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(54) **ROBOTIC 5-DIMENSIONAL ULTRASOUND**

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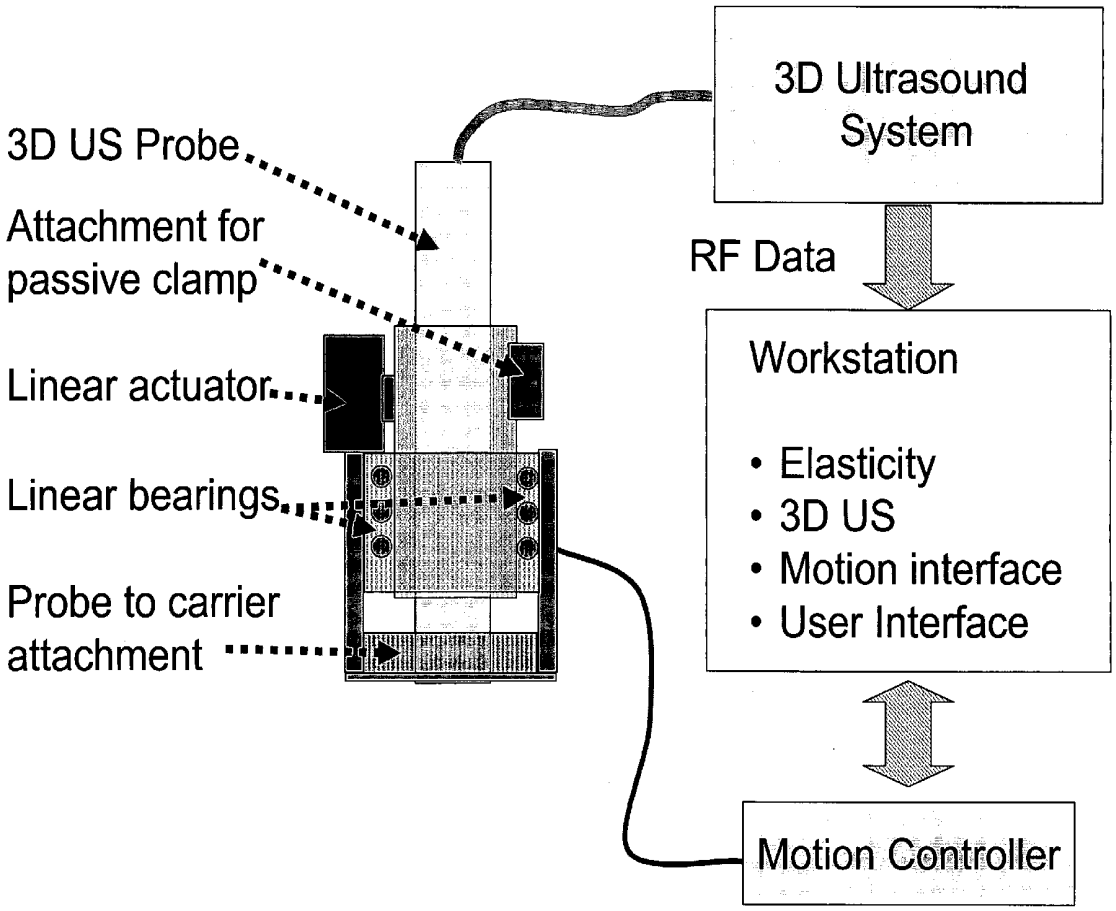
(52) **U.S. Cl.** **600/437**

(57) **ABSTRACT**

A robotic 5D ultrasound system and method, for use in a computer integrated surgical system, wherein 3D ultrasonic image data is integrated over time with strain (i.e., elasticity) image data. By integrating the ultrasound image data and the strain image data, the present invention is capable of accurately identifying a target tissue in surrounding tissue; segmenting, monitoring and tracking the target tissue during the surgical procedure; and facilitating proper planning and execution of the surgical procedure, even where the surgical environment is noisy and the target tissue is isoechoic.



