

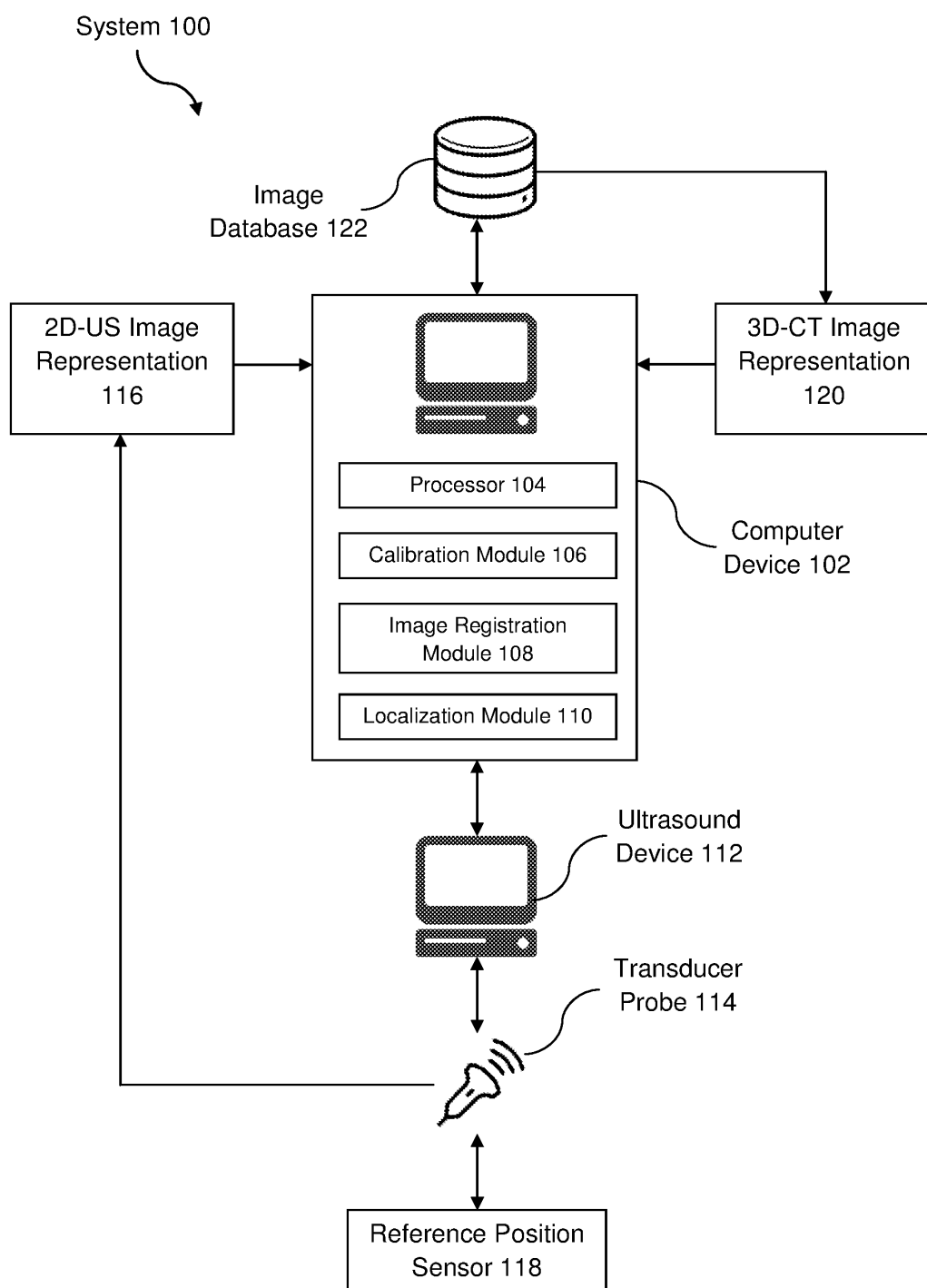


Figure 1

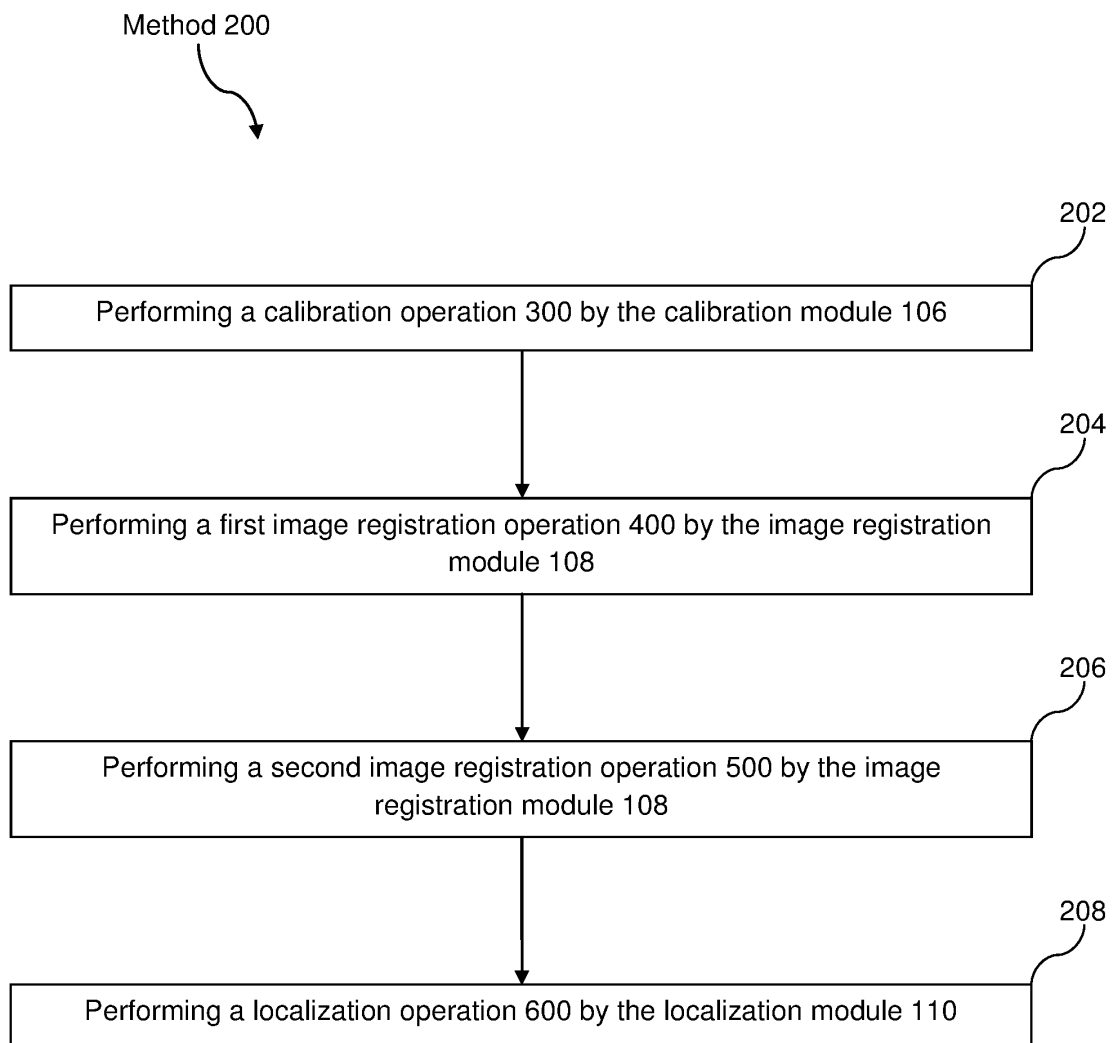


Figure 2

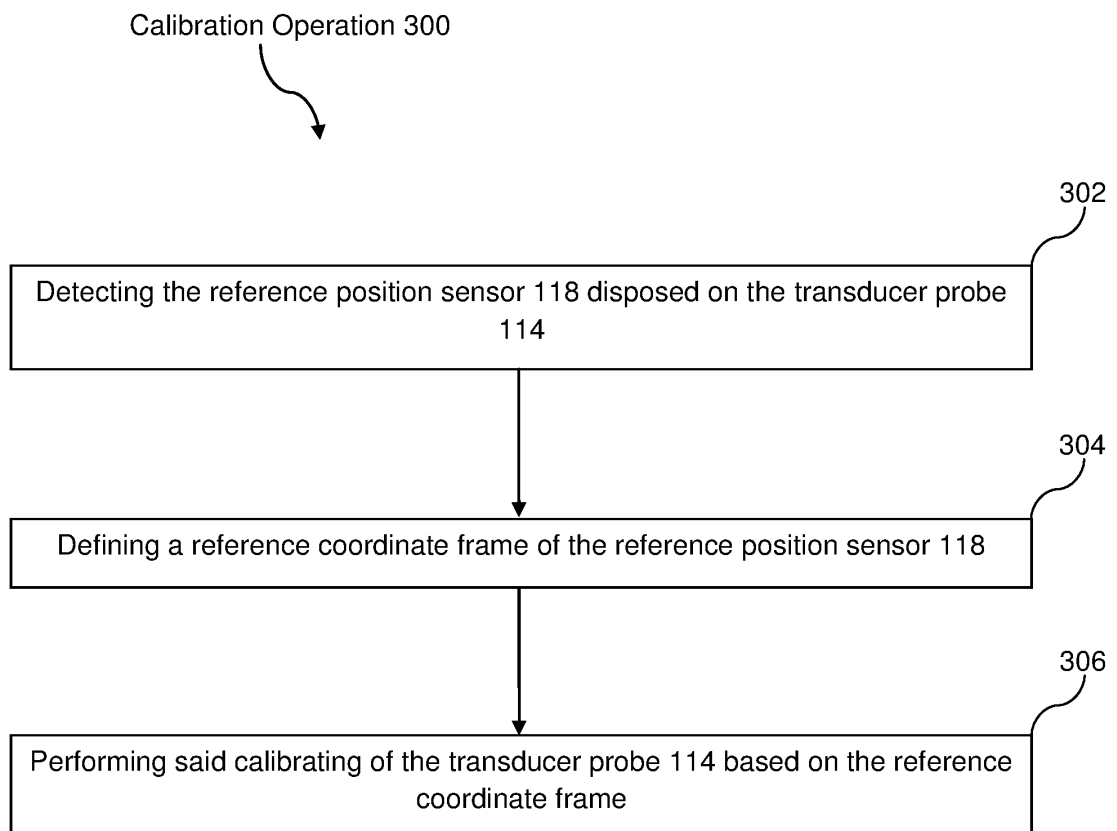


Figure 3

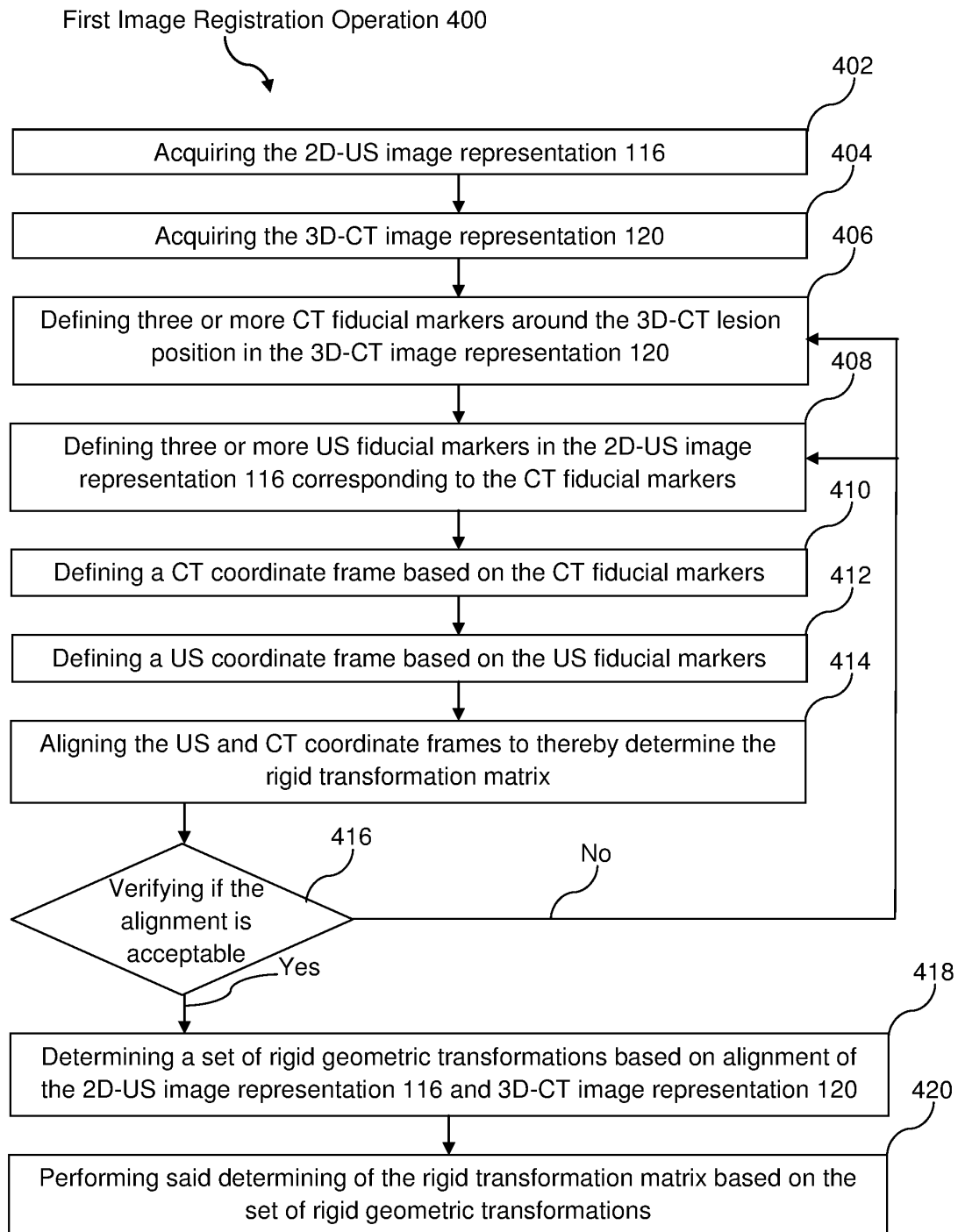


Figure 4A

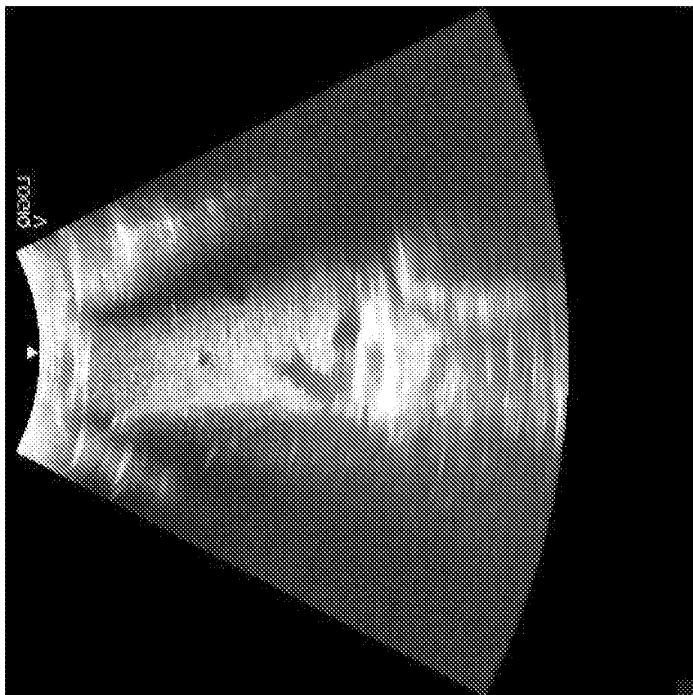


Figure 4B

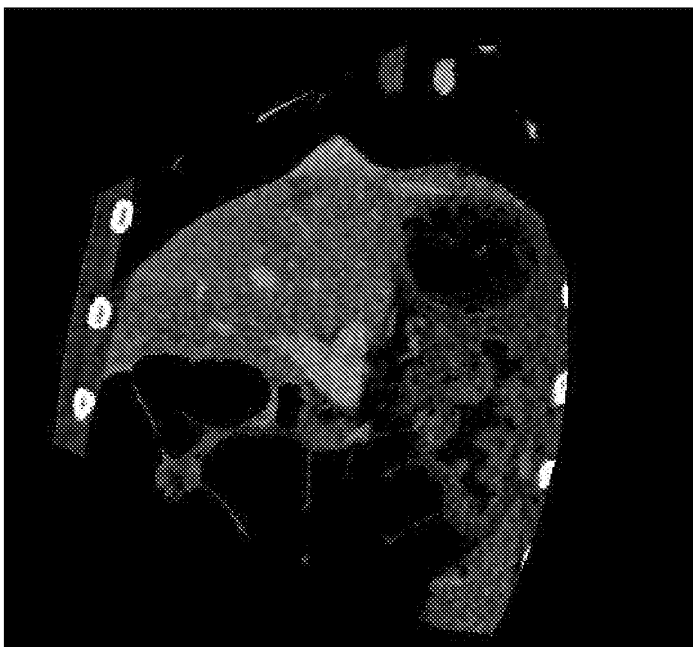


Figure 4C

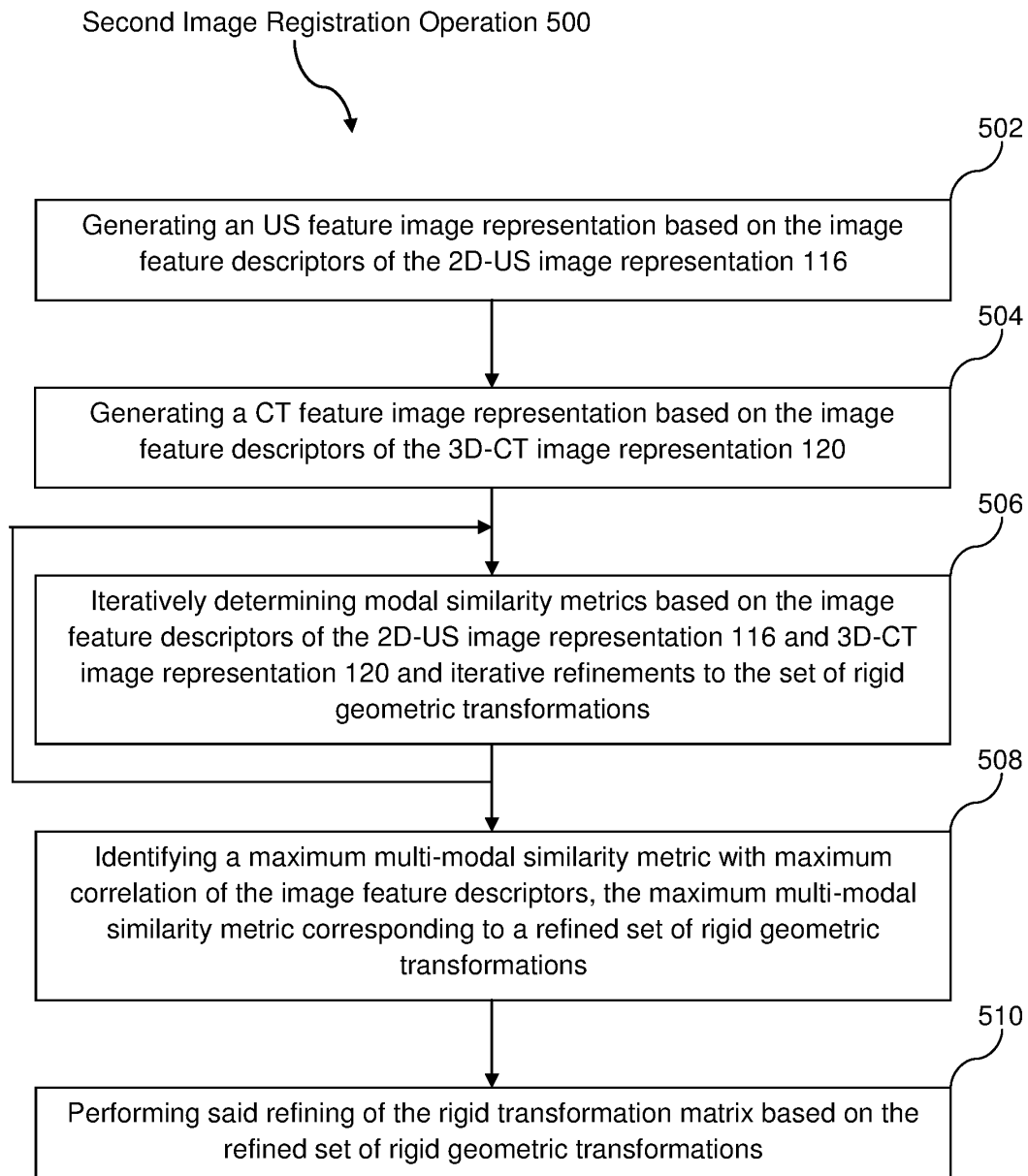


