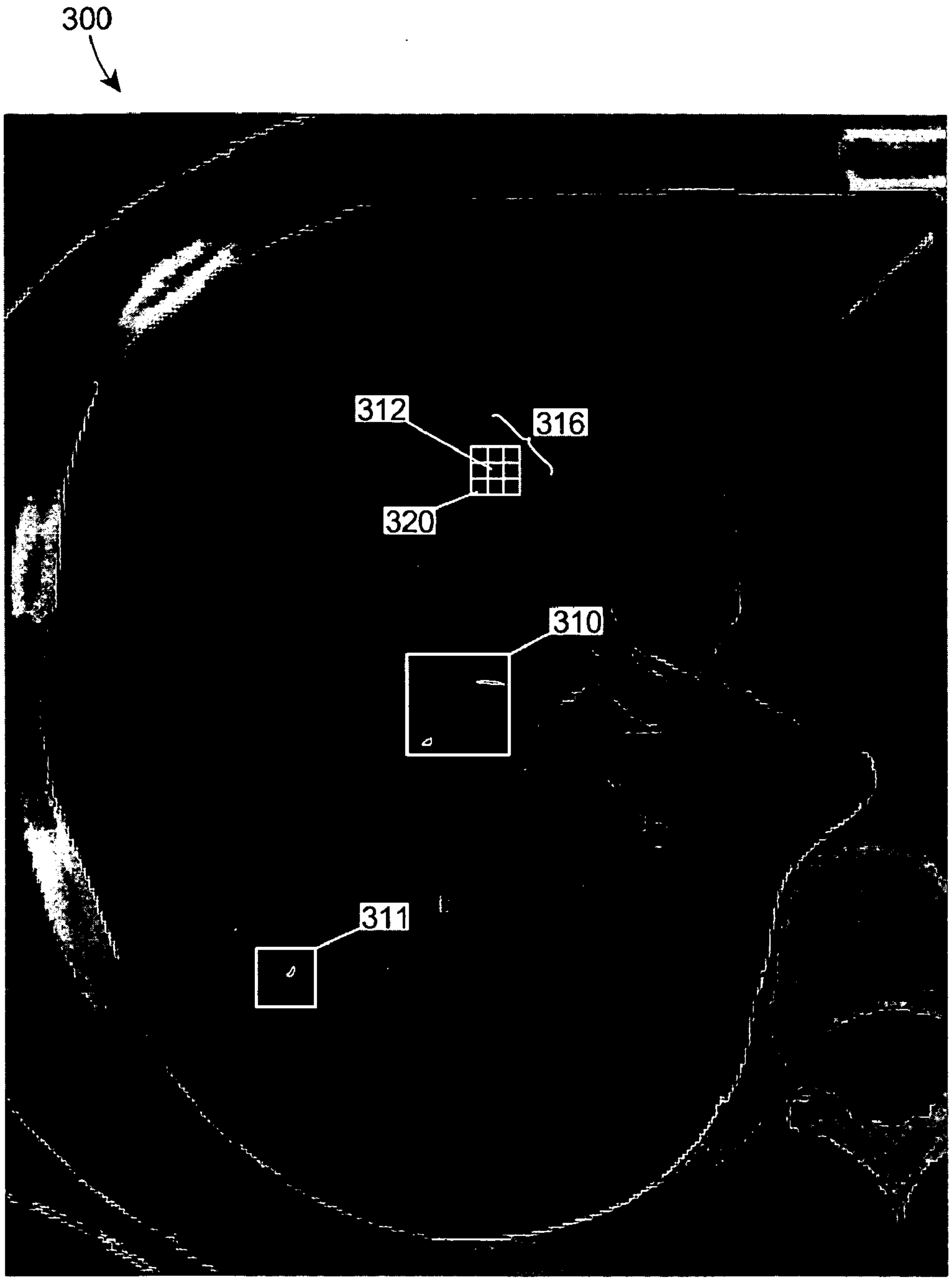


FIG. 3

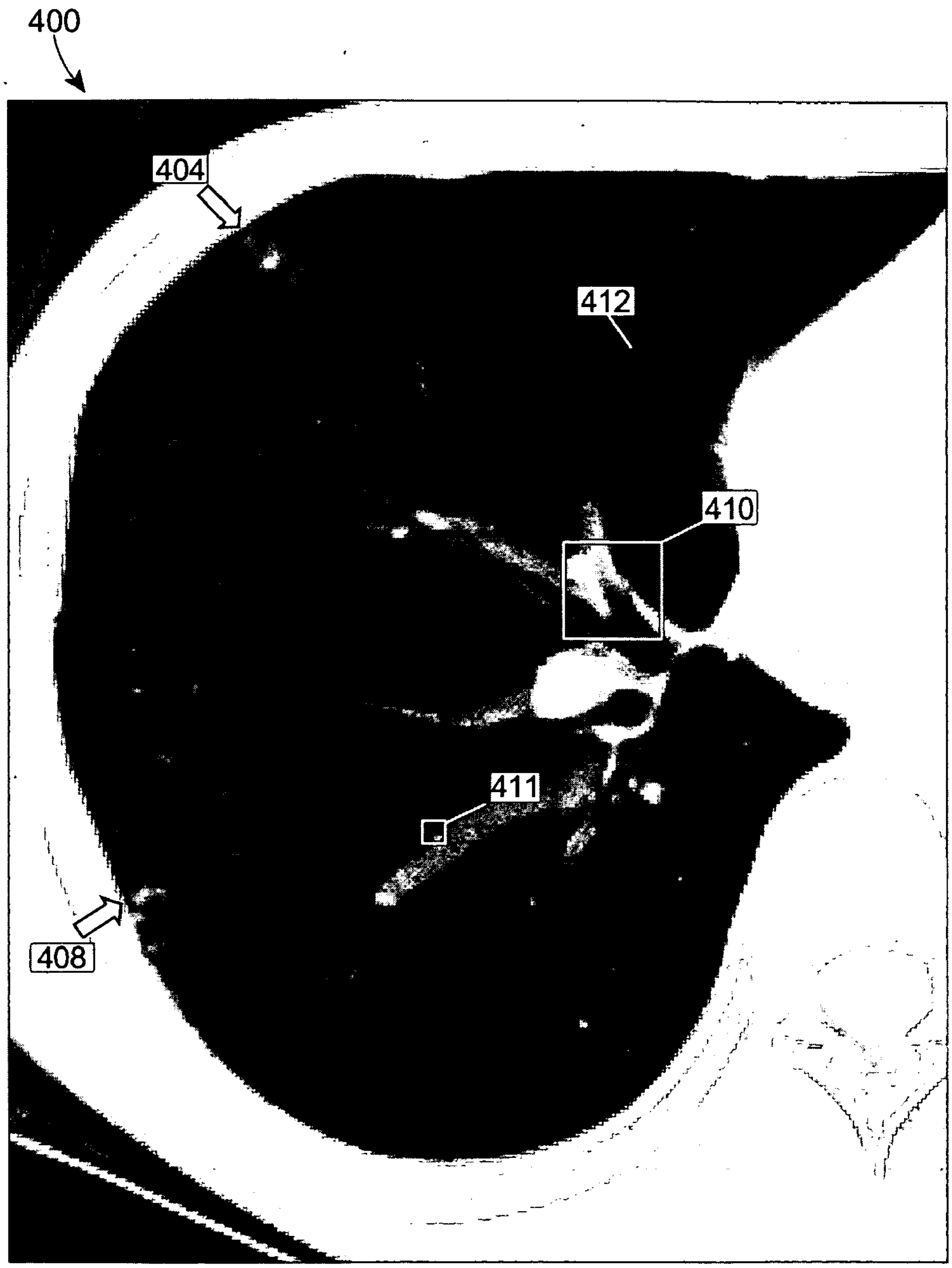


FIG. 4

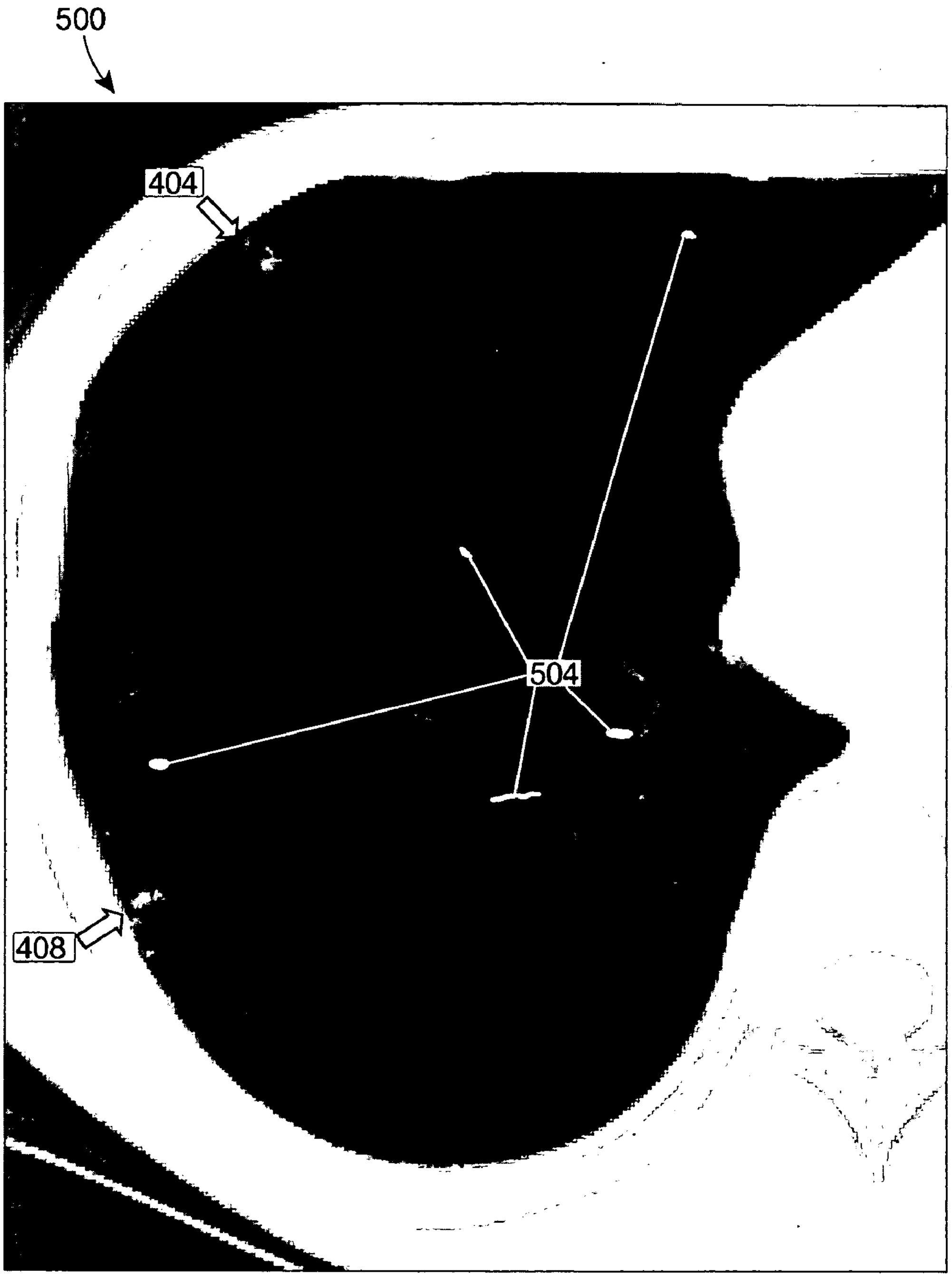


FIG. 5

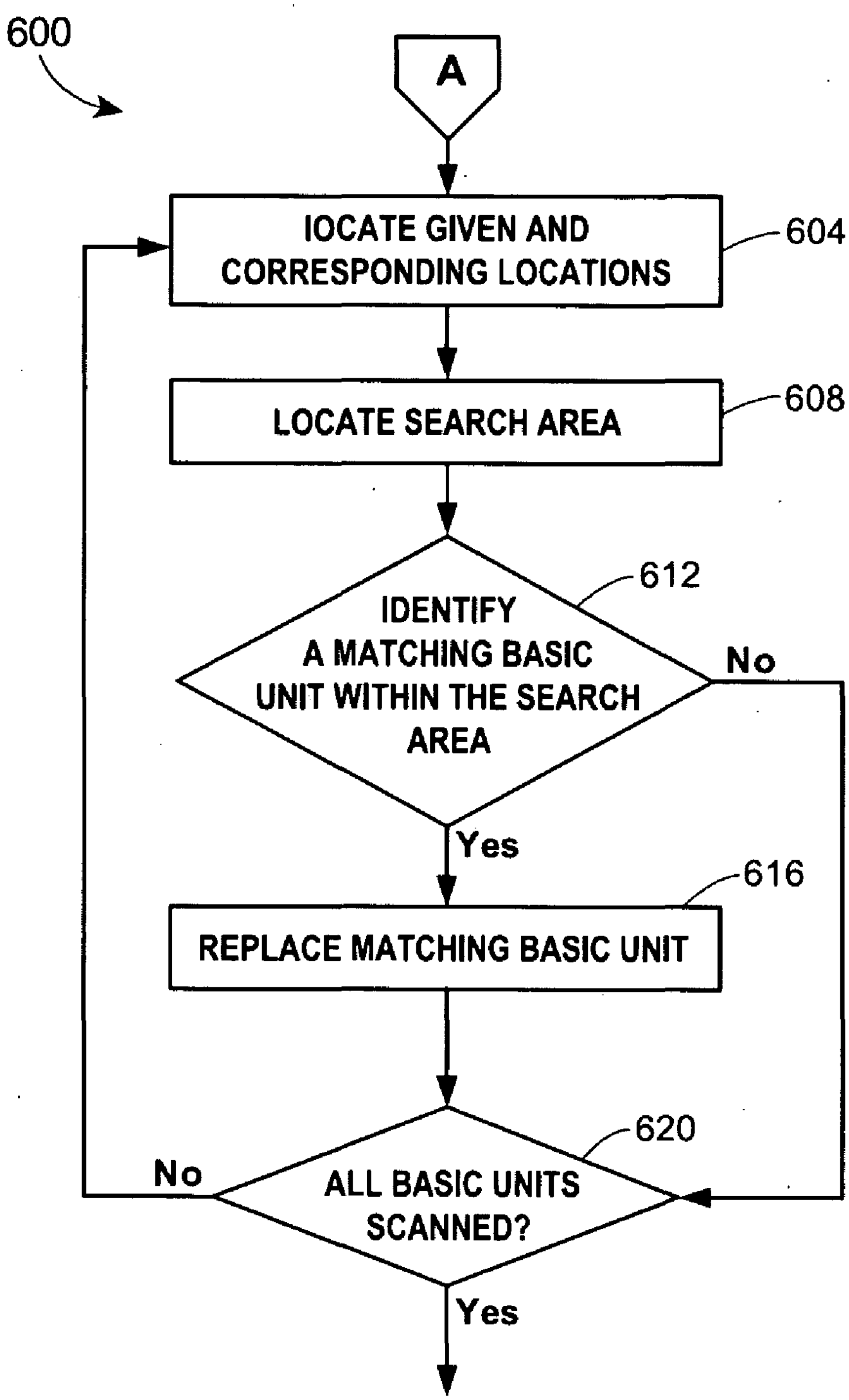

600
A
IOCATE GIVEN AND CORRESPONDING LOCATIONS
604
LOCATE SEARCH AREA
608
IDENTIFY A MATCHING BASIC UNIT WITHIN THE SEARCH AREA
612
No
Yes
REPLACE MATCHING BASIC UNIT
616
ALL BASIC UNITS SCANNED?
620
No
Yes