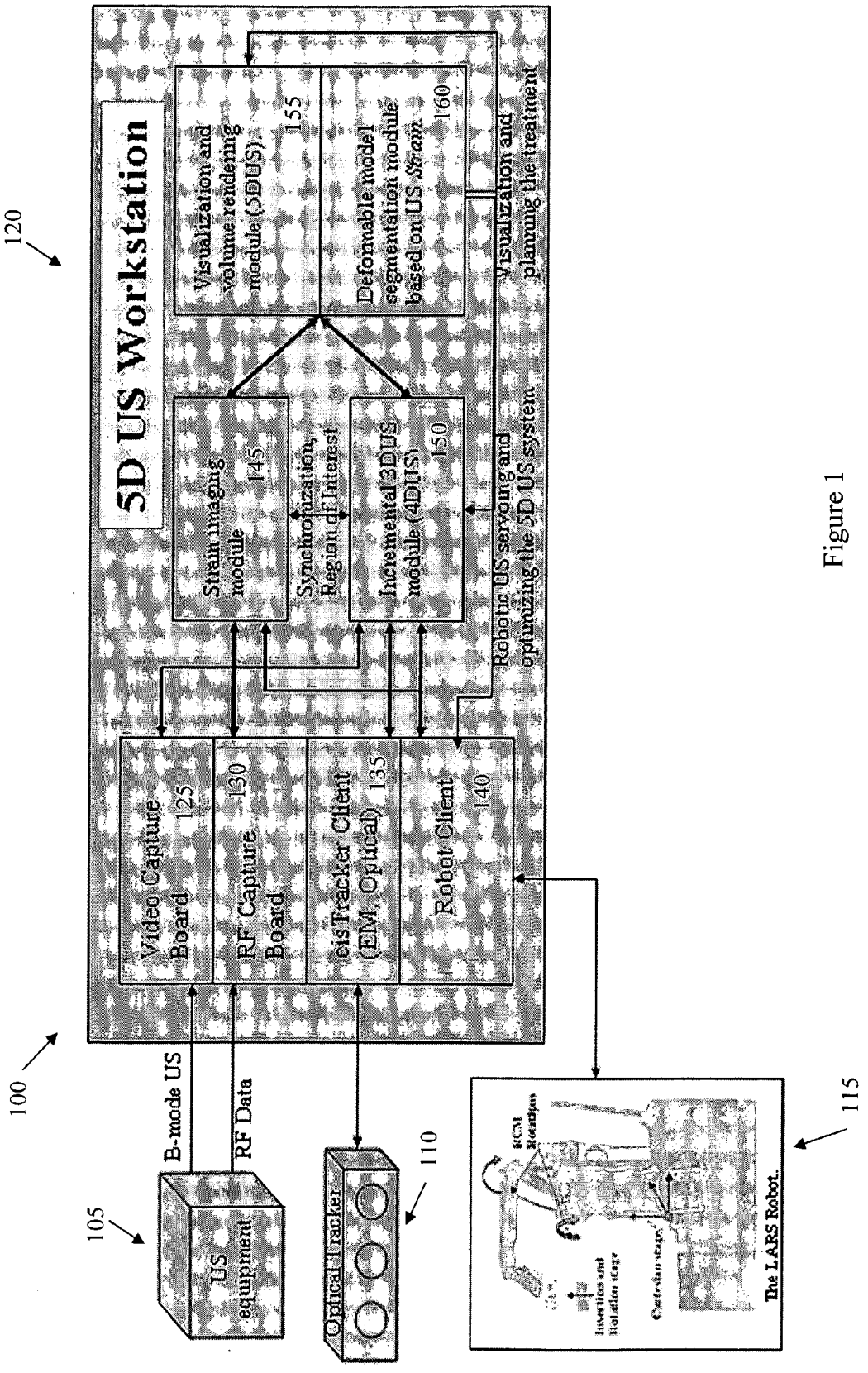

120
5D US Workstation
Visualization and volume rendering module (5DUS) 155
Deformable model segmentation module based on US Scan 160
Strain Imaging module 145
Synchronization, Region of Interest
Incremental 3DUS module (4DUS) 150
Visualization and planning the treatment
Robotic US servoing and optimizing the 5D US system
Video Capture Board 125
RF Capture Board 130
Cis Tracker Client (EM, Optical) 135
Robot Client 140
100
B-mode US
RF Data
105
US equipment
Optical Tracker
110
The LARS Robot.
115