Figure 5A

Second Aligned Image
Representation 126

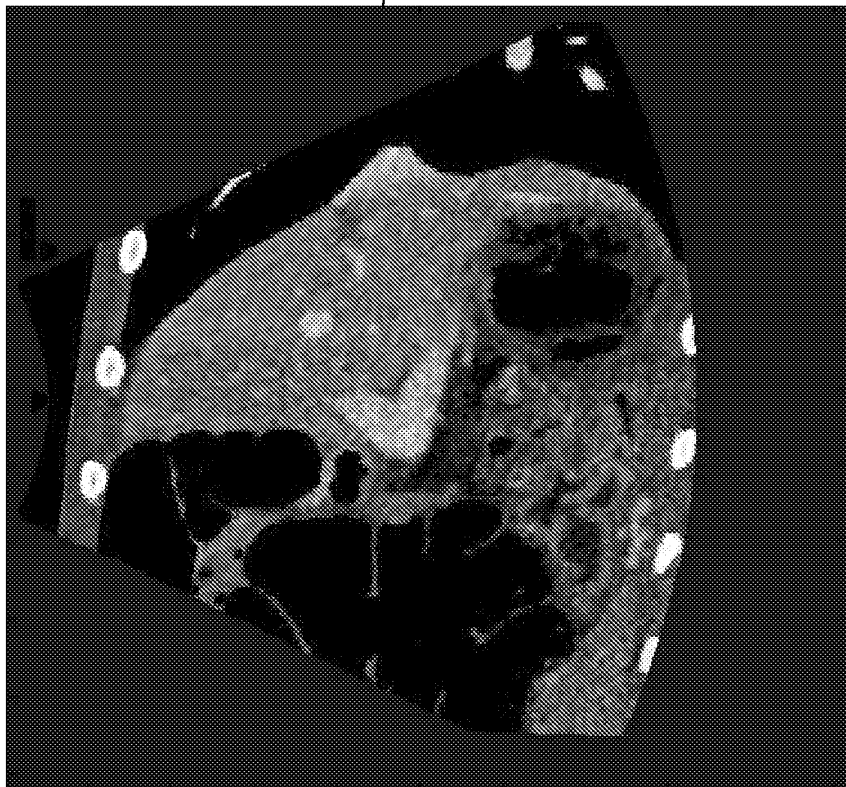


Figure 5B

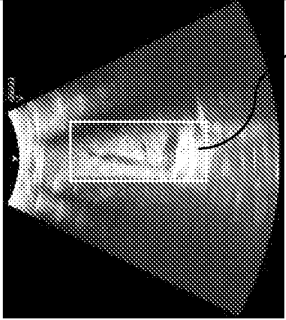
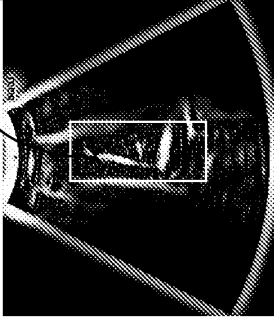
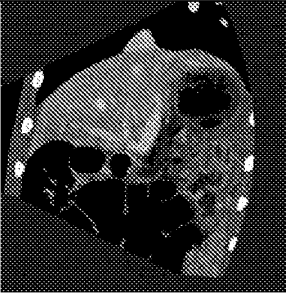
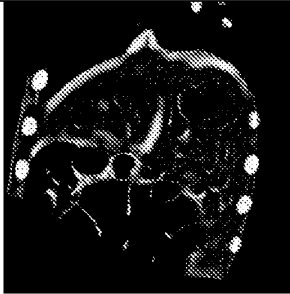
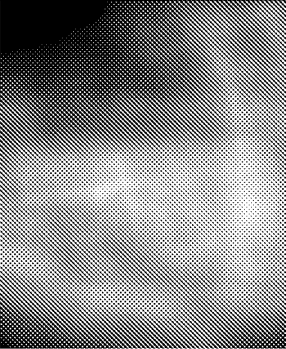
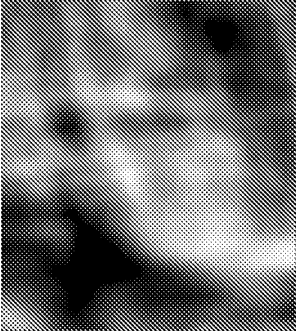
	Density Images	Feature Images
US	 A grayscale ultrasound image showing a fan-shaped field of view. A white rectangular box highlights a region of interest (ROI) in the center. A line points from the label 'ROI' to this box.	 A grayscale ultrasound image showing a fan-shaped field of view. A white rectangular box highlights a region of interest (ROI) in the center, corresponding to the ROI in the density image.
CT	 A grayscale CT scan image showing a cross-section of a body part. The image is noisy and has a grainy texture.	 A grayscale CT scan image showing a cross-section of a body part. The image is noisy and has a grainy texture.
MI	 A grayscale medical image showing a cross-section of a body part. The image is noisy and has a grainy texture.	 A grayscale medical image showing a cross-section of a body part. The image is noisy and has a grainy texture.
CC	 A grayscale medical image showing a cross-section of a body part. The image is noisy and has a grainy texture.	 A grayscale medical image showing a cross-section of a body part. The image is noisy and has a grainy texture.

