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(54) **PROVIDING A 2-DIMENSIONAL CT IMAGE CORRESPONDING TO A 2-DIMENSIONAL ULTRASOUND IMAGE**

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(57) **ABSTRACT**

There is disclosed a system and method for providing a 2-dimensional CT image corresponding to a 2-dimensional ultrasound image by performing an image registration between a 3-dimensional ultrasound image and a 3-dimensional CT image. The system comprises: a CT image forming unit configured to form a plurality of 3-dimensional CT images for an object of interest inside a target object; an ultrasound image forming unit configured to form at least one 3-dimensional ultrasound image for the object of interest; a processor configured to perform image registration between the 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a first transform function; and a user input unit configured to receive input information from a user, wherein the ultrasound image forming unit is further configured to form a 2-dimensional ultrasound image from the at least one 3-dimensional ultrasound image based on the input information, and wherein the processor is further configured to obtain a plurality of 2-dimensional CT images from the 3-dimensional CT images based on the input information and the first transform function and to detect similarities between the 2-dimensional ultrasound image and the 2-dimensional CT images to select one of the 2-dimensional CT images corresponding to the 2-dimensional ultrasound image.

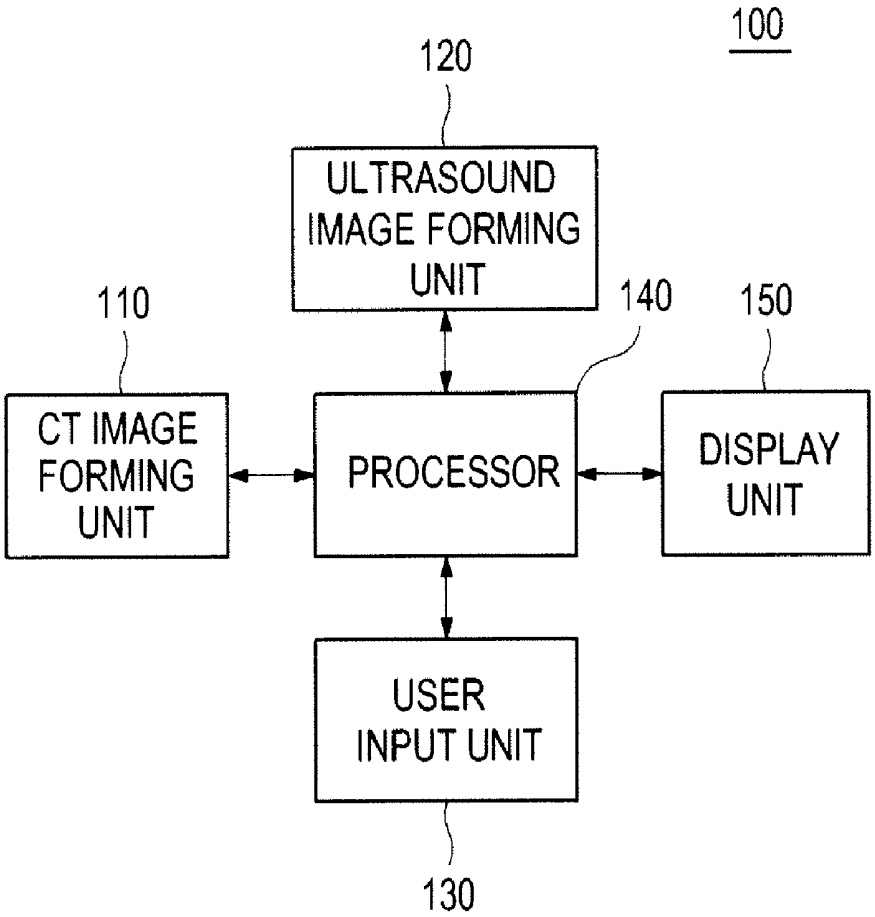


FIG. 1

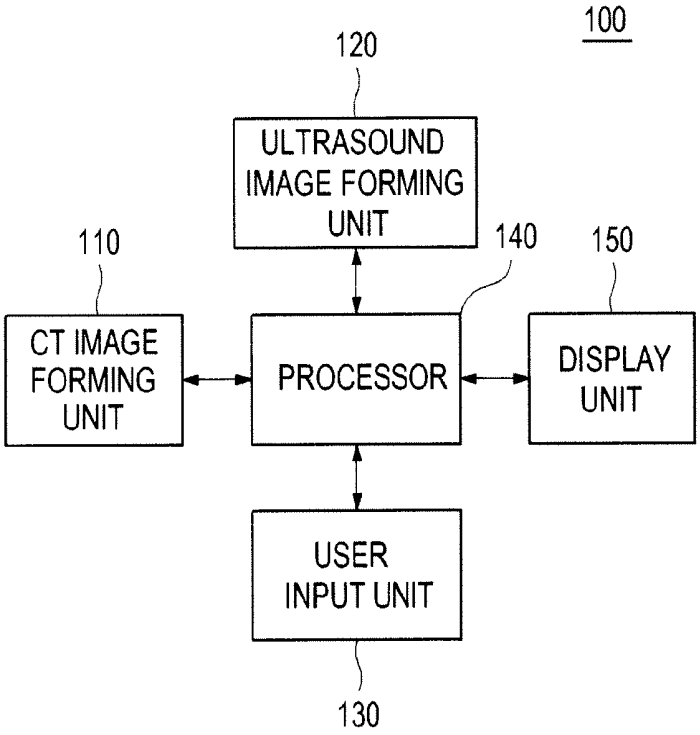

100
120
ULTRASOUND IMAGE FORMING UNIT
110
140
150
CT IMAGE FORMING UNIT
PROCESSOR
DISPLAY UNIT
USER INPUT UNIT
130

FIG. 2

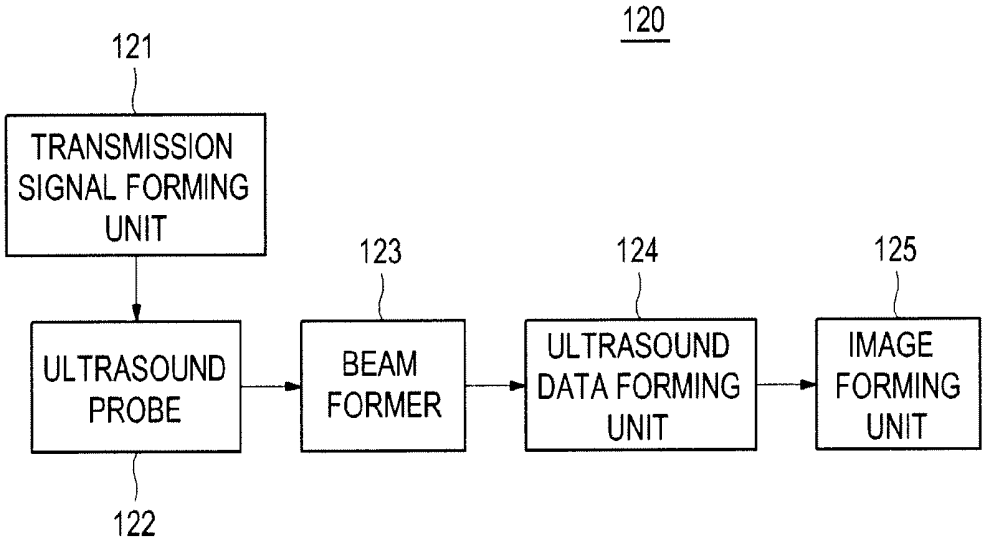

120
121
TRANSMISSION SIGNAL FORMING UNIT
123
124
125
ULTRASOUND PROBE
BEAM FORMER
ULTRASOUND DATA FORMING UNIT
IMAGE FORMING UNIT
122