Figure 1

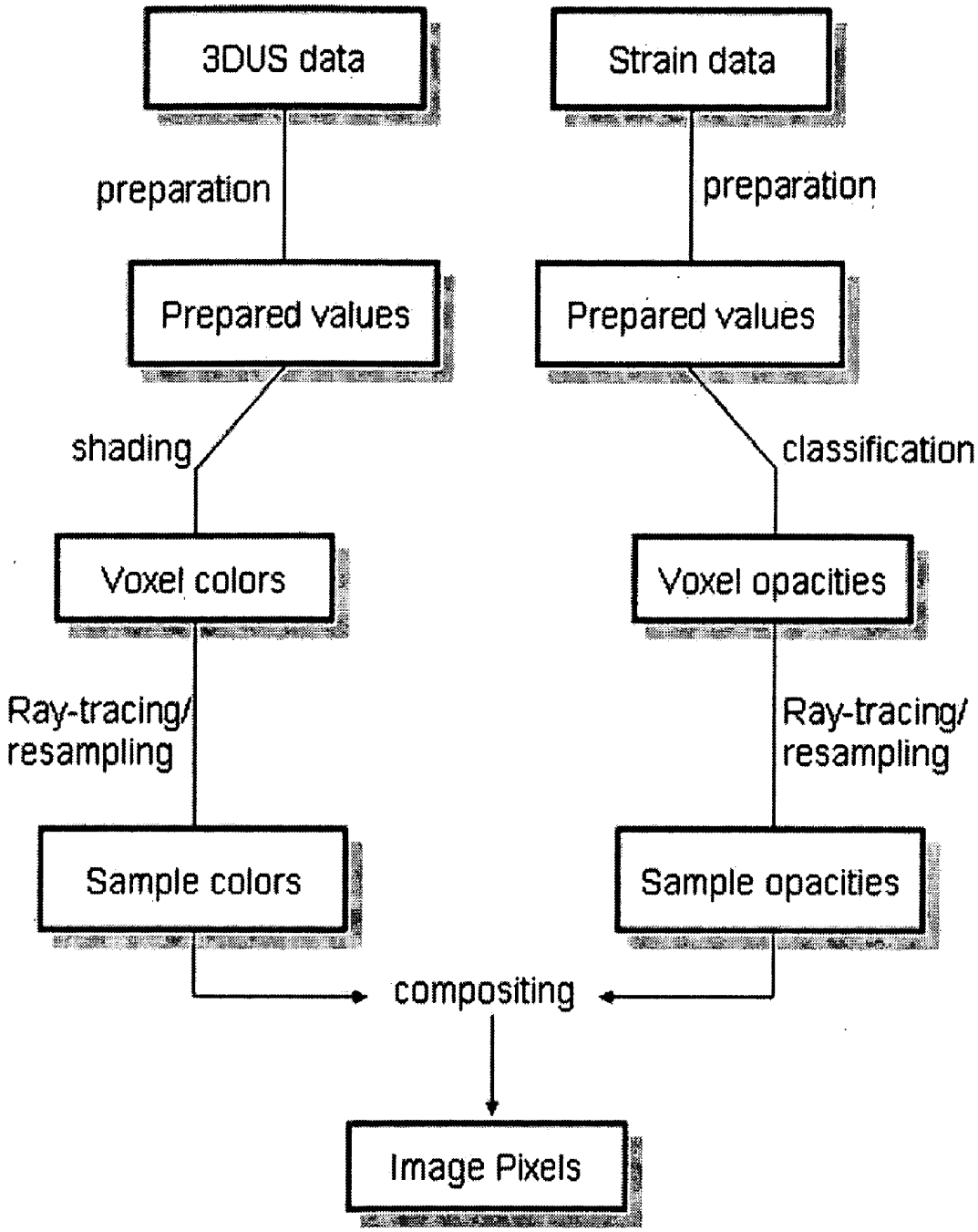

3DUS data
Strain data
preparation
preparation
Prepared values
Prepared values
shading
classification
Voxel colors
Voxel opacities
Ray-tracing/
resampling
Ray-tracing/
resampling
Sample colors
Sample opacities
compositing
Image Pixels