Figure 5C

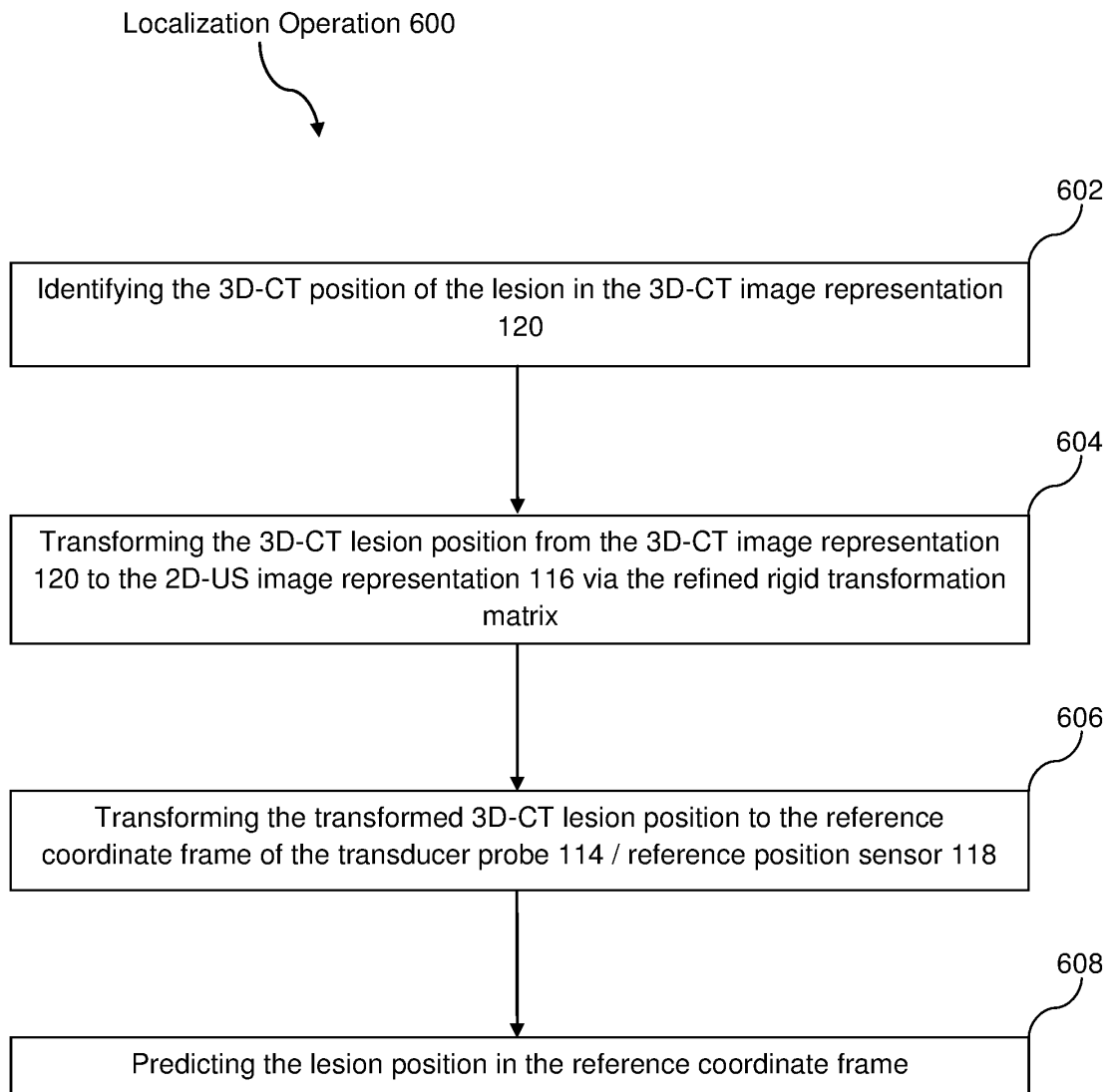


Figure 6

Pseudocode 700

Step 1: Calibrate US to Position Sensor attached on the US probe *Tus2probe*

Step 2: Anatomical fiducial-based Registration

Input US image
Load Tus2probe
Set 3 fiducial points on CT interactively [Pct1, Pct2, Pct3]
Calculate coordinate frame Tct
Set 3 fiducial points on US interactively [Pus1, Pus2, Pus3]
Calculate coordinate frame Tus
*Calculate initial transform matrix Tinit = Tct * Tus*
Calculate US image's correspondence in CT volume
*ImageCT = Tinit*imageUS*

Step 3: Feature image-based refinement

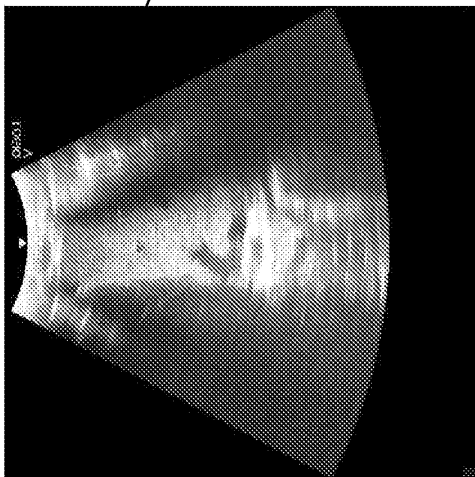
Assume 6 DOF rigid transformation
Random sampling 6 dimensional parameters $\Delta x, \Delta y, \Delta z, \Delta \alpha, \Delta \beta, \Delta \theta$
*Calculate ImageCT $(x, y, z, \alpha, \beta, \theta) = T(x, y, z, \alpha, \beta, \theta) * imageUS$*
Extract feature image of imageCT $(x, y, z, \alpha, \beta, \theta)$ and imageUS
Calculate the similarity metric
 $S_i(x, y, z, \alpha, \beta, \theta) = \text{Corr2} \{F[\text{imageCT}(x, y, z, \alpha, \beta, \theta)], F(\text{imageUS})\}$
Select the parameter that can maximize S_i
 $S_i(x_m, y_m, z_m, \alpha_m, \beta_m, \theta_m) = \max(S_i)$
Calculate transformation matrix $T(x_m, y_m, z_m, \alpha_m, \beta_m, \theta_m)$