FIG. 6

700

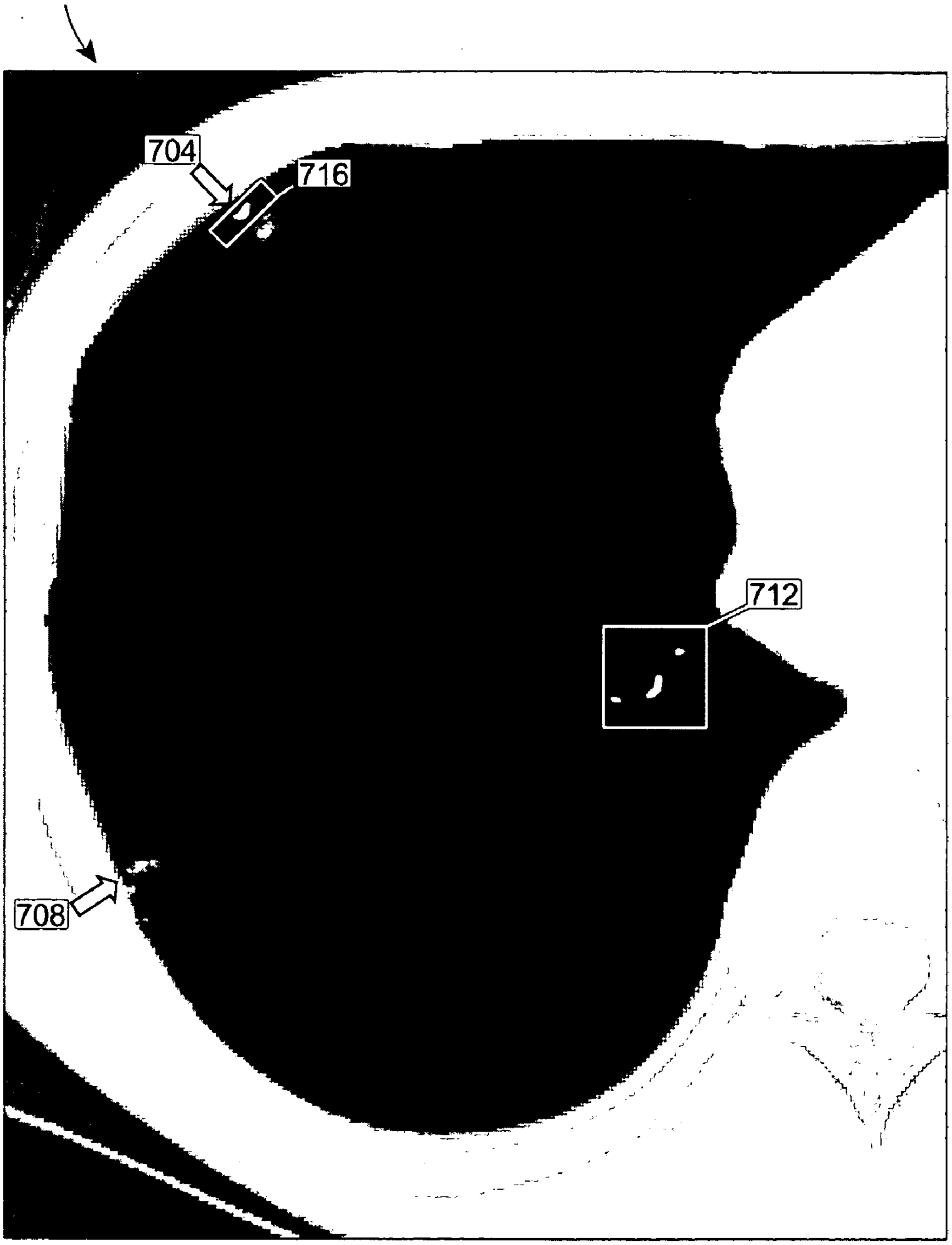


FIG. 7

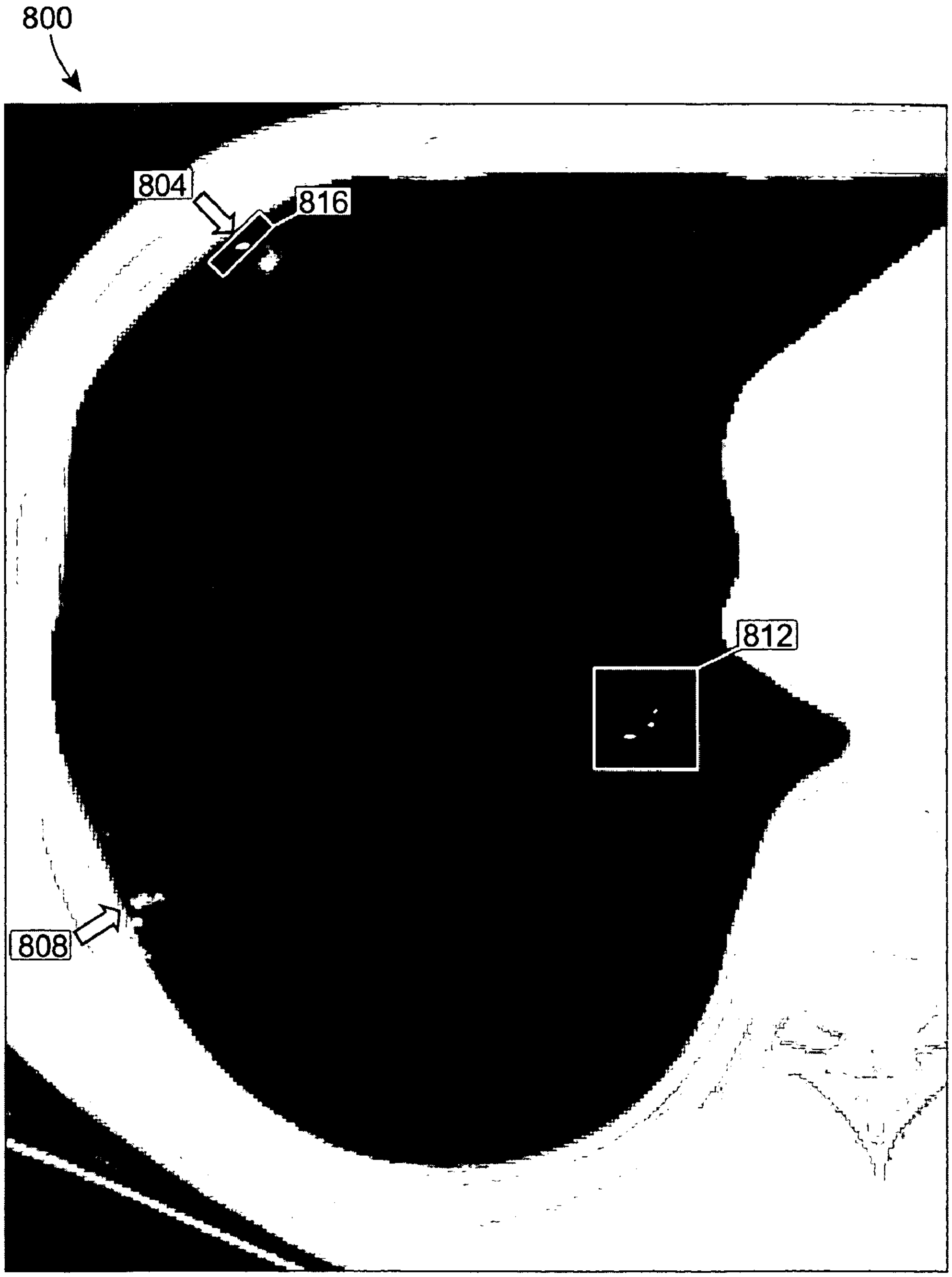


FIG. 8

VOXEL MATCHING TECHNIQUE FOR REMOVAL OF ARTIFACTS IN MEDICAL SUBTRACTION IMAGES

RELATED DOCUMENTS

[0001] The present application claims the benefit of U.S. Provisional Patent Application No. 60/973,615 filed on Sep. 19, 2007, the entire disclosure of which is hereby incorporated by reference.

GOVERNMENT RIGHTS

[0002] This invention was made with government support under grant number CA98119 awarded by the National Institutes of Health (NIH). The government has certain rights in the invention.

TECHNICAL FIELD

[0003] This patent relates to image analysis, and more particularly, to a technique for removing artifacts in medical subtraction images by voxel matching.

BACKGROUND

[0004] Digital imagery and computer-aided diagnosis (CAD) has, in most instances, replaced film and other imaging techniques in the field of radiology. Because of their inherent portability, digital radiological images may be easily delivered and analyzed by radiologists and other medical professionals. For example, systems and methods that produce computed tomography (CT) images conforming to the Digital Imaging and Communications in Medicine (DICOM) standard are ubiquitous. Further, computer-implemented methods may assist or supplement the radiologist's analysis of these images during a patient's course of treatment.

[0005] Radiologists analyze CT images to detect subtle abnormalities. These abnormalities may appear in a CT image as an area of contrast that is incongruent with other image structures. However, small lesions, aneurysms, or other abnormalities that are extremely low in contrast may be difficult to discern because the abnormality (e.g., a small lung nodule, an intracranial aneurism, or other abnormality) may appear to be noise or even a portion of a normal structure. Further, workload and other constraints may decrease radiologists' ability to accurately analyze many CT images.

[0006] Temporal subtraction is a known method by which a radiologist may identify low contrast abnormalities. For example, a temporal subtraction image is obtained by subtracting the structures that are common to both a previous and a current CT image. The remaining structures enhance the interval changes, and thus, abnormalities, on medical images by the removal of most normal structures. Therefore, a radiologist's detection of new abnormalities and changes to existing abnormalities provides robust evidence for diagnosis. The temporal subtraction method is known to improve radiologists' diagnostic accuracy and reduce their reading time.