Figure 2

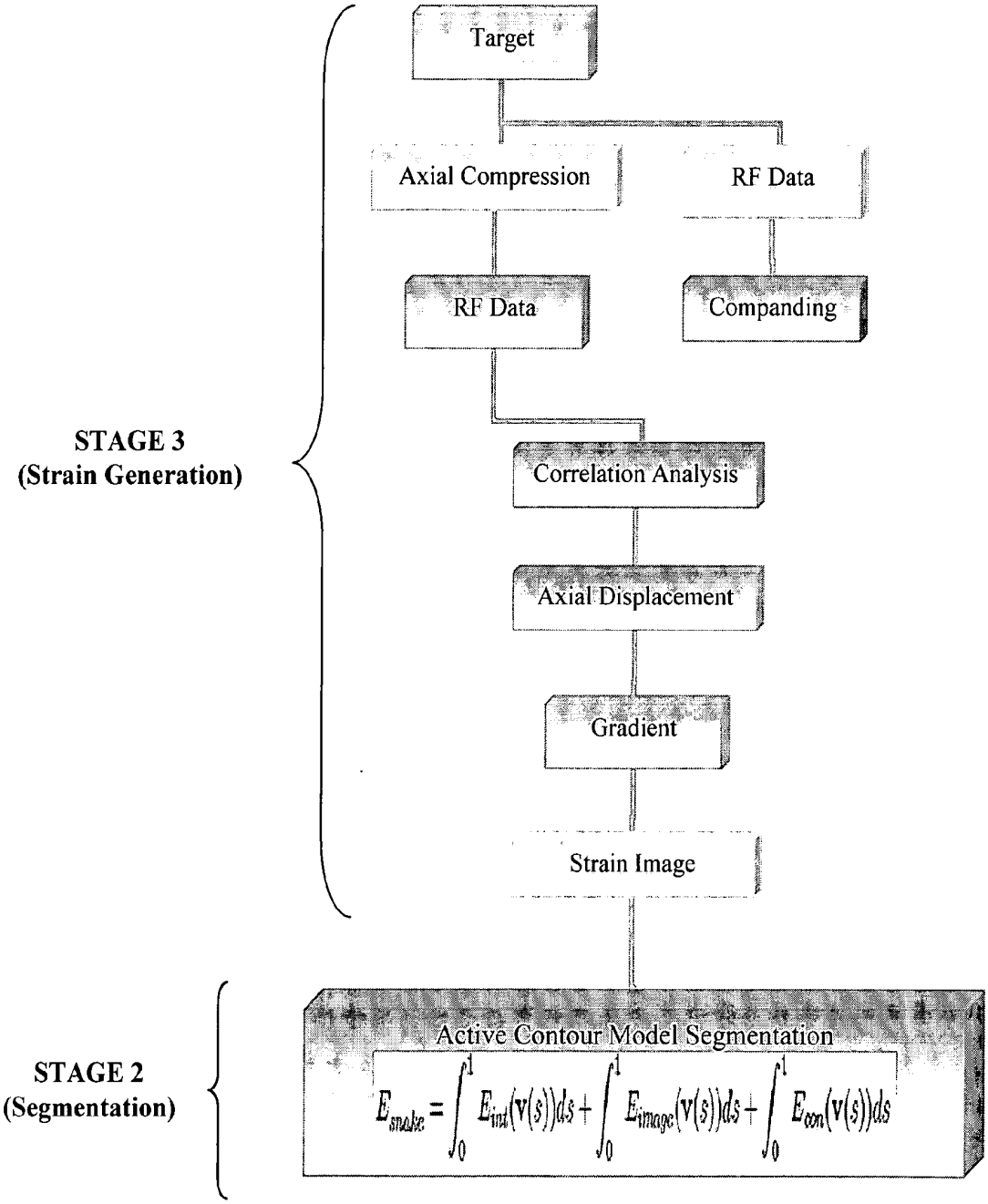

Target
Axial Compression
RF Data
RF Data
Companding
STAGE 3
(Strain Generation)
Correlation Analysis
Axial Displacement
Gradient
Strain Image
STAGE 2
(Segmentation)
Active Contour Model Segmentation
$E_{snake} = \int_0^1 E_{int}(v(s))ds + \int_0^1 E_{image}(v(s))ds + \int_0^1 E_{con}(v(s))ds$