FIG. 3

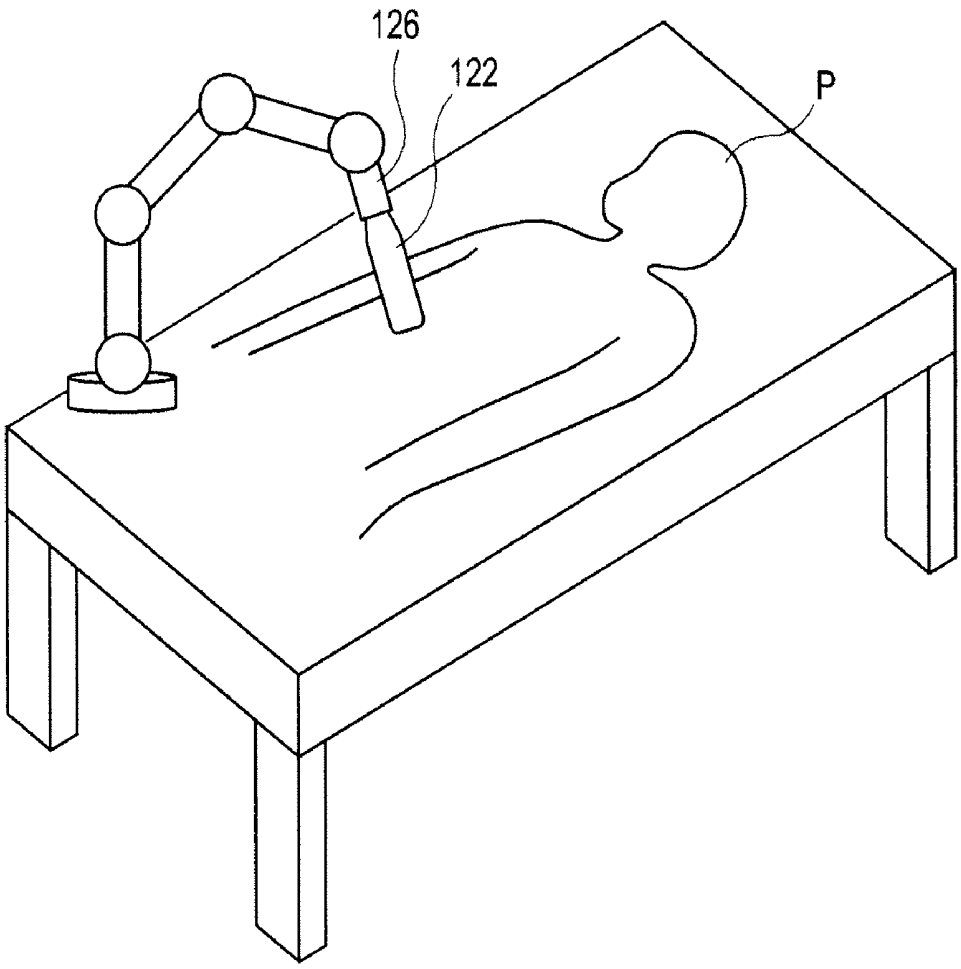


FIG. 4

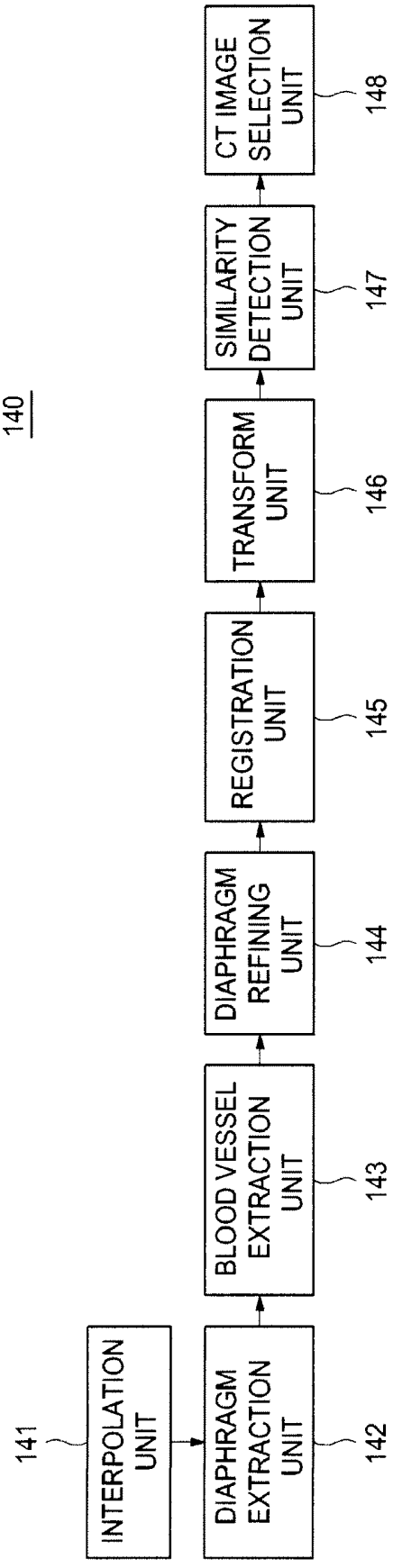

140
141
INTERPOLATION UNIT
142
DIAPHRAGM EXTRACTION UNIT
143
BLOOD VESSEL EXTRACTION UNIT
144
DIAPHRAGM REFINING UNIT
145
REGISTRATION UNIT
146
TRANSFORM UNIT
147
SIMILARITY DETECTION UNIT
148
CT IMAGE SELECTION UNIT