[0007] However, the temporal subtraction method commonly introduces further complications. For example, chest images such as chest radiographs and thoracic CT images commonly include artifacts from the subtraction method. The artifacts are created by slight differences in the size, shape, and/or location of anatomic structures such as blood vessels, nodules, chest walls, ribs, and other lung and cardiac structures that are included in both the current and previous images. Even differences as slight as one pixel in two-dimensional images and one voxel in three-dimensional images may cause disturbing subtraction artifacts in temporal subtraction images. The artifacts may be difficult to distinguish from new abnormalities or changes in existing abnormalities. Thus, it is desirable to remove these subtraction artifacts from temporal subtraction images.

[0008] If the anatomic structures of both a current and previous medical image were identical, then subtraction artifacts would disappear. However, changes in patient physiology, the position of the subject during the imaging process, and other factors make having identical current and previous images nearly impossible. To remedy positioning changes and other problems with temporal subtraction, an image warping technique may be applied to accurately deform or register the previous image to match the current image (or vice-versa). However, if the warping is inaccurate, normal structures will produce artifacts in the subtraction image and degrade the image quality.

[0009] Warping techniques for 2-dimensional (2-D) radiological images are known in CAD. However, few techniques exist for accurately warping 3-dimensional (3-D) images. For example, in temporal subtraction images obtained with multiple-detector CT (MDCT) volume images used in thoracic examinations, it is necessary to employ a more complex 3-D technique for registration and warping of lung regions between the current and previous images. Examples of previous 3-D image warping methods are disclosed in "Development of 3D CT temporal subtraction based on nonlinear 3D image warping technique," by T. Ishida, S. Katsuragawa, H. Abe, K. Ashizawa, and K. Doi, Proc. The 91st Radiological Society of North America (RSNA), 111, Chicago, USA, 2005; "Temporal subtraction on 3D CT images by using nonlinear image warping technique" by T. Ishida, S. Katsuragawa, I. Kawashita, H. Kim, Y. Itai, K. Awai, Q. Li, and K. Doi, Int. J. CARS, 1, pp. 468, 2006; "3D elastic matching for temporal subtraction employing thorax MDCT image" by Y. Itai, H. Kim, S. Ishikawa, S. Katsuragawa, T. Ishida, I. Kawashita, K. Awai, Q. Li, and K. Doi, Proc. of the World Congress on Medical Physics and Biomedical Engineering, pp. 2181-2191, 2006; and "Development of temporal subtraction multislice CT images by using a 3D local matching with a genetic algorithm" by Y. Itai, H. Kim, S. Ishikawa, S. Katsuragawa, T. Ishida, and K. Doi, Proc. The 92nd Radiological Society of North America (RSNA), pp. 779, Chicago, USA, November 2006. Despite these known improvements in temporal subtraction imaging, misregistration or other image alignment inaccuracies introduced artifacts in subtraction image analysis using these and other prior techniques.