Figure 3

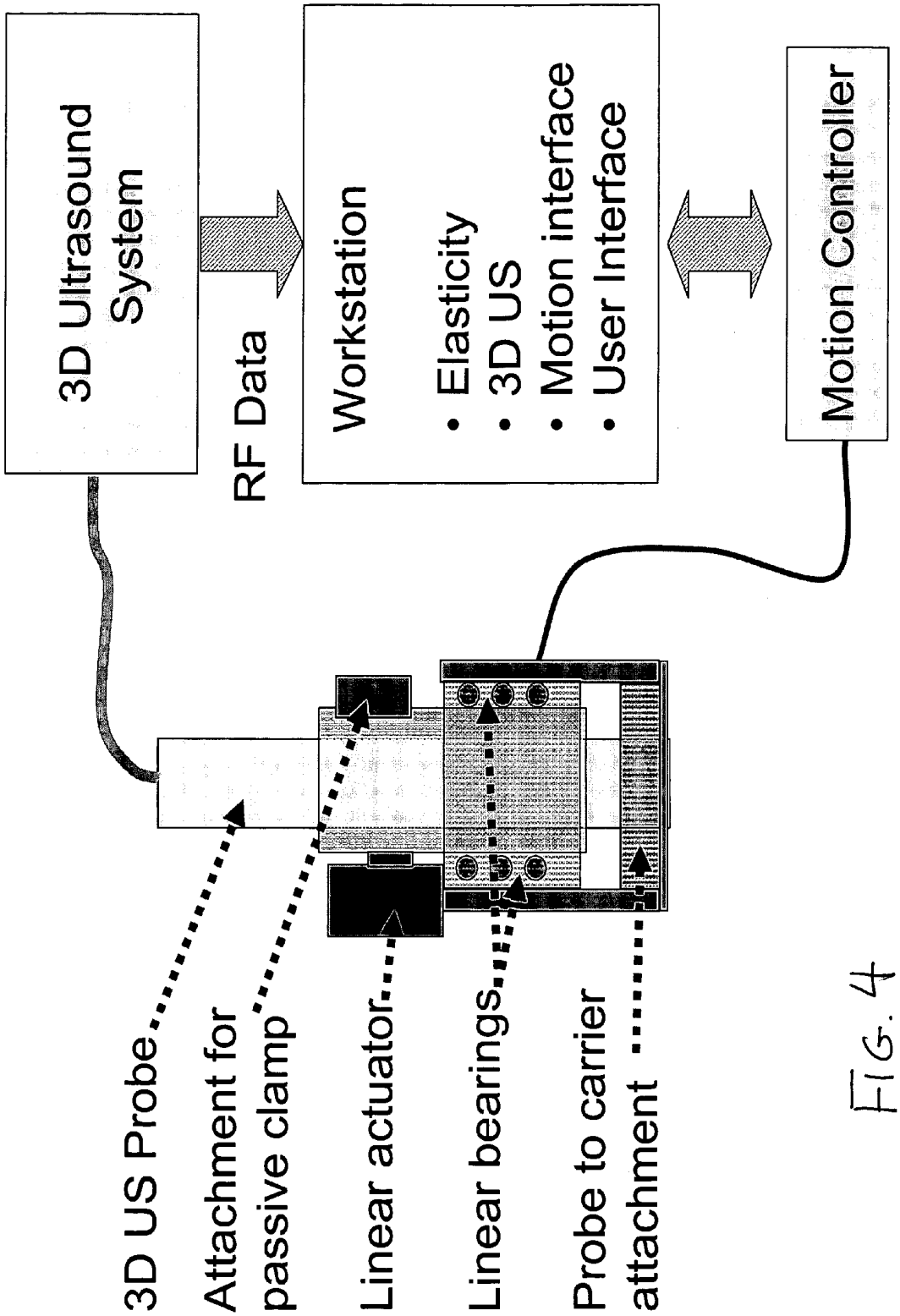

3D Ultrasound System
RF Data
Workstation
• Elasticity
• 3D US
• Motion interface
• User Interface
Motion Controller
3D US Probe
Attachment for passive clamp
Linear actuator
Linear bearings
Probe to carrier attachment

FIG. 4

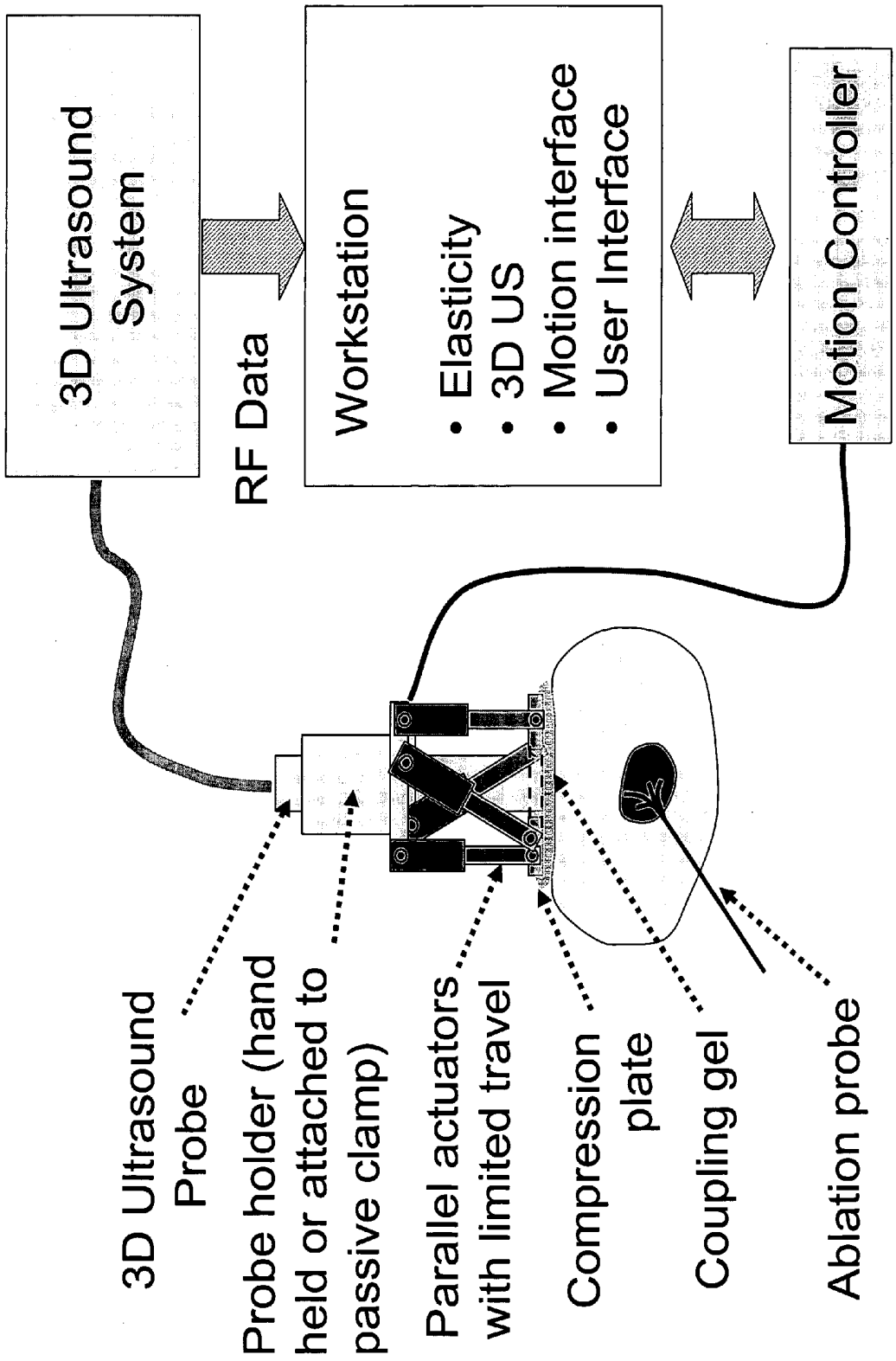

3D Ultrasound System
RF Data
Workstation
• Elasticity
• 3D US
• Motion interface
• User Interface
Motion Controller
3D Ultrasound Probe
Probe holder (hand held or attached to passive clamp)
Parallel actuators with limited travel
Compression plate
Coupling gel
Ablation probe