FIG. 5

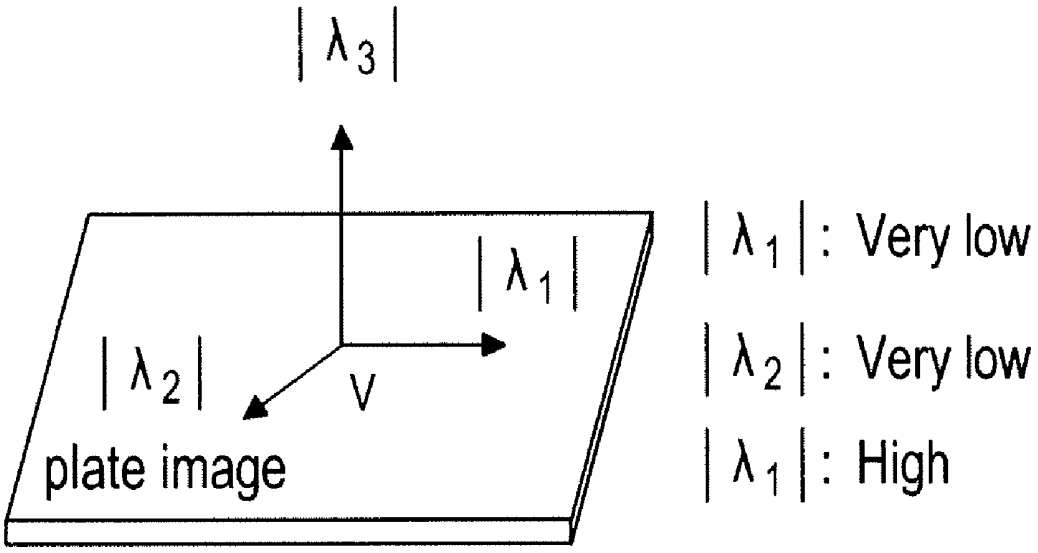
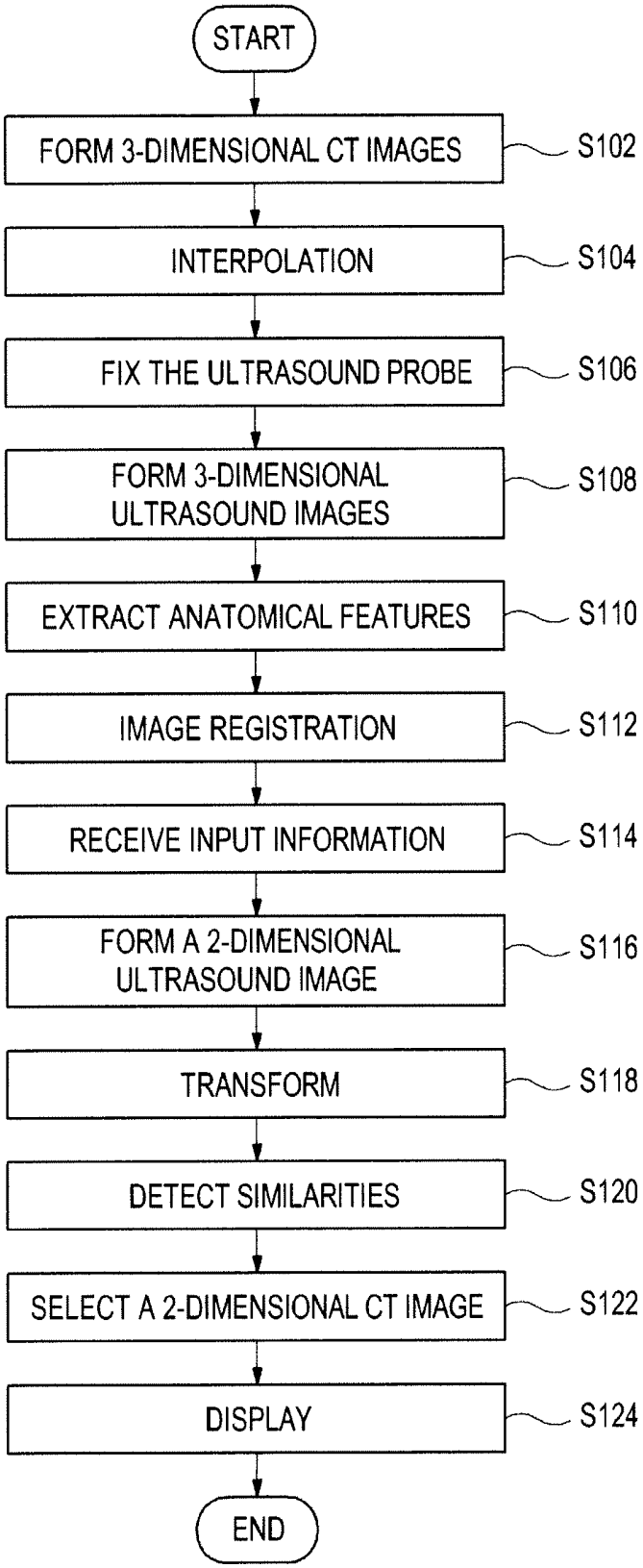


FIG. 6


START
FORM 3-DIMENSIONAL CT IMAGES
S102
INTERPOLATION
S104
FIX THE ULTRASOUND PROBE
S106
FORM 3-DIMENSIONAL ULTRASOUND IMAGES
S108
EXTRACT ANATOMICAL FEATURES
S110
IMAGE REGISTRATION
S112
RECEIVE INPUT INFORMATION
S114
FORM A 2-DIMENSIONAL ULTRASOUND IMAGE
S116
TRANSFORM
S118
DETECT SIMILARITIES
S120
SELECT A 2-DIMENSIONAL CT IMAGE
S122
DISPLAY
S124
END

PROVIDING A 2-DIMENSIONAL CT IMAGE CORRESPONDING TO A 2-DIMENSIONAL ULTRASOUND IMAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority from Korean Patent Application No. 10-2009-0070981, filed on Jul. 31, 2009, the entire subject matter of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to ultrasound image processing, and more particularly to an image registration-based system and method for providing a 2-dimensional computerized tomography (CT) image corresponding to a 2-dimensional ultrasound image.

BACKGROUND

[0003] Due to its non-invasive and non-destructive nature, an ultrasound system has been extensively used in the medical field to acquire internal information of a target object. The ultrasound system is highly useful in the medical field since it can provide doctors with a high resolution image of internal tissues of the target object without the need of surgical treatment.

[0004] However, since the signal-to-noise ratio (SNR) of an ultrasound image is low, the method of performing image registration between a CT image and an ultrasound image to provide a CT image and an ultrasound image has been used.

[0005] Conventionally, a sensor was used to perform image registration between a CT image and an ultrasound image. Accordingly, the sensor became essential to the system. In addition, there is a problem in that errors can occur when internal organs are transformed due to a movement of the target object such as respiration, etc. Conventionally, when the ultrasound probe is moved to another location to acquire a 2-dimensional ultrasound image, there is a problem in that the sensor is essential to identify whether the 2-dimensional ultrasound image is an ultrasound image within the 3-dimensional ultrasound image or to detect the 2-dimensional CT image corresponding to the 2-dimensional ultrasound image in the 3-dimensional CT image, which has been image registered onto the 3-dimensional ultrasound image.

SUMMARY

[0006] The present invention provides a system and method for performing image registration between a 3-dimensional ultrasound image and a 3-dimensional CT image and detecting a 2-dimensional CT image corresponding to a 2-dimensional ultrasound image on the image-registered 3-dimensional CT image, thereby providing the 2-dimensional CT image without using a sensor.

[0007] According to an aspect of the present invention, the image providing system comprises: a CT image forming unit configured to form a plurality of 3-dimensional CT images for an object of interest inside a target object; an ultrasound image forming unit configured to form at least one 3-dimensional ultrasound image for the object of interest; a processor configured to perform image registration between the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a first transform function; and a user input unit configured to receive input information from a user, wherein the ultrasound image forming unit is further configured to form a 2-dimensional ultrasound image from the at least one 3-dimensional ultrasound image based on the input information, and wherein the processor is further configured to obtain a plurality of 2-dimensional CT images from the plurality of 3-dimensional CT images based on the input information and the first transform function and to detect similarities between the 2-dimensional ultrasound image and the plurality of 2-dimensional CT images to select one of the 2-dimensional CT images corresponding to the 2-dimensional ultrasound image.

[0008] According to another aspect of the present invention, the image providing method comprises: forming a plurality of 3-dimensional CT images for an object of interest inside a target object; forming at least one 3-dimensional ultrasound image for the object of interest; performing image registration between the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a first transform function; receiving input information from a user; forming a 2-dimensional ultrasound image from the at least one 3-dimensional ultrasound image based on the input information; obtaining a plurality of 2-dimensional CT images from the plurality of 3-dimensional CT images based on the input information and the first transform function; and detecting similarities between the 2-dimensional ultrasound image and the plurality of 2-dimensional CT images to select one of the 2-dimensional CT images corresponding to the 2-dimensional ultrasound image.