SUMMARY

[0010] A method for improving the alignment accuracy between different medical images is disclosed. A warped or non-warped previous image and a warped or non-warped current image may include a plurality of respective previous and current basic units, for example, pixels in a 2-dimensional image or voxels in a 3-dimensional image. To ensure accurate registration between the previous and current images, a first basic unit from the previous image may be replaced or modified by a second basic unit from the current image if a value of the first and second basic units are identical or nearly identical. The first and second basic units may be selected from a nearly-identical region or "kernel" within the previous and current images.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is an illustration of an exemplary computing system for use with the techniques described herein;

[0012] FIG. **2** is a flowchart illustrating an example of a portion of a method for creating a temporal subtraction image;

[0013] FIG. **3** is an example of a first or previous medical image;

[0014] FIG. **4** is an example of a second or current medical image;

[0015] FIG. **5** is an example of a temporal subtraction medical image without the basic unit matching technique applied;

[0016] FIG. **6** is a flowchart illustrating an example of another portion of a flowchart illustrating a method for creating a temporal subtraction image;

[0017] FIG. **7** is an example of a temporal subtraction image with the basic unit matching technique applied; and

[0018] FIG. **8** is another example of a temporal subtraction image with the basic unit matching technique applied.

DETAILED DESCRIPTION

[0019] Referring to FIG. **1**, a computer system **100** may include a processing unit (CPU) **102**, for example, an Intel Pentium™ class microprocessor. One or more memory devices **104** may be connected to a bus **106**, including random access memory (RAM) **108** and read only memory (ROM) **110**. A basic input/output system (BIOS) **112**, containing the routines that may transfer information between elements within the computer **100**, is typically stored in ROM **110**. RAM **108** typically contains immediately accessible program modules such as the operating system **114** or application programs **115** currently used by the CPU **102**. A display **116** may be connected to the system bus **106** though a video interface **118**. Input devices **120** may be connected to the system bus **106** though an input interface **122**. Input devices **120** may include a mouse **124**, a keyboard **126**, a camera **128**, a scanner **130**, a Computed Tomography (CT) Scanner **131**, or other image capture device. The CT Scanner **131** may be any type of medical imaging equipment employing tomography where digital geometry processing may be used to generate a 3-dimensional (3-D) image of the internal composition of an object from a series of 2-dimensional (2-D) X-ray or other radiological images taken around an axis of rotation. Output **132** devices may be connected to the system bus **106** through an output interface **134** and may include a printer **136**, a plotter **138**, a facsimile device **140**, a photocopier **142**, and the like.

[0020] The CT Scanner **131** and other specialized medical imaging equipment may be in communication with the computer system **100** to display anatomical information, such as anatomical information generated by a specialized imaging processes. For example, the anatomical information may be generated by various computed tomography (CT) techniques (e.g., computed axial tomography and CT angiography, etc.), Dynamic Contrast Magnetic Resonance Imaging (DCMRI), Magnetic Resonance Imaging (MRI), sonography (e.g., Ultrasound), positron emission tomography (PET), body section roentgenography, X-ray, or other processes.

[0021] The computer system **100** may include a computer-readable medium having a computer program or computer system **100** software accessible therefrom. The computer program may include instructions for performing methods. The computer-readable medium may be stored on a non-removable, non-volatile memory device **144** such as a hard disk, or a removable, non-volatile memory device such as a floppy disk drive **146** or an optical disk drive **148**. The non-removable, non-volatile memory device **144** may communicate with the computer **100** system bus **106** through a non-removable, non-volatile memory interface **150**. The computer-readable medium may include a magnetic storage medium (disk medium, tape storage medium, microdrives, compact flash cards), an optical storage medium (compact disks such as CD-ROM, CD-RW, and DVD), a non-volatile memory storage medium, a volatile memory storage medium, and data transmission or communications medium including packets of electronic data, and electromagnetic or fiber optic waves modulated in accordance with instructions. Thus, the computer readable medium tangibly embodies a program, functions, and/or instructions that are executable by the computer system **100** to perform methods as described herein.

[0022] The computer system **100** may be connected to a network, including local area networks (LANs) **152**, wide area networks (WANs) **154**, portions of the Internet such as a private Internet, a secure Internet, a value-added network, or a virtual private network. Suitable network clients **156** may include personal computers, laptops, workstations, disconnectable mobile computers, mainframes, information appliances, personal digital assistants, handheld and/or embedded processing systems, or a CT Scanner as described above in relation to element **131**. The signal lines that support communications links to clients **156** may include twisted pair, coaxial, or optical fiber cables, telephone lines, satellites, microwave relays, modulated AC power lines, and other data transmission "wires" known to those of skill in the art. Further, signals may be transferred wirelessly through a wireless network or wireless LAN (WLAN) using any suitable wireless transmission protocol, such as the IEEE series of 802.x standards. Although particular individual and network computer systems and components are shown, those of skill in the art will appreciate that the techniques described herein also work with a variety of other networks and computers.

[0023] A temporal subtraction image may be obtained by subtraction of a previous image from a current one and may be used for enhancing interval changes on medical images by removal of most normal structures that are common to both images. For example, a subtraction technique applied to CT angiography (CTA) may compare several CT images of arterial and venous vessels taken over a period of time. CTA images are acquired as a temporal sequence. Angiography images may also be taken while a bolus of contrast material proceeds through a vessel. The image contrast of an opacified vessel at any particular location usually changes from one image to the next, i.e., the image contrast of the vessel is a function of time. By removing the common structures of the several CTA images, interval changes may improve detection of embolisms, stenosis, aneurysms, dissection, intracranial arteriovenous malformations, atherosclerotic disease, thrombosis, or other abnormalities. An angiography technique for measuring blood flow rate is disclosed in U.S. Pat. No. 5,150,292, the entire disclosure of which is hereby expressly incorporated by reference herein.

[0024] Other examples of interval changes include the formation of new lesions and tumors, or changes to existing abnormalities. Subtraction methods such as temporal subtraction, digital subtraction angiography imaging, bilateral subtraction, and contralateral subtraction may be applied to clinical cases to improve radiologists' diagnostic accuracy and reduce their reading time. With the subtraction method, an image-warping technique may accurately deform the previous image to match or "register" the current image so that correspondence between not only the image structures, but also the image basic units, e.g., voxels (3-D images) or pixels (2-D images) may be achieved. Increasing the accuracy of image registration may reduce the potential for misregistration or subtraction artifacts in a resulting subtraction image. Further, subtraction images, such as temporal subtraction images from multiple-detector CT (MDCT) volume images as used in thoracic examinations, may employ a 3-D registration and warping technique between the current and previous images.