FIG. 5

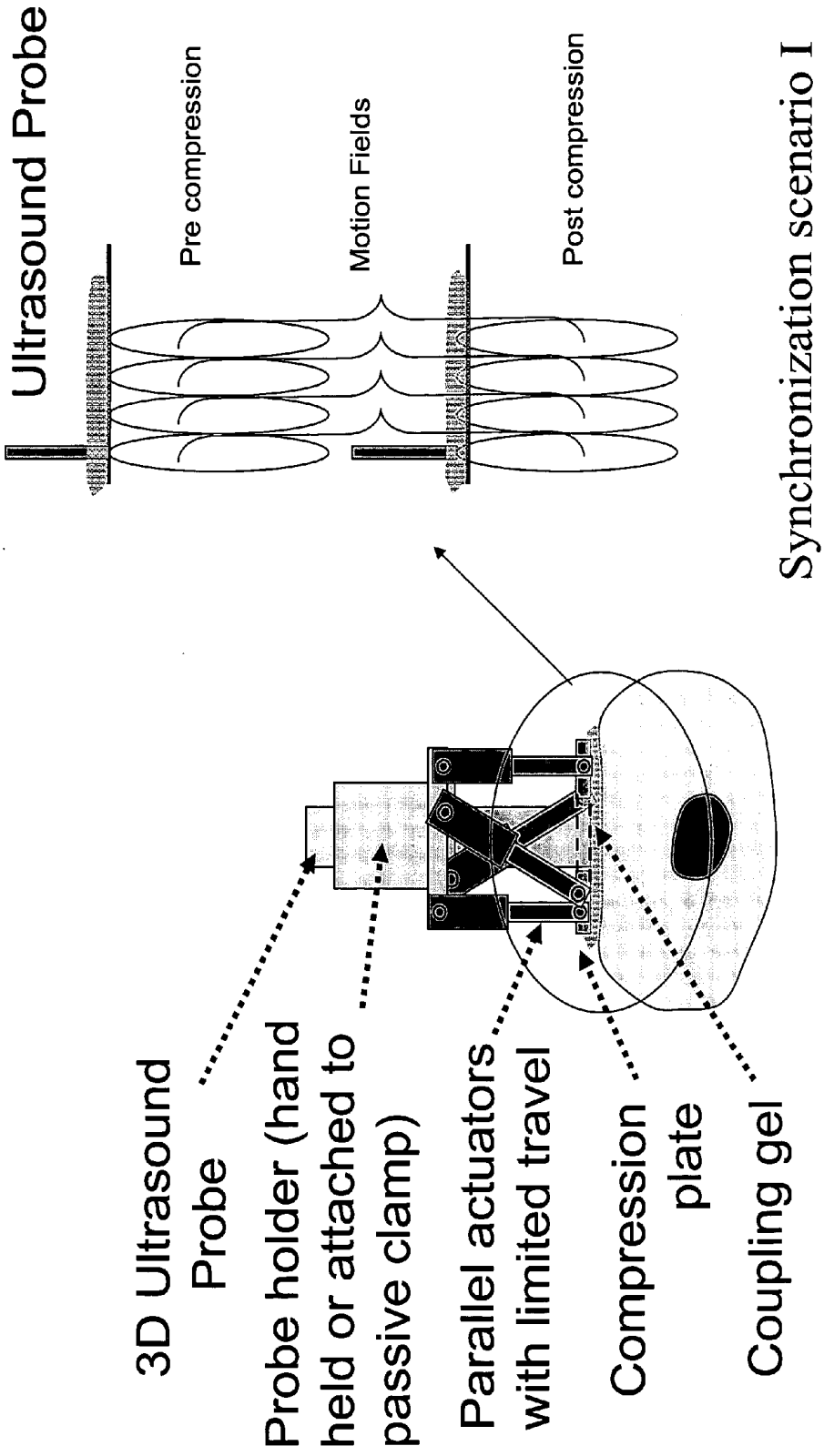

Ultrasound Probe
Pre compression
Motion Fields
Post compression
Synchronization scenario I
3D Ultrasound Probe
Probe holder (hand held or attached to passive clamp)
Parallel actuators with limited travel
Compression plate
Coupling gel