[0009] The present invention may provide a 2-dimensional CT image corresponding to a 2-dimensional ultrasound image within a 3-dimensional ultrasound image on a 3-dimensional CT image registered onto the 3-dimensional ultrasound image without using a sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a block diagram showing an arrangement of an image providing system according to an embodiment of the present invention.

[0011] FIG. **2** is a block diagram showing an arrangement of the ultrasound image forming unit according to an embodiment of the present invention.

[0012] FIG. **3** is a schematic diagram showing an ultrasound probe holder and an ultrasound probe fixed at the ultrasound probe holder according to an embodiment of the present invention.

[0013] FIG. **4** is a block diagram showing an arrangement of the processor according to an embodiment of the present invention.

[0014] FIG. **5** is an exemplary diagram showing Hessian matrix eigen values according to directions.

[0015] FIG. **6** is a flow chart showing the process of providing a 2-dimensional CT image corresponding to a 2-dimensional ultrasound image by performing image registration between a 3-dimensional ultrasound image and a 3-dimensional CT image according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0016] Embodiments of the present invention are described below with reference to the accompanying drawings. The term "object of interest" used in this embodiment may comprise a liver inside a target object.

[0017] FIG. **1** is a block diagram showing an arrangement of an image providing system **100** according to an embodiment of the present invention. The image providing system **100** comprises a computerized tomography (CT) image forming unit **110**, an ultrasound image forming unit **120**, a user input unit **130**, a processor **140** and a display unit **150**.

[0018] The CT image forming unit **110** forms a 3-dimensional CT image for an object of interest inside a target object, which is composed of a plurality of 2-dimensional CT images. In this embodiment, the CT image forming unit **110** may be configured to consecutively form 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$ at a predetermined interval during a respiratory cycle from inspiration to expiration.

[0019] The ultrasound image forming unit **120** forms a 3-dimensional ultrasound image for the object of interest inside the target object. In this embodiment, the ultrasound image forming unit **120** forms 3-dimensional ultrasound images $I_{US}(t_i)$ $(1 \leqq j \leqq 2)$ at maximum inspiration and maximum expiration. Further, the ultrasound image forming unit **120** forms a 2-dimensional ultrasound image of the object of interest inside the target object.

[0020] Although it is explained to form the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ at maximum inspiration and maximum expiration in the foregoing embodiment, the 3-dimensional image can be formed at either maximum inspiration or maximum expiration in other embodiments. In the following description, it is explained that the ultrasound image forming unit **120** forms the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ at maximum inspiration and maximum expiration for the brevity of the description.

[0021] FIG. **2** is a block diagram showing an arrangement of the ultrasound image forming unit **120** according to an embodiment of the present invention. The ultrasound image forming unit **120** comprises a transmission signal forming unit **121**, an ultrasound probe **122**, a beam former **123**, an ultrasound data forming unit **124** and an image forming unit **125**. The ultrasound image forming unit **120** may comprise an ultrasound probe holder **126** for fixing the ultrasound probe **122** in a specific location of the target object (P) as described in FIG. **3**.

[0022] The transmission signal forming unit **121** forms a first transmission signal to acquire each of the plurality of frames. In this embodiment, the first transmission signal comprises at least one among the transmission signal to acquire each of the plurality of frames at maximum inspiration and the transmission signal to acquire each of the plurality of frames at maximum expiration. Also, the transmission signal forming unit **121** forms a second transmission signal to acquire a frame. The frame may comprise a brightness mode (B-mode) image.

[0023] The ultrasound probe **122** comprises multiple transducer elements (not shown). The ultrasound probe **122** may comprise a 3-dimensional probe. However, it should be noted herein that the ultrasound probe **122** may not be limited thereto. The ultrasound probe **122** converts the first transmission signal provided from the transmission signal forming unit **121** into an ultrasound signal, transmits the ultrasound signal to the target object and receives an ultrasound echo signal reflected by the target object to thereby form a first reception signal. In addition, the ultrasound probe **122** moves the transducer elements to the position set by the user. The ultrasound probe **122** then converts the second transmission signal provided from the transmission signal forming unit **121** into an ultrasound signal, transmits the ultrasound signal to the target object and receives an ultrasound echo signal reflected by the target object, thereby forming a second reception signal.

[0024] If the first reception signal is provided from the ultrasound probe **122**, then the beam former **123** analog/digital converts the first reception signal to form a first digital signal. The beam former **123** forms a first receive-focused signal by receive-focusing the first digital signal considering the focal points and the locations of the transducer elements. If the second reception signal is provided from the ultrasound probe **122**, then the beam former **123** analog/digital converts the second reception signal to form a second digital signal. The beam former **123** forms a second receive-focused signal by receive-focusing the second digital signal considering the focal point and the location of the transducer elements.

[0025] The ultrasound data forming unit **124** forms first ultrasound data using the first receive-focused signal when the first receive-focused signal is provided from the beam former **123**. The ultrasound data forming unit **124** forms second ultrasound data using the second receive-focused signal when the second receive-focused signal is provided from the beam former **123**. In addition, the ultrasound data fainting unit **124** may perform signal processing, which is required to form ultrasound data (e.g., gain control, filtering, etc.) on the first or second receive-focused signal.

[0026] The image forming unit **125** forms a 3-dimensional ultrasound image using the first ultrasound data when the first ultrasound data is provided from the ultrasound data forming unit **124**. In this embodiment, the 3-dimensional ultrasound image comprises at least one of the 3-dimensional ultrasound image at maximum inspiration ($I_{US}(t_1)$) and the 3-dimensional ultrasound image at maximum expiration ($I_{US}(t_2)$). The image forming unit **125** forms the 2-dimensional ultrasound image using the second ultrasound data when the second ultrasound data is provided from the ultrasound data forming unit **124**.

[0027] Referring back to FIG. **1**, the user input unit **130** receives input information from the user. In this embodiment, the input information comprises reference plane setting information that sets a reference plane in the 3-dimensional ultrasound image across which the 2-dimensional ultrasound image will be obtained, diaphragm area setting information which sets diaphragm areas on the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$ and blood vessel area setting information which sets blood vessels area on the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$. As an example, the reference plane setting information may comprise reference plane setting information that sets one rotation angle within the rotation angle range in which the transducer element of the ultrasound probe **122** (i.e., 3-dimensional probe) can swing (i.e., −35° to 35°). Thus, the ultrasound image forming unit **120** can form the 2-dimensional ultrasound image corresponding to the reference plane setting information. The user input unit **130** may be implemented with control panel which comprises dial button and the like, mouse, keyboard, etc.

[0028] The processor **140** performs image registration between 3-dimensional CT image and 3-dimensional ultrasound image to obtain a transform function between the 3-dimensional CT image and the 3-dimensional ultrasound image (i.e., location of ultrasound probe **122** T_{probe}). Hereinafter, it is explained that the 3-dimensional ultrasound images I_{US} $(1 \leqq j \leqq 2)$ comprise the 3-dimensional ultrasound image at maximum inspiration ($I_{US}(t_1)$) and the 3-dimensional ultrasound image at maximum expiration ($I_{US}(t_2)$). However, it

should be noted that the present invention is not limited thereto. In addition, the processor **140** detects a 2-dimensional CT image corresponding to the 2-dimensional ultrasound image using the transform function.