[0025] Turning to FIG. **2**, a method **200** for accurately registering and subtracting a pair of medical images using basic unit matching and image subtraction is disclosed. The method **200** may be employed with ordinary computer-aided detection or diagnosis (CAD), CAD that is specialized to read subtraction images, or in any other technique for analyzing medical images. At step **204**, the method **200** may capture a first medical image **300** (FIG. **3**) during a first time period. At step **208**, the method **200** may capture a second medical image **400** (FIG. **4**) during a second time period. An image **300**, **400** may be a representation of a physical scene, in which the image **300**, **400** has been generated by some imaging technology. The initial medium on which an image **300**, **400** is recorded may be a computer-readable medium, an electronic solid-state device, a photographic film, a photostimulable phosphor, or some other medium or device. The recorded image **300**, **400** may also be converted into digital form by a combination of electronic (e.g., a Charged Coupled Device) or mechanical/optical means (e.g., digitizing a photographic film or digitizing the data from a photostimulable phosphor). The image **300**, **400** may be recorded in any number of dimensions, for example, one (e.g., acoustic signals), two (e.g., X-ray radiological images) or more (e.g., nuclear magnetic resonance images).

[0026] Each of the first **300** and second **400** medical images may include a plurality of basic units. In one embodiment employing 3-D medical images, the basic units comprise voxels. In a further embodiment employing 2-D medical images, the basic units comprise pixels. A voxel is a unit of graphic information that defines a point in 3-dimensional space, whereas a pixel defines a point in 2-dimensional space.

[0027] In addition to location information, each basic unit may also include a value, for example, a measure of color or density. In specialized medical imaging processes, a basic unit value may be a value from a quantitative scale that was measured by the imaging process. For example, in CT, the voxel value may be a measure of radiodensity expressed in Hounsfield units (a quantitative measure of radiodensity). However, in Dynamic Contrast MRI, the voxel value may be associated with a measure of kinetic parameters associated observed tissues while a bolus of contrast material proceeds through the imaged subject. In MRI, sonography, PET, or any other imaging technique, a basic unit value may be a measure of signal or image intensity. Of course, many other values may be associated with a medical image basic unit.

[0028] The first **300** and second **400** images may be captured to obtain images containing basic units of approximately the same size. In one embodiment, the first **300** and second **400** images are both captured with identical devices. In a further embodiment, different exposure conditions between the first **300** and second **400** images, whether from different devices or other exposure conditions, may be corrected by adjusting the basic unit values in the images so that a majority of the basic units between the first **300** and second **400** images match. The second medical image **400** may include abnormalities **404**, **408** that were not present in the first medical image **300** that may indicate lesions, aneurysms, or other maladies. In one embodiment, the first **300** and second **400** medical images may be captured using any suitable medical imaging equipment, as previously discussed. As used herein, when applied to an imaging subtraction technique, the first image may represent a "previous" image, while the second image may represent a "current" image.

[0029] When the method **200** employs a CT scanner **131**, the scanner **131** may be a multi-slice CT scanner **131** and may include any suitable number of row detectors. Suitable CT scanners may be the LightSpeed® QXi scanner manufactured by General Electric Medical Systems of Waukesha, Wis., USA, or the Aquilion® scanner manufactured by Toshiba of Japan. Further, the CT scanner **131** may capture slice images in various matrix and voxel sizes. In one embodiment, a matrix size for each slice image may be 512×512 and the voxel size may range from 0.488 mm to 0.712 mm (mean, 0.646 mm) on the x and y axes, and 5.00 mm or 1.00 mm on the z axis. Of course, any matrix and voxel or pixel size may be employed to produce a slice image for use with the method **200**. When slice images with generally a 5-mm or greater slice thickness are employed, a z axis resolution may be increased by interpolating images between slice images.

[0030] At step **212**, a basic unit of the first **300** and second **400** medical images may be normalized. The images **300**, **400** may be 3-dimensional and the basic unit may be a voxel having a position represented by an x-axis value, a y-axis value, and a z-axis value. The images **300**, **400** may also be 2-dimensional and the basic unit may be a pixel having an x-axis value and a y-axis value. In one embodiment, a value associated with the basic unit in one or both of the first **300** and second **400** images may be normalized. For example, in CTA, the measure of radiodensity may be normalized for all basic unit values. Of course, other types of medical images may have various values associated with the basic units that may be normalized. Normalization of the basic units may be required when the basic unit sizes or values in the first **300** medical image are different from the second **400** medical image basic units. The basic units may be normalized using any suitable technique. In one embodiment, the basic units may be normalized by linear interpolation.

[0031] At step **216**, the method **200** may adjust the first **300** and second **400** images for differences in subject positioning by calculating a global shift vector. Where CT images are employed, the global shift vector may be determined for each of the first **300** or second **400** image slices. In one embodiment, a 2-dimensional template matching technique based on a 2-dimensional cross-correlation method may be employed as generally described in "Development of 3D CT temporal subtraction based on nonlinear 3D image warping technique," by T. Ishida, S. Katsuragawa, H. Abe, K. Ashizawa, and K. Doi in Proc. The 91st Radiological Society of North America (RSNA), 111, Chicago, USA, 2005, the entire disclosure of which is hereby incorporated by reference herein. In a further embodiment, blurred images may be obtained from the first and second images by a Gaussian filter. The images may be modified to reduce computation time or to emphasize larger structures in the images. For example, the images may begin with a matrix size of 512×512 and be reduced in the x-y plane to 128×128. In each second **400** image, an area may be selected as a template image **410**. A corresponding template image **310** on the first **300** image may be moved to determine the global shift vector. The global shift vector may be indicated by a template location with a maximum of the 2-dimensional cross-correlation value that may be a measure of the similarity between the first **300** and second **400** images.

[0032] At step **220**, a registration between the first **300** and second **400** images may be further refined by adjusting the images resulting from step **216**. For example, the images may be registered locally to correct warping or deformation between the first **300** and second **400** image. In one embodiment, the method **200** may employ a local matching technique to determine local shift vectors for each basic unit of the first or second image. When 3-D images are subtracted using the method **200**, a local shift vector for each image voxel may be determined.

[0033] One embodiment determines local shift vectors as generally described in "Temporal subtraction on 3D CT images by using nonlinear image warping technique," by T. Ishida, S. Katsuragawa, I. Kawashita, H. Kim, Y. Itai, K. Awai, Q. Li, and K. Doi, in Int. J. CARS, 1, pp. 468, 2006, the entire disclosure of which is hereby incorporated by reference herein. In a further embodiment, a template area of interest **411** may be located within the second **400** image and a search area of interest **311** may be located within the first image **300**. The matrix sizes of the template **411** and search **311** areas of interest may be any size within the respective image. For example, the search area of interest **311** may be twice as large as the template area of interest **411**. In one embodiment, in a 3-D image, the search area of interest **311** may be 64×64×32 voxels and the template area of interest **411** may be 32×32×16 voxels. Of course, the template **411** and search **311** areas of interest as shown in FIGS. **4** and **3**, respectively, are exaggerated for illustration only. The areas of interest **411**, **311** may be smaller or larger as compared to the corresponding images **400**, **300**. A larger search area of interest **311** may increase the likelihood that a basic unit within the template area of interest **411** may correspond to a basic unit within the search area of interest **311**. Distances between the template **411** and search **311** areas of interest within their corresponding images may also be twice as large in the x-y plane as in the z axis. A 3-D cross-correlation value for each template-search area of interest pair **411**, **311** may be calculated with translation of a template area of interest **411** within a corresponding search area of interest **311**. A local shift vector may result for each template-search area of interest pair **411**, **311** when a 3-D cross-correlation value reaches a maximum.