Step 4: Tumor position prediction

Read in tumor position in CT volume P_{tumorCT}
Calculate tumor position in position sensor
 *$P_{\text{target}} = Tus2probe * T^{-1}(x_m, y_m, z_m, \alpha_m, \beta_m, \theta_m) * P_{\text{tumorCT}}$*

Figure 7

2D-US Image Representation 116a



3D-CT Image Representation 120a

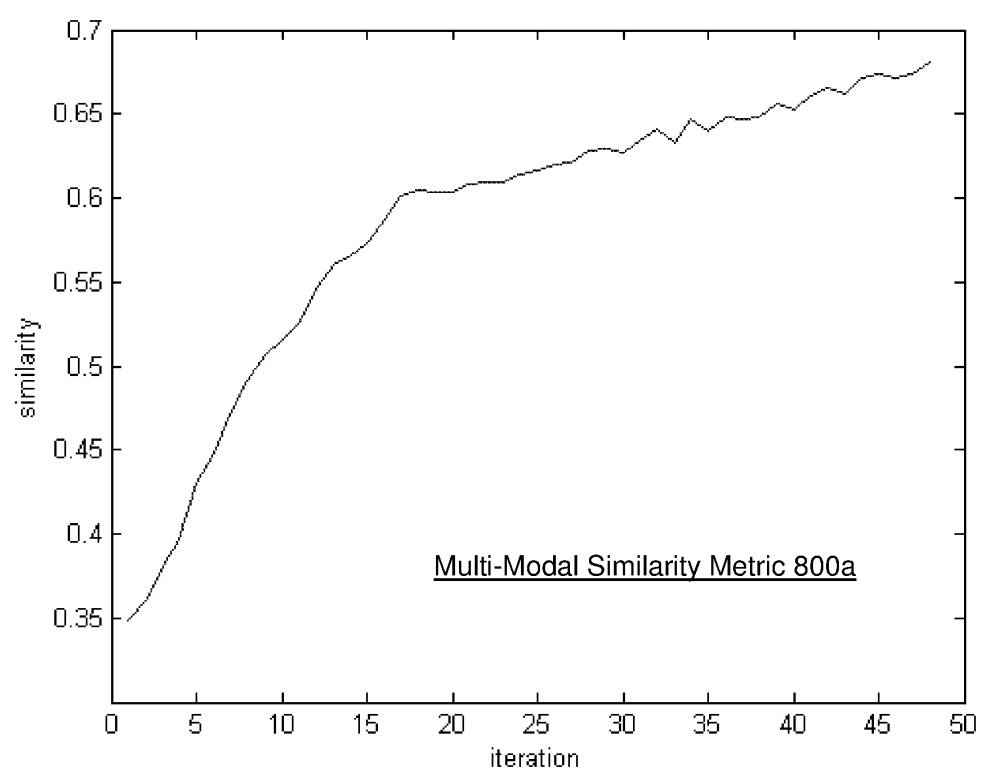
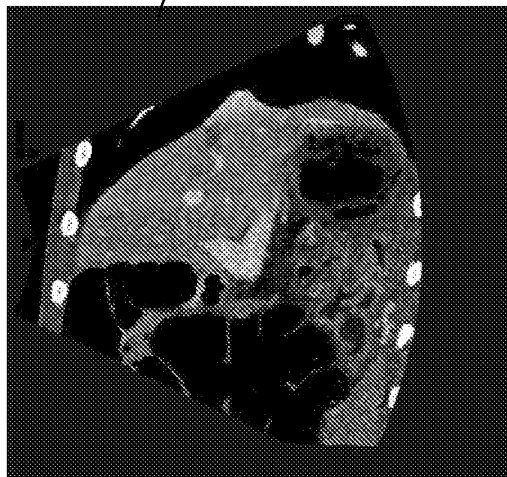


Figure 8A (Inhalation Phase)