[0029] FIG. **4** is a block diagram showing an arrangement of the processor **140** according to an embodiment of the present invention. The processor **140** comprises an interpolation unit **141**, a diaphragm extraction unit **142**, a blood vessel extraction unit **143**, a diaphragm refining unit **144**, a registration unit **145**, a transform unit **146**, a similarity detection unit **147** and a CT image selection unit **148**.

[0030] The interpolation unit **141** interpolates the 3-dimensional CT image $I_{CT}(t_i)$ and the 3-dimensional CT image $I_{CT}(t_{i+1})$ provided from the CT image forming unit **110** to form at least one 3-dimensional CT image between the 3-dimensional CT image $I_{CT}(t_i)$ and the 3-dimensional CT image $I_{CT}(t_{i+1})$. As an example, the interpolation unit **141** performs interpolation between the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$ provided from the CT image forming unit **110** to acquire N 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$.

[0031] The diaphragm extraction unit **142** extracts a diaphragm from each of the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ provided from the interpolation unit **141**. In addition, the diaphragm extraction unit **142** extracts a diaphragm from the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ provided from the ultrasound image forming unit **120**.

[0032] In one embodiment, the diaphragm extraction unit **142** perform a flatness test on the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ based on a Hessian matrix to extract the diaphragm. That is, the diaphragm extraction unit **142** extracts an area in which the change in the voxel intensity perpendicular to the surface is larger than the change in the voxel intensity parallel to the surface as the diaphragm, considering that the diaphragm is a curved surface on the 3-dimensional CT image and the 3-dimensional ultrasound image. FIG. **5** shows Hessian matrix eigen values λ_1, λ_2, λ_3 according to directions.

[0033] More particularly, the diaphragm extraction unit **142** selects voxels having flatness higher than a reference value to extract the diaphragms from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$. The flatness $\mu(v)$ is defined as below.

$$\mu(v)=\phi_1(v)\phi_2(v)\phi_3(v)/\phi_{3_{max}}(v) \tag{1}$$

[0034] $\phi_1(v)$, $\phi_2(v)$, and $\phi_3(v)$ of the equation (1) are expressed as below.

$$\phi_1(v)=\left(1-\frac{\lambda_1(v)}{\lambda_3(v)}\right)^2,\ \phi_2(v)=\left(1-\frac{\lambda_2(v)}{\lambda_3(v)}\right)^2,\ \phi_3(v)=\sum_i \lambda_i(v)^2 \tag{2}$$

[0035] The foregoing $\lambda_1(v)$, $\lambda_2(v)$ and $\lambda_3(v)$ represent the Hessian matrix eigen values according to the location of the voxel. The flatness $\mu(v)$ is normalized to have a value between 0 and 1. The diaphragm extraction unit **142** forms a flatness map using the flatness obtained from the equations (1) and (2), and selects voxels having relatively higher flatness. In this embodiment, the diaphragm extraction unit **142** selects voxels having flatness of 0.1 or more.

[0036] The diaphragm extraction unit **142** removes small clutters by performing morphological opening for the selected voxels (morphological filtering). The morphological opening means performing erosion and dilation sequentially. The diaphragm extraction unit **142** removes edge of the area in which the voxel values exist morphologically as many as the predetermined number of voxels to contract the edge (erosion), and then expands it as many as the predetermined number of the voxels (dilation). In an embodiment of the present invention, the diaphragm extraction unit **142** contracts and expands the edge by 1 voxel.

[0037] Since the diaphragm is the largest surface in the 3-dimensional CT image and the 3-dimensional ultrasound image, the largest surface among candidate surfaces obtained by the intensity-based connected component analysis (CCA) for the voxels may be selected as the diaphragm. The voxel-based CCA is one of the methods of grouping regions in which voxel values exist. For example, the diaphragm extraction unit **142** computes the number of voxels connected to each of the voxels through a connectivity test by referring to values of voxels neighboring to the corresponding voxel (e.g., 26 voxels), and selects the voxels of which the number of connected voxels are greater than the predetermined number as candidate groups. Since the diaphragm is the widest curved surface in the region of interest, the diaphragm extraction unit **142** extracts the candidate group having the largest number of connected voxels as the diaphragm. Thereafter, the diaphragm extraction unit **142** can smoothen the surface of the diaphragm.

[0038] In other embodiments, the diaphragm extraction unit **142** extracts the diaphragm by performing the foregoing process on the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$. In addition, the diaphragm extraction unit **142** extracts the diaphragm from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ based on the input information (i.e., diaphragm area setting information). More particularly, since the 3-dimensional CT image has more distinct boundaries of liver than typical ultrasound images, the diaphragm extraction unit **142** may extract the diaphragm using methods such as a commercial program for extracting liver area or a seeded region growing segmentation method.

[0039] The blood vessel extraction unit **143** extracts blood vessels from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$. In addition, the blood vessel extraction unit **143** extracts blood vessels from the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$.

[0040] In one embodiment, the blood vessel extraction unit **143** can perform a blood vessel extraction from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ through masking, blood vessel segmentation and classification.

[0041] More specifically, to avoid mis-extraction of the blood vessel due to mirroring artifacts, the blood vessel extraction unit **143** sets the region of interest (ROI) masking on the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ by modeling the diaphragms as a polynomial curved surface. The blood vessel extraction unit **143** may remove the portions of the modeled polynomial curved surface lower than the diaphragm using the ROI masking on the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$. In such a case, the blood vessel extraction unit **143** may perform modeling the diaphragm as the polynomial curved surface using the least means square (LMS). However, if all of the lower portions of the modeled polynomial curved surface are eliminated, then meaningful blood vessel information may be lost at some regions due to

errors of the polynomial curved surface. To avoid losing the blood vessel information, the blood vessel extraction unit **143** applies a marginal distance of about 10 voxels from the bottom of the ROI mask and then eliminates the lower portion.

[0042] The blood vessel extraction unit **143** segments blood vessel regions and non-vessel regions. To exclude the non-vessel regions with high intensity such as the diaphragm and the vessel walls, the blood vessel extraction unit **143** estimates the low intensity bound having less intensity than a reference bound value in the ROI masked image, and removes voxels having higher intensity than the reference bound value. The blood vessel extraction unit **143** binarizes the remaining regions by applying an adaptive threshold scheme. The binarized regions become blood vessel candidates.

[0043] The blood vessel extraction unit **143** removes non-vessel-type clutters to classify real blood vessels from the blood vessel candidates. The process of blood vessel classification includes a size test for removing small clutters, a structure-based vessel test that removes non-vessel type by evaluating the goodness of fit (GOF) to a cylindrical tube (i.e., initial vessel test), gradient magnitude analysis and a final vessel test for perfectly removing the clutters. An initial threshold $C_{initial}$ is marginally set such that all blood vessels are included even if some clutters are not removed in the structure-based vessel test. In this embodiment, the initial threshold is set to 0.6. As the final vessel test, the blood vessel extraction unit **143** considers the variation of voxel values (i.e., gradient magnitude), and precisely removes all of the clutters formed by shading artifacts having low gradient magnitudes to extract the blood vessel. In this embodiment, a threshold of the final vessel test is set to 0.4.