FIG. 6

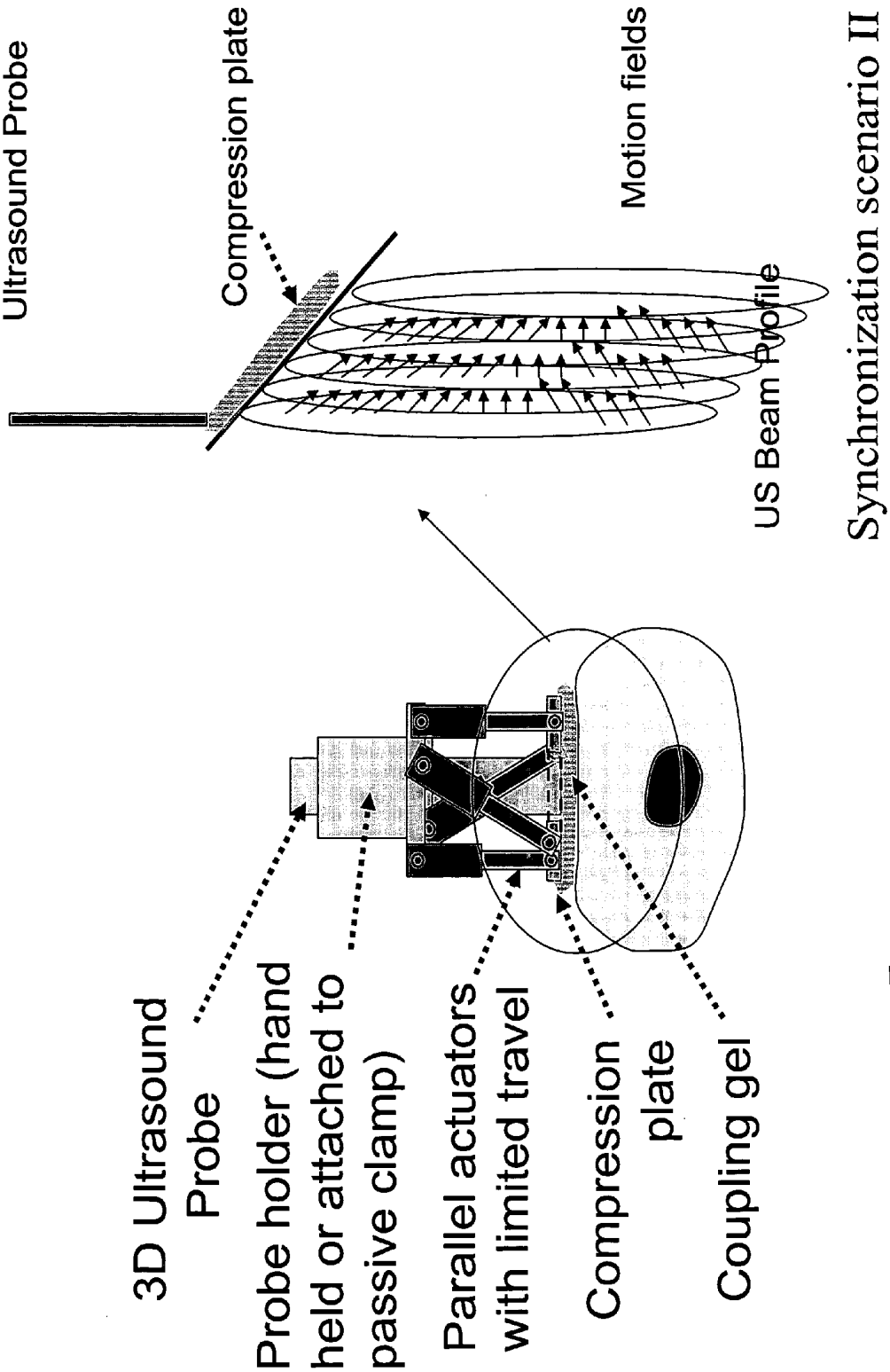

Ultrasound Probe
Compression plate
Motion fields
US Beam Profile
Synchronization scenario II
3D Ultrasound Probe
Probe holder (hand held or attached to passive clamp)
Parallel actuators with limited travel
Compression plate
Coupling gel

FIG. 7

ROBOTIC 5-DIMENSIONAL ULTRASOUND

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/488,941, filed on Jul. 21, 2003, which is hereby incorporated by reference for all purposes as if fully set forth herein.

[0002] The research and development effort associated with the subject matter of this patent application was supported by the National Science Foundation under grant no. EEC9731478.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] The present invention relates to ultrasound imaging, and more particularly, to robotic 5-dimensional (5D) ultrasound imaging.

[0005] 2. Discussion of the Related Art

[0006] Ultrasound is widely used in the medical community for intervention therapy. Examples include thermal ablation, external beam radiation therapy (EBRT), Brachy therapy, and needle insertion procedures, including biopsy procedures.

[0007] As stated, thermal ablation is but one procedure for which ultrasound is commonly used. Primary and metastatic liver cancer represents a significant source of morbidity and mortality in the United States, as well as worldwide. The medical community has focused on such techniques as thermal ablation, and in particular, radiofrequency ablation (RFA), to treat this and other similar diseases. Thermal ablation typically utilizes images to guide the placement of the ablation probe to or within the target area (e.g., a lesion or tumor) of the liver parenchyma. Heat created around the electrode, which is generally located at the tip of the ablation probe, is conducted into the target area tissue, causing coagulative necrosis at a temperature between 50° C. and 100° C.

[0008] There are several problems associated with conventional thermal ablation techniques. First and foremost is the ability to effectively utilize the imagery to precisely control the ablation probe during the ablation procedure. To some extent, this problem has been addressed by the development and use of 3D ultrasound imaging systems. While ultrasound is commonly used for target imaging, in general, and ablation monitoring, problems still exist even with these systems, as they do not provide adequate imagery and, as a result, they cannot effectively identify, segment, monitor or track target tissue, nor do they facilitate planning or control prior to and during the ablation process.