[0034] At step **224**, the first **300** and second **400** images may be further registered by adjusting the images with 3-D non-linear image warping by using 3-D voxel matching. In one embodiment, a shift vector for image warping may be obtained by a combination of the global shift vector as described in step **216** and the local shift vector as described in step **220**. The resulting shift vectors may represent the extent of warping or deformation of the first image **300** relative to the second image **400**. However, the orientation and amplitude of a single shift vector may change in comparison to an adjacent shift vector due to noise in some types of medical images, for example, MDCT images. To remedy an unwanted shift due to image noise, the method may employ a 3-D elastic matching method for smoothing shift vectors as generally disclosed in "3D elastic matching for temporal subtraction employing thorax MDCT image," by Y. Itai, H. Kim, S. Ishikawa, S. Ishikawa, T. Ishida, I. Kawashita, K. Awai, Q. Li, and K. Doi, in Proc. of the World Congress on Medical Physics and Biomedical Engineering, pp. 2181-2191, 2006, the entire disclosure of which is hereby incorporated by reference herein.

[0035] A 2-D elastic matching method, may obtain the shift vector corresponding to a specific pixel that preserves a high cross-correlation value and high consistency over the other shift vectors associated with other pixels. In a 3-D space, a 3-D elastic matching technique be employed to similar effect. In the elastic matching method, the smoothed shift vector may be obtained by minimizing a cost function that is a weighted sum of an internal and an external energy. The internal energy may be the squared sum of the first- and second-order derivative values of the shift vectors because smoother shift vectors correspond to smaller internal energy. In one embodiment, the external energy may be equal to the negative value of the 3-D cross-correlation value that is obtained with the template-search area of interest pair, as described above. A shift vector with a large correlation value may provide a small external energy. Therefore, with the 3-D elastic matching technique, the smoothed shift vector may be obtained by taking into account not only the similarity between the second **400** and the first **300** images, but also the consistency of the shift vectors. With the smoothed shift vectors obtained, the shift vectors in all voxels in the previous image may be determined by use of a tri-interpolation in the case of 3-D images, or another interpolation method with other types of images. Interpolation of the shift vectors to the images may result in a warped image that accounts for deformities between the first **300** and second **400** medical images.

[0036] After warping the first (or previous) image **300**, the general appearance of the warped previous image **300** may be very similar to that of the second **400** (or current) image. With reference to FIG. **5**, despite warping the first or previous image as described in blocks **212**-**224** of FIG. **2**, any temporal subtraction image **500** obtained by the subtraction of the warped or non-warped first image **300** from the second (or current) image **400** may contain subtraction artifacts **504**.

[0037] Continuing with block **224**, with reference to FIG. **6**, a basic unit matching technique **600** may be described to further register the first **300** and second **400** images and remove or reduce subtraction artifacts. In one embodiment, the basic unit matching technique may accurately match a basic unit between a first **300** and second **400** image. At step **604**, for a given location **412** in the second **400** image, the method **200** may locate a corresponding location **312** in the first **300** warped or non-warped image. In one embodiment, the given location **412** and the corresponding location **312** may each be located in a substantially identical area of the first **300** and second **400** images. At step **608**, the method **600** may locate a search area **316** or "kernel" surrounding the corresponding location **312**. The search area **316** as illustrated in FIG. **3** is exaggerated for the sake of clarity and explanation. Generally, the search area **316** may be a volume of 3×3×3 basic units (for a 3-D image where the basic units are voxels). Depending on the resolution of the first **300** and second **400** images, the search area **316** may be very small in comparison to the entire image **300**. In a further embodiment, the size of the search area **316** may be made smaller or larger and may encompass a variety of shapes, as further explained in relation to block **228**, below.

[0038] At block **612**, the method **600** may identify a basic unit within the search area **316** that most closely matches the basic unit identified by the given location **412**. In one embodiment, the matching basic unit **320** value may be nearly identical to the given location basic unit **412**. For example, where the images **300**, **400** are CT images, the Hounsfield value of the matching basic unit **320** and the given location basic unit may be substantially identical. In a further embodiment, the matching basic unit **320** size (area or volume) may be nearly identical to the given location basic unit **412**. Further, the given location basic unit **412** value and the matching basic unit **320** value may be nearly identical for purposes of matching if the difference is statistically insignificant. For example, the difference may be statistically insignificant if it is within an average visual noise level of the first **300** or second image **400**. If a matching basic unit **320** is found, then the method proceeds to block **616**, otherwise, the method **600** proceeds to block **620**.

[0039] At block **616**, the method **600** may replace the given location basic unit **412** with the matching basic unit **320** found at block **612** or otherwise normalize any basic unit that is not an abnormality **404**, **408**. In one embodiment, the method **600** may modify the values of the given location basic unit **412** to match the values of the matching basic unit **320**. In a further embodiment, the method **600** may cut and paste the matching basic unit **320** from the first image **300** to the given location basic unit **412**. In a still further embodiment, the method **600** may replace the given location basic unit **412** with the difference between the values of the given location basic unit **412** and the matching basic unit **320**. In a still further embodiment, the method **600** may modify the value of all matching basic units to the same value, for example, zero, thereby representing all matching basic units in a resulting subtraction image as identical. Of course, other embodiments may encompass other techniques to normalize any basic unit of either a warped or non-warped first **300** or second **400** image to remove any basic unit that is common to both images **300**, **400** thus leaving the basic units that include an abnormality **404**, **408** generally unmodified.

[0040] Returning to FIG. **2**, at block **228**, the method **200** may create a subtraction image **700** (FIG. **7**). In one embodiment, if, at block **616**, the method **600** modifies the values of the basic units of one of the images to match the other, then, at block **228**, the method **200** may output the image containing the modified basic units as the subtraction image **700**. In a further embodiment, if, at block **616**, the method **600** cuts and pastes the matching basic unit **320** from one of the first **300** or second **400** images to the corresponding, matched basic unit of the other image **300**, **400**, then, at block **228**, the method **200** may output the image containing the pasted basic units as the subtraction image **700**. In a still further embodiment, if, at block **616**, the method **600** replaces all of the matching basic units within either the first **300** or second **400** image with the difference between the values of the matching basic units, then, at block **228**, the method **200** may subtract the image containing the replaced basic units from the unmodified image to create the subtraction image **700**. Other embodiments may subtract a warped or non-warped first previous image **300**, as described in relation to blocks **212-224** above, from a second or current image **400** to produce a subtraction image **700**. The method **200** may then optionally apply the basic unit matching technique described in relation to FIG. **6** to further refine and produce a temporal subtraction image.

[0041] With reference to FIGS. **7** and **8**, the size of the search area **316**, as described in relation to block **608** above, may be made smaller or larger and may encompass a variety of shapes. For example, a larger search area, such as 5×5×5, may decrease the detection sensitivity for small abnormalities while increasing the elimination of subtraction artifacts **504**. On the other hand, a smaller search area may increase the detection sensitivity for small abnormalities while decreasing the elimination of subtraction artifacts **504**. FIG. **8** illustrates a larger search area voxel-matched subtraction image that may be produced with a larger search area **316** than the subtraction image of FIG. **7**. A smaller search area subtraction image **700** may include areas, for example, area **712**, that includes subtraction artifacts. In comparison, a larger search area subtraction image **800** may eliminate or reduce the same subtraction artifacts in a similar area **812**. However, the smaller search area subtraction image **700** may also detect a larger portion **716** of an abnormality **704** than the same portion **816** of a larger search area subtraction image **800**.