[0044] In other embodiments, the blood vessel extraction unit **143** extracts blood vessels by performing the process described above on the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$. Further, the blood vessel extraction unit **143** extracts blood vessel from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ based on the input information (i.e., blood vessel area setting information) provided from the user input unit. More specifically, using the characteristic that blood vessels have brighter pixel value than the tissues in the liver area in the 3-dimensional CT angiography image, the blood vessel extraction unit **143** set a value of 255 only to the pixels having the value between a first threshold (T**1**) and a second threshold (T**2**), and set a value of 0 to the rest of the pixels. This process is referred to as intensity thresholding using two thresholds. As a result of this process, areas that have bright pixel values such as ribs and kidneys other than the object of interest (i.e., blood vessel) are also appeared. To remove these non-vessel regions, the blood vessel extraction unit **143** uses the connectivity of the blood vessels. Typically, the blood vessels within the liver area are composed of the portal vein and hepatic vein. Thus, the blood vessel extraction unit **143** extracts only the blood vessels by entering two specific locations corresponding to each of the blood vessels as seed points and performing the seeded region growing method using the seed points as starting points.

[0045] The diaphragm refining unit **144** refines the diaphragms on the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ by using the blood vessels extracted from the blood vessel extraction unit **143**. More specifically, the diaphragm refining unit **144** removes the clutters by performing refinement of the diaphragm using the blood vessels extracted from the blood vessel extraction unit **143**. The clutters are typically located near the vessel walls in the extracted diaphragm. For example, the inferior vena cava (IVC) is connected to the diaphragm and causes clutters. Since these clutters may degrade the accuracy of the image registration if they are extracted as features and used in the image registration, the diaphragm refining unit **144** enhances the diaphragm by removing the clutters. The diaphragm refining unit **144** extracts the blood vessel regions from the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$, dilates the extracted blood vessel regions, and removes the blood vessels through which the blood is flowing to thereby estimate the vessel walls. The diaphragm refining unit **144** extracts the diaphragm by applying CCA and the size text once more.

[0046] The registration unit **145** sets sample points on anatomical features (i.e., blood vessel region and diaphragm region) for the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images I_{US} $(1 \leqq j \leqq 2)$. The registration unit **145** then performs image registration between the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ using the set sample points to obtain the transform function T_{probe} between the 3-dimensional ultrasound image and the 3-dimensional CT image. Here, the transform function T_{probe} may be represented by a matrix. In this embodiment, the transform function T_{probe} can be obtained by the equation (3).

$$T_{probe} = \underset{X}{\operatorname{argmin}}\left[\frac{1}{N}\sum_{j=1}^{2}\min_{i}\{Dist(I_{US}(t_j), I_{CT}(t_i), X)\}\right] \quad (3)$$

wherein the Dist function is defined as the distance between the corresponding feature points of the 3-dimensional ultrasound image and the 3-dimensional CT image.

[0047] That is, the registration unit **145** defines the dist value with the smallest error between the 3-dimensional ultrasound image at maximum inspiration ($I_{US}(t_1)$) and the 3-dimensional CT image ($I_{CT}(t_i)$) as a first error, and defines the dist value with the smallest error between the 3-dimensional ultrasound image at maximum expiration ($I_{US}(t_2)$) and the 3-dimensional CT image ($I_{CT}(t_i)$) as a second error. Then, the registration unit **145** obtains the transform function T_{probe} by calculating X that makes the smallest sum of the first error and the second error.

[0048] The transform unit **146** generates the transform function T for transforming the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ based on the input information provided from the user input unit **130** and the transform function T_{probe} provided from the registration unit **145**. Then, the transform unit **146** acquires the 2-dimensional CT images $I_{2CT}(t_i)$ $(1 \leqq i \leqq N)$ by applying the generated transform function T to the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$.

[0049] The similarity detection unit **147** detects the similarities between the 2-dimensional ultrasound image and the 2-dimensional CT images $I_{2CT}(t_i)$ $(1 \leqq i \leqq N)$. In this embodiment, the similarities can be detected using cross correlation, mutual information, sum of squared intensity difference (SSID) and the like.

[0050] The CT image selection unit **148** selects a 2-dimensional CT image $I_{2CT}(t_i)$ that has the largest similarity by comparing the similarities detected at the similarity detection unit **147**.

[0051] Referring back to FIG. **1**, the display unit **150** displays the 2-dimensional ultrasound image provided from the ultrasound image forming unit **120** and the 2-dimensional CT

image provided from the processor **140**. In one embodiment, the 2-dimensional ultrasound image and the 2-dimensional CT image can be displayed in an overlapping manner. In other embodiments, the 2-dimensional ultrasound image and the 2-dimensional CT image can be displayed top and bottom or left and right on the same screen.

[0052] In the following, the process of providing the 2-dimensional CT image corresponding to the 2-dimensional ultrasound image by performing the image registration between the 3-dimensional CT image and the 3-dimensional ultrasound image with reference to the accompanying drawings. It is explained to automatically extract the diaphragm and the blood vessel from the 3-dimensional CT image for the brevity of the description. However, the present invention is not limited thereto.

[0053] Referring to FIG. **6**, the CT image forming unit **110** forms 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$ at a predetermined interval during a respiratory cycle from inspiration to expiration (S**102**).

[0054] The interpolation unit **141** of the processor **140** performs interpolation between the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq K)$ provided from the CT image forming unit **110** to acquire 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ (S**104**).

[0055] Once the ultrasound probe **122** is fixed at the ultrasound probe holder **126** (S**106**), the ultrasound image forming unit **120** forms the 3-dimensional ultrasound image of the object of interest inside the target object at maximum inspiration ($I_{US}(t_1)$) and the 3-dimensional ultrasound image of the object of interest inside the target object at maximum expiration ($I_{US}(t_2)$) (S**108**).

[0056] The processor **140** extracts anatomical features (e.g., blood vessel and diaphragm) from the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$ (S**110**).

[0057] The registration unit **145** of the processor **140** sets sample points on anatomical features (i.e., blood vessel region and diaphragm region) for the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_j)$ $(1 \leqq j \leqq 2)$. The registration unit **145** then performs image registration between the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ and the 3-dimensional ultrasound images $I_{US}(t_i)$ $(1 \leqq j \leqq 2)$ using the set sample points to obtain the transform function T_{probe} between the 3-dimensional ultrasound image and the 3-dimensional CT image (S**112**).

[0058] Upon receiving the input information (i.e., reference plane setting information) through the user input unit **130** (S**114**), the ultrasound image forming unit **120** forms the 2-dimensional ultrasound image of the section corresponding to the input information (S**116**).

[0059] The transform unit **146** of the processor **140** generates transform function T for transforming the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ based on the input information (i.e., reference plane setting information) provided from the user input unit **130** and the transform function T_{probe} provided from the registration unit **145**. Then, the transform unit **146** acquires the 2-dimensional CT images $I_{2CT}(t_i)$ $(1 \leqq i \leqq N)$ by applying the generated transform function T to the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ (S**118**).

[0060] More specifically, the transform unit **146** obtains a transform function T_{plane} representing the location of the 2-dimensional ultrasound image on the 3-dimensional ultrasound images I_{US} $(1 \leqq j \leqq N)$ (i.e., location of ultrasound probe **122** for 2-dimensional ultrasound image) based on the input information provided from the user input unit **130**. Here, the transform function T_{plane} can be represented as a matrix. The transform unit **146** generates a transform function T for transforming the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$ using the transform function T_{probe} and the transform function T_{plane}. In this embodiment, the transform unit **146** can generate the transform function T by multiplying the transform function T_{probe} by the transform function T_{plane}. The transform unit **146** acquires the 2-dimensional CT images $I_{2CT}(t_I)$ $(1 \leqq i \leqq N)$ by applying the transform function T to each of the 3-dimensional CT images $I_{CT}(t_i)$ $(1 \leqq i \leqq N)$.