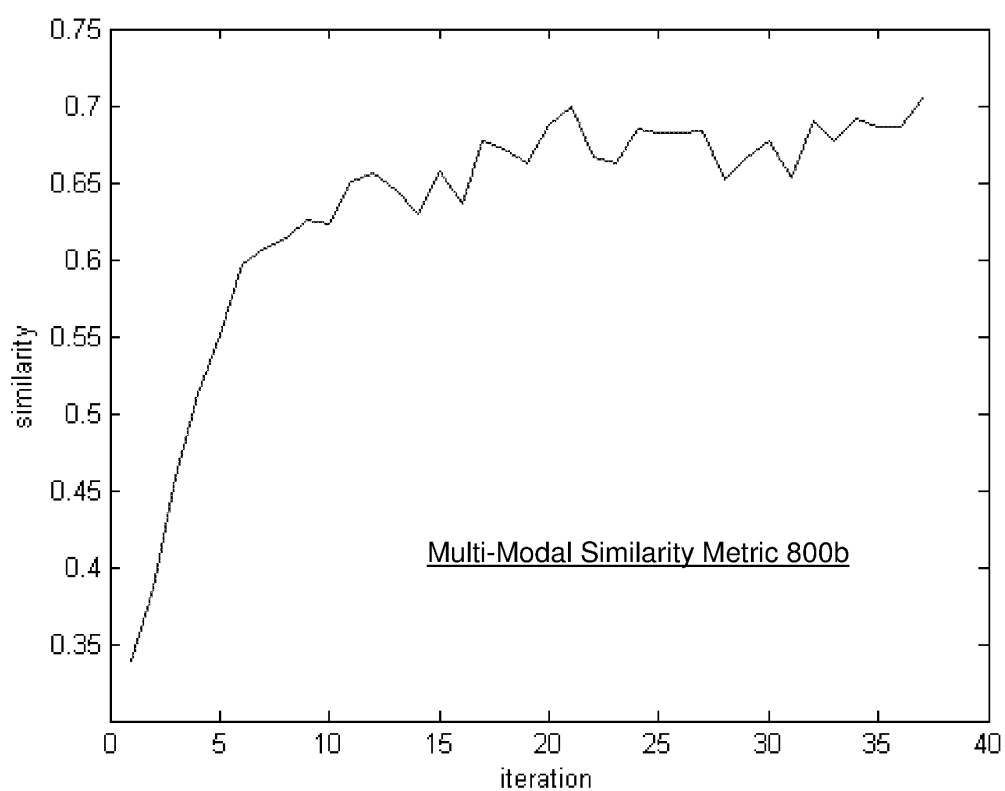
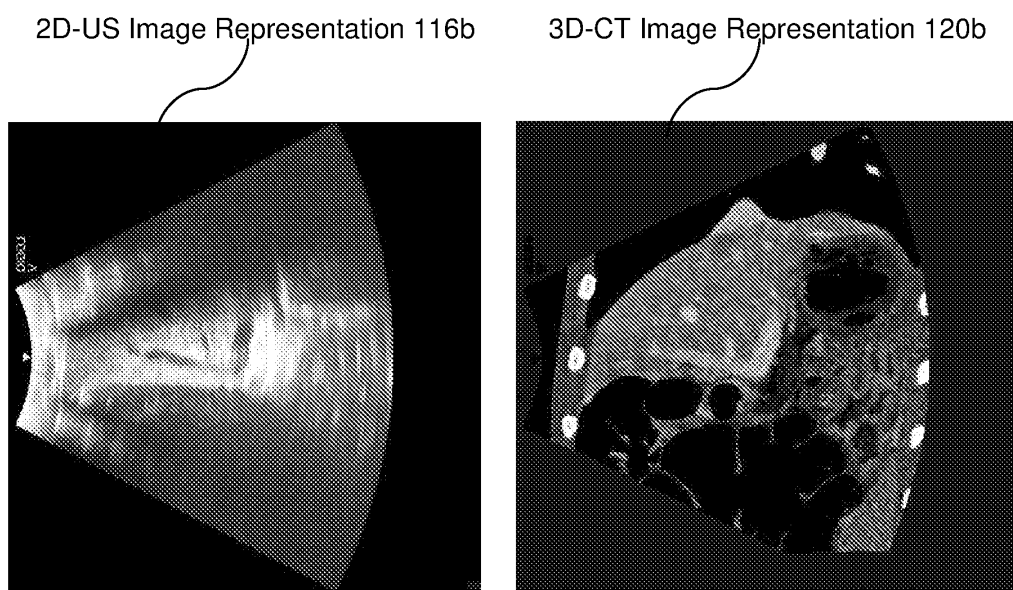


Figure 8B (Exhalation Phase)

Performance Comparison
Table 900

Rank	Method	Organ	Imaging Modality	TRE
1	Local Structure Orientation Descriptor (Reference [20])	Liver	2D-US and 3D-MRI	1.76±1.9 mm
2	Dip Image-Based (Reference [14])	Liver	3D-US and 3D-MRI	3.6 mm
3	Linear Combination (LC ²) Metric-Based (References [18] and [20])	Liver	2D-US and 3D-MRI	5.23±3.35 mm
4	Method 200 of Present Disclosure	Pig Liver	2D-US and 3D-CT	8.02 mm
5	3D-US Reconstruction (Reference [15])	Liver	3D-US and 3D-CT	8.1 mm
6	Shape-Based (Reference [16])	Liver	3D-XA and 3D-CT	9.41±4.13 mm
7	Modality Independent Neighborhood Descriptor (References [17] and [20])	Liver	2D-US and 3D-MRI	9.79±5.03 mm

Figure 9

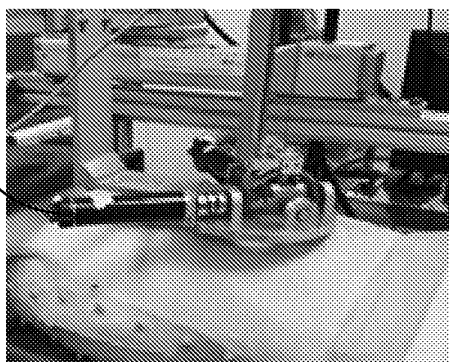
Ablation
Apparatus 128

Figure 10