[0042] The search area **316** size may be automatically or manually selected depending on a desired sensitivity and the presence of subtraction artifacts **504**. Generally, when the method **600** employs a search area **316** that is 3×3×3 basic units, abnormalities **404**, **408** of 2 mm or larger may be detected, although smaller abnormalities **404**, **408** may be present and detectable in subtraction images employing a smaller or larger search area **316**. Additionally, the search area **316** may encompass any form including a sphere, a cylinder, a square (where the first **300** and second **400** images are 2-D), or any irregular shape.

[0043] The method **200** may also cycle through the number of search area **316** sizes to determine a size that may result in a desirable subtraction image. For example, two temporal subtraction images produced with differing search areas may be produced. The method **200** may compare the subtraction images to determine which image includes the least amount of subtraction artifacts while producing the most accurate contrast image to detect abnormalities. In one embodiment, the method **200** may buffer a number of subtraction images before display to determine the most accurate or desirable image. Upon determining an optimal search area **316**, the method may re-execute a subtraction block to produce a subtraction image as described in relation to block **228**, above.

[0044] The basic unit-matching technique described above may also include a user interface that is responsive to user inputs in various portions of the user interface on the display **116** of the computer system **100**, on the CT Scanner **131**, or other devices. For example, one portion of an interface may render a sequence of tomographic sections. These tomographic sections may be maximum intensity projection (MIP) images or 3D images or slices of 3D images. The orientations or views of these sections or images may be manipulated by an input device **120**, for example. The section or sections displayed may be selectable by an input device **120** and a portion of the interface may render a subtraction image. In one embodiment, clicking on a button using a mouse **124**, or similar control, in a portion of the user interface causes the subtraction image to be replaced by a corresponding basic unit matched subtraction image. In a further embodiment, the basic unit matched subtraction image is only displayed while the control is activated. In a still further embodiment, a control of the graphical user interface may also allow the user to vary the size of a search area **316** as the basic unit matched subtraction image corresponding to the selected search area size is displayed. In a still further embodiment, a sub-portion (e.g., a rectangular or circular sub-portion) of the subtraction image is replaced by a corresponding sub-portion of the basic unit matched subtraction image. In a still further embodiment, the position of the sub-portion may be moved about the image by the user through an input device **120**. In a still further embodiment, the size and shape of the sub-portion may also be controlled by the user.

[0045] With the basic unit-matching technique described above, subtraction artifacts may be removed due to very slight differences in the size, shape, and location of normal anatomic structures. Thus, the technique may produce smooth temporal subtraction images except for new abnormalities, as illustrated in FIGS. **7** and **8**. In addition, the majority of the noise in medical images may be removed by use of the technique, as shown by the smooth background in the temporal subtraction images of FIGS. **7** and **8**.

[0046] The previously-described techniques include several embodiments, including a number of features, functions, and method blocks. Not all features and functions are required for every embodiment. The features discussed herein are intended to be illustrative of those features that may be implemented; however, such features should not be considered exhaustive of all possible features that may be implemented in a device configured in accordance with the embodiments. Further, the described method blocks may be executed in any order to produce a temporal subtraction image by the techniques disclosed herein. Moreover, the herein described embodiments are illustrative and not limiting; the embodiments are defined and limited only by the following claims.

We claim:

1. A method for producing a basic unit-matched temporal subtraction image comprising:

capturing a first medical image including a plurality of first basic units during a first time period;

capturing a second medical image including a plurality of second basic units during a second time period, wherein the first and second medical images comprise an approximately identical subject;

locating a plurality of given location basic units in the plurality of second basic units within the second medical image;

locating a plurality of corresponding location basic units in the plurality of first basic units within the first medical image, wherein each of the plurality of corresponding location basic units corresponds to one of the plurality of given location basic units, and each pair of the corresponding location basic units and given location basic units are located at a substantially identical location within the first and second medical images;

identifying a plurality of search areas in the first medical image, each of the plurality of search areas centered on one of the plurality of corresponding location basic units;

identifying a plurality of matching basic units within the plurality of search areas, wherein each matching basic unit corresponds to one of the plurality of given location basic units, and each pair of the matching basic units and given location basic units are substantially identical; and

creating the basic unit-matched temporal subtraction image from the plurality of matching basic units.

2. The method of claim **1**, further comprising registering the first and second medical images.

3. The method of claim **2**, wherein registering the first and second medical images comprises:

normalizing a value of each of the plurality of first basic units and the plurality of second basic units;

correcting the first medical image for subject positional differences between the first and second medical images.

4. The method of claim **1**, further comprising setting each of the plurality of matching basic unit values to zero.

5. A method for producing a voxel-matched subtraction image comprising:

capturing a first image including a plurality of first voxels;

capturing a second image including a plurality of second voxels, wherein the first and second images comprise an approximately identical subject;

locating a plurality of given location voxels in the plurality of second voxels within the second image;

locating a plurality of corresponding location voxels in the plurality of first voxels within the first image, wherein each of the plurality of corresponding location voxels corresponds to one of the plurality of given location voxels, and each pair of the corresponding location voxels and given location voxels are located at a substantially identical location within the first and second images;

identifying a plurality of search areas in the first image, each of the plurality of search areas containing one of the plurality of corresponding location voxels;

identifying a plurality of matching voxels within the plurality of search areas, wherein each matching voxel corresponds to one of the plurality of given location voxels, and each pair of the matching voxels and given location voxels are substantially identical; and

creating the voxel-matched subtraction image from the plurality of matching voxels.

6. The method of claim **5**, further comprising registering the first and second images.

7. The method of claim **6**, wherein registering the first and second images comprises:

normalizing a value of each of the plurality of first voxels and the plurality of second voxels;

8. The method of claim **5**, wherein creating the voxel-matched subtraction image comprises:

for each pair of the matching voxels and given location voxels, replacing the corresponding location voxel with the matching voxel; and

subtracting the corresponding location voxels from the given location voxels.

9. A method for producing a voxel-matched subtraction image comprising:

capturing a first image including a plurality of first voxels;

capturing a second image including a plurality of second voxels, wherein the first and second images comprise an approximately identical subject;

locating a plurality of given location voxels in the plurality of second voxels within the second image;

for each given location voxel, locating a corresponding location voxel in the plurality of first voxels within the first image, wherein each pair of the corresponding location voxels and given location voxels are located at a substantially identical location within the first and second images;

identifying a plurality of search areas in the first image, wherein each of the plurality of search areas contains a corresponding location voxel and corresponds to one of the plurality of given location voxels;

determining whether a matching voxel is present within each of the plurality of search areas;

for each given location voxel having a matching voxel, replacing the corresponding location voxel with the matching voxel; and

subtracting the corresponding location voxels from the given location voxels.

10. The method of claim **9**, wherein a voxel is matching if the matching voxel and given location voxel are substantially identical in value.

11. The method of claim **9**, wherein a voxel is matching if the matching voxel and given location voxels are identical in value.

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