[0061] The similarity detection unit **147** of the processor **140** detects the similarities between the 2-dimensional ultrasound image provided from the ultrasound image forming unit **120** and the 2-dimensional CT images $I_{2CT}(t_i)$ $(1 \leqq i \leqq N)$ provided from the transform unit **146** (S**120**).

[0062] The CT image selection unit **148** selects a 2-dimensional CT image $I_{2CT}(t_i)$ that has the largest similarity by comparing the similarities detected at the similarity detection unit **147** (S**122**). The display unit **150** displays the 2-dimensional ultrasound image provided from the ultrasound image forming unit **120** and the 2-dimensional CT image provided from the CT image selection unit **148** (S**124**).

[0063] While the present invention is described via some preferred embodiments, it will be appreciated by those skilled persons in the art that many modifications and changes can be made without departing the spirit and scope of the appended claims.

What is claimed is:

1. An image providing system, comprising:

a CT image forming unit configured to form a plurality of 3-dimensional CT images for an object of interest inside a target object;

an ultrasound image forming unit configured to form at least one 3-dimensional ultrasound image for the object of interest;

a processor configured to perform an image registration between the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a first transform function; and

a user input unit configured to receive input information from a user,

wherein the ultrasound image forming unit is further configured to form a 2-dimensional ultrasound image from the at least one 3-dimensional ultrasound image based on the input information, and wherein the processor is further configured to obtain a plurality of 2-dimensional CT images from the plurality of 3-dimensional CT images based on the input information and the first transform function and to detect similarities between the 2-dimensional ultrasound image and the plurality of 2-dimensional CT images to select one of the 2-dimensional CT images corresponding to the 2-dimensional ultrasound image.

2. The system of claim **1**, wherein the input information comprises reference plane setting information that sets a reference plane in the at least one 3-dimensional ultrasound image across which the 2-dimensional ultrasound image will be obtained.

3. The system of claim **1**, wherein the CT image forming unit is further configured to form each of the 3-dimensional CT images during a respiratory cycle from inspiration to expiration.

4. The system of claim 3, wherein the at least one 3-dimensional ultrasound image comprises at least one of a 3-dimensional ultrasound image acquired at maximum inspiration and a 3-dimensional ultrasound image acquired at maximum expiration.

5. The system of claim 1, wherein the processor comprises:

a diaphragm extraction unit configured to extract diaphragms from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

a blood vessel extraction unit configured to extract blood vessels from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

a diaphragm refining unit configured to remove clutters from the diaphragms based on the blood vessels to refine the diaphragm for the at least one 3-dimensional ultrasound image;

a registration unit configured to set sample points on the blood vessels and the diaphragms for the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image, the registration unit being further configured to perform an image registration between the 3-dimensional CT images and the at least one 3-dimensional ultrasound image based on the sample points to obtain the first transform function;

a transform unit configured to obtain the 2-dimensional CT images from the 3-dimensional CT images based on the input information and the first transform function;

a similarity detection unit configured to detect the similarities between the 2-dimensional ultrasound image and the plurality of 2-dimensional CT images; and

a CT image selection unit configured to select a 2-dimensional CT image having the largest similarity among the similarities.

6. The system of claim 5, wherein the processor further comprises an interpolation unit configured to perform interpolation among the plurality of 3-dimensional CT images.

7. The system of claim 5, wherein the diaphragm extraction unit is configured to:

calculate a degree of flatness of each of voxels of the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a flatness map including degrees of flatness of the voxels;

select voxels having a higher degree of flatness than a reference value based on the flatness map to provide a 3-dimensional area comprising the selected voxels;

remove a predetermined number of morphological edge voxels from the selected voxels to contract the 3-dimensional area and expand the contracted 3-dimensional area by the predetermined number of morphological edge with voxels having a predetermined intensity to thereby remove the clutters;

obtain a plurality of candidate areas from the 3-dimensional area based on a intensity-based connected component analysis (CCA); and

select a largest area from the plurality of candidate areas to extract the diaphragm.

8. The system of claim 5, wherein the blood vessel extraction unit is configured to:

extract the blood vessels from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

model the diaphragm as a polynomial curved surface to set region of interest (ROI) masking on the plurality of 3-dimensional CT image and the at least one 3-dimensional ultrasound image;

remove voxels having higher intensity than a reference bound value from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to select vessel candidates; and

remove non-vessel type clutters from the selected vessel candidates to classify real blood vessels.

9. The system of claim 5, wherein the input information comprises diaphragm region setting information which sets diaphragm regions on the plurality of 3-dimensional CT images and blood vessel region setting information which sets blood vessel regions on the plurality of 3-dimensional CT images.

10. The system of claim 9, wherein the diaphragm extraction unit is configured to:

extract the diaphragms from the plurality of 3-dimensional CT images based on the diaphragm region setting information;

calculate a degree of flatness of each of voxels of the at least one 3-dimensional ultrasound image to obtain a flatness map comprising degrees of flatness of the voxels;

select the voxels having higher degree of flatness than a reference value based on the flatness map to provide a 3-dimensional area comprising the selected voxels;

remove a predetermined number of morphological edge voxels from the selected voxels to contract the 3-dimensional area and expand the contracted 3-dimensional area by the predetermined number of morphological edge with voxels having a predetermined intensity to thereby remove the clutters;

obtain a plurality of candidate areas from the 3-dimensional area based on a intensity-based connected component analysis (CCA); and

select a largest area from the plurality of candidate areas to extract the diaphragm.

11. The system of claim 9, wherein the blood vessel extraction unit is configured to:

extract the blood vessels from the plurality of 3-dimensional CT images based on the blood vessel setting information;

extract the blood vessels from the at least one 3-dimensional ultrasound image;

model the diaphragm as a polynomial curved surface to set region of interest (ROI) masking on the at least one 3-dimensional ultrasound image;

remove voxels having higher intensity than a reference bound value from the at least one 3-dimensional ultrasound image to select vessel candidates; and

remove non-vessel type clutters from the selected vessel candidates to classify real blood vessels.

12. The system of claim 5, wherein the blood vessel extraction unit is configured to perform a structure-based vessel test, a gradient magnitude analysis, and a final vessel test for removing a non-vessel type clutters.

13. The system of claim 5, wherein the transform unit is configured to:

generate a second transform function representative of a location of the 2-dimensional ultrasound image on the at least one 3-dimensional ultrasound image based on the input information;

generate a third transform function to transform the plurality of 3-dimensional CT images based on the first transform function and the second transform function; and

apply the third transform function to the plurality of 3-dimensional CT images to obtain the plurality of 2-dimensional CT images.

14. The system of claim **5**, wherein the similarity detection unit is configured to calculate the similarities using one of cross correlation, mutual information and sum of squared intensity difference (SSID).

15. A method of providing an image, comprising:

forming a plurality of 3-dimensional CT images for an object of interest inside a target object;

forming at least one 3-dimensional ultrasound image for the object of interest;

performing image registration between the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a first transform function;

receiving input information from a user;

forming a 2-dimensional ultrasound image from the at least one 3-dimensional ultrasound image based on the input information;

obtaining a plurality of 2-dimensional CT images from the plurality of 3-dimensional CT images based on the input information and the first transform function; and

detecting similarities between the 2-dimensional ultrasound image and the plurality of 2-dimensional CT images to select one of the 2-dimensional CT images corresponding to the 2-dimensional ultrasound image.