[0009] One reason conventional robotic 3D ultrasound systems are inadequate is that ultrasound cannot detect all lesions and tumors. Lesions and tumors are may be categorized as either hyperechoic (i.e., appear brighter than the surrounding tissue in an image), hypoechoic (i.e., appear darker than the surrounding tissue in an image), or isoechoic (i.e., have the same intensity as the surrounding tissue in an image). Ultrasound cannot visualize lesions or tumors that are isoechoic. Thus, conventional 3D ultrasound systems cannot effectively identify, segment, monitor or track target tissue, or facilitate planning and control prior to and during an ablation process where the target tissue is isoechoic.

[0010] Another reason conventional 3D ultrasound based systems are not always effective is that such systems do not necessarily provide adequate imaging in a noisy environment. As one skilled in the art will appreciate, the operation of an ablation probe generates a significant amount of noise which otherwise interferes with the ultrasound signal, and the ability of the system to generate accurate imagery.

[0011] Thermal ablation is, as stated, only one example of a medical procedure for which ultrasound is used to facilitate the procedure. Given the important of ablation therapy, as well as other medical procedures that utilize ultrasound, it is clear there is a tremendous need to enhance the capabilities of imaging systems to overcome the problems described above.

SUMMARY OF THE INVENTION

[0012] The present invention involves robotic 5D ultrasound imaging to overcome the various problems associated with conventional 3D ultrasound systems. In general, the present invention achieves this by integrating 3D ultrasound imagery with strain (i.e., elasticity) imagery over time, where strain imagery and time represent a fourth and a fifth degree of freedom, respectively, hence, 5D ultrasound imagery. In addition, the present invention utilizes a robotic end-effector to provide different compression profiles and to provide precise synchronization between the ultrasound acquisition and strain estimation. Still further, the present invention integrates this 5D information and projects it into a 4D visualization over time.

[0013] Elasticity imaging is generally known, where elasticity imaging provides a remote and non-invasive representation based on the mechanical properties of the target tissue. These elastic or mechanical properties associated with the target tissue cannot be measured directly. Thus, a mechanical disturbance is applied, and the resulting response is evaluated. One may categorize elasticity imaging into static (i.e., strain based) imaging, dynamic (i.e., wave based) imaging, and mechanical (i.e., stress based) imaging. The strain based approach involves imaging the internal motion if the tissue under static deformation. In contrast, the dynamic approach involves imaging shear wave propagation, and the mechanical approach involves measuring surface stress distribution. Each of these approaches further involve 1) capturing data during externally or internally induced tissue motion or deformation, 2) evaluating tissue response (displacement, strain, or stress), and if needed 3) reconstructing the elastic modulus based on the theory of elasticity.

[0014] In accordance with a preferred embodiment of the present invention, the strain based imaging approach is employed. However, one of skill in the art will understand that the use of any one of the other elastic imaging approaches is within the scope and spirit of the present invention.

[0015] One advantage of the present invention is that it provides an adequate visualization of the target area, even where the target tissue is isoechoic.

[0016] Another advantage of the present invention is that it provides for the accurate identification and segmentation

of the target area, such that the boundaries and/or contours of the lesion or tumor can more accurately be distinguished from the surrounding tissue, thereby providing more accurate information based on which the system can more accurately and more effectively plan, monitor, track and control the treatment procedure.

[0017] Yet another advantage of the present invention is it provides for different synchronization scenarios to assist in generating strain images at the same rate it acquires the ultrasound image data.

[0018] In accordance with a first aspect of the present invention, the aforementioned and other advantages are achieved by a computer integrated surgical system. The system comprises an ultrasound imaging system and a workstation. The workstation, in turn, is configured for receiving ultrasound signals from the ultrasound imaging system, and it includes an elasticity imaging module configured for deriving elasticity related parameters relating to target tissue, an ultrasound module configured for providing ultrasound image data reflecting the anatomical structure of the target tissue, and a volume rendering module configured for integrating the strain distribution information and the ultrasound image data and generating a visualization of the target tissue based on both the strain distribution data and the ultrasound image data.

[0019] In accordance with a second aspect of the present invention, the aforementioned and other advantages are achieved by a workstation for use in a computer integrated surgical system. The workstation comprises a strain imaging module configured for deriving strain distribution information relating to target tissue, an ultrasound module configured for providing ultrasound image data reflecting the anatomical structure of the target tissue, and a volume rendering module configured for integrating the strain distribution information and the ultrasound image data and generating a visualization of the target tissue based on both the strain distribution data and the ultrasound image data.

[0020] In accordance with a third aspect of the present invention, the aforementioned and other advantages are achieved by a method for rendering an ultrasonic image. The method involves acquiring ultrasound image data of a target tissue and acquiring strain image data of the target tissue. Then, the ultrasound image data and strain image data are integrated and a visualization of the target tissue based on both the ultrasound image data and the strain image data is generated.

[0021] In accordance with a fourth aspect of the present invention, the aforementioned and other advantages are achieved by a method of generating segmentation data