16. The method of claim **15**, wherein the input information comprises reference plane setting information that sets a reference plane in the at least one 3-dimensional ultrasound image across which the 2-dimensional ultrasound image will be obtained.

17. The method of claim **15**, wherein forming a plurality of 3-dimensional CT images further comprises performing interpolation among the plurality of 3-dimensional CT images.

18. The method of claim **17**, wherein forming a plurality of 3-dimensional CT images further comprises forming each of the plurality of 3-dimensional CT images during a respiratory cycle from inspiration to expiration.

19. The method of claim **18**, wherein the at least 3-dimensional ultrasound image comprises at least one of a 3-dimensional ultrasound image acquired at maximum inspiration and a 3-dimensional ultrasound image acquired at maximum expiration.

20. The method of claim **15**, wherein performing image registration comprises:

extracting diaphragms from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

extracting blood vessels from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

removing clutters from the diaphragms based on the blood vessels to refine the diaphragms for the at least one 3-dimensional ultrasound image;

setting sample points on the blood vessels and the diaphragms for the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image; and

performing image registration between the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image based on the sample points to obtain the first transform function.

21. The method of claim **20**, wherein extracting diaphragms comprises:

calculating a degree of flatness of each of voxels of the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to obtain a flatness map including degrees of flatness of the voxels;

selecting voxels having a higher degree of flatness than a reference value based on the flatness map to provide a 3-dimensional area comprising the selected voxels;

removing a predetermined number of morphological edge from the selected voxels to contract or eliminate the 3-dimensional area and expanding the contracted 3-dimensional area by the predetermined number of morphological edge with voxels having a predetermined intensity to thereby remove the clutters;

obtaining a plurality of candidate areas from the 3-dimensional area based on a intensity-based connected component analysis (CCA); and

selecting a largest area from the plurality of candidate areas to extract the diaphragm.

22. The method of claim **20**, wherein extracting blood vessels comprises:

extracting the blood vessels from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image;

modeling the diaphragms as a polynomial curved surface to set region of interest (ROI) masking on the plurality of 3-dimensional CT image and the at least one 3-dimensional ultrasound image;

removing voxels having higher intensity than a reference bound value from the plurality of 3-dimensional CT images and the at least one 3-dimensional ultrasound image to select vessel candidates; and

removing non-vessel type clutters from the selected vessel candidates to classify real blood vessels.

23. The method of claim **20**, further comprising, prior to performing image registration, receiving diaphragm region setting information which sets diaphragm regions on the plurality of 3-dimensional CT images and blood vessel region setting information which sets blood vessel regions on the plurality of 3-dimensional CT images.

24. The method of claim **23**, wherein extracting a diaphragm comprises:

extracting the diaphragms from the plurality of 3-dimensional CT images based on the diaphragm region setting information;

calculating a degree of flatness of each of voxels of the plurality of at least one 3-dimensional ultrasound image to obtain a flatness map including degrees of flatness of the voxels;

selecting voxels having a higher degree of flatness than a reference value based on the flatness map to provide a 3-dimensional area comprising the selected voxels;

removing a predetermined number of morphological edge voxels from the selected voxels to contract or eliminate the 3-dimensional area and expand the contracted 3-dimensional area by the predetermined number of morphological edge with voxels having a predetermined intensity to thereby remove the clutters;

obtaining a plurality of candidate areas from the 3-dimensional area based on a intensity-based connected component analysis (CCA); and

selecting a largest surface from the plurality of candidate areas to extract the diaphragm.

25. The method of claim **23**, wherein extracting a blood vessel comprises:

extracting the blood vessels from the plurality of 3-dimensional CT images based on the blood vessel setting information; and

extracting the blood vessels from the at least one 3-dimensional ultrasound image,

wherein the extracting the blood vessels from the at least one 3-dimensional ultrasound image further comprises:

modeling the diaphragm as a polynomial curved surface to set region of interest (ROI) masking on the at least one 3-dimensional ultrasound image;

removing voxels having higher intensity than a reference bound value from the at least one 3-dimensional ultrasound image to select vessel candidates; and

removing non-vessel type clutters from the selected vessel candidates to classify real blood vessels.

26. The method of claim **20**, wherein performing image registration further comprises performing a structure-based vessel test, a gradient magnitude analysis, and a final vessel test for removing the non-vessel type clutters.

27. The method of claim **15**, wherein obtaining a plurality of 2-dimensional CT images comprises:

generating a second transform function representative of a location of the 2-dimensional ultrasound image on the at least one 3-dimensional ultrasound image based on the input information;

generating a third transform function to transform the plurality of 3-dimensional CT images based on the first transform function and the second transform function; and

applying the third transform function to the plurality of 3-dimensional CT images to obtain the plurality of 2-dimensional CT images.

28. The method of claim **15**, wherein detecting similarities comprises:

calculating the similarities using one of cross correlation, mutual information and sum of squared intensity difference (SSID); and

comparing the generated similarities to select the 2-dimensional CT image having largest similarity.

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专利名称(译)	提供对应于2维超声图像的2维CT图像		
公开(公告)号	US20110028843A1	公开(公告)日	2011-02-03
申请号	US12/846528	申请日	2010-07-29
当前申请(专利权)人(译)	三星MEDISON CO.，LTD.		
[标]发明人	HYUN DONG GYU RA JONG BEOM LEE DUHGOON NAM WOO HYUN		
发明人	HYUN, DONG GYU RA, JONG BEOM LEE, DUHGOON NAM, WOO HYUN		
IPC分类号	A61B8/14		
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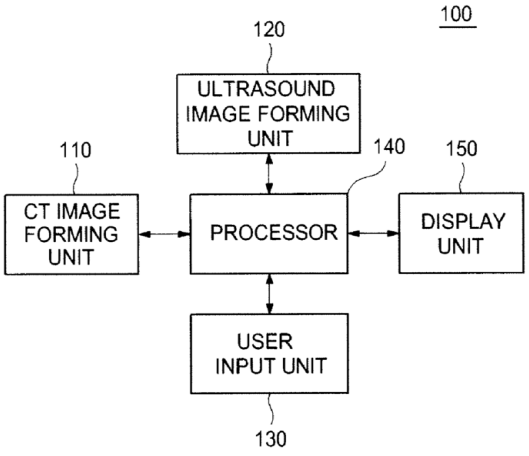
优先权	1020090070981 2009-07-31 KR		
外部链接	Espacenet USPTO		

摘要(译)

公开了一种用于通过在三维超声图像和三维CT图像之间执行图像配准来提供与二维超声图像对应的二维CT图像的系统和方法。该系统包括：CT图像形成单元，被配置为在目标对象内形成用于感兴趣对象的多个三维CT图像;超声图像形成单元，被配置为形成关注对象的至少一个三维超声图像;处理器，被配置为在三维CT图像和至少一个三维超声图像之间执行图像配准，以获得第一变换函数;用户输入单元，被配置为从用户接收输入信息，其中，超声图像形成单元还被配置为基于输入信息从至少一个三维超声图像形成二维超声图像，并且其中，处理器还被配置为基于输入信息和第一变换函数从3维CT图像获得多个2维CT图像，并检测2维超声图像和2维CT图像之间的相似性。选择对应于二维超声图像的二维CT图像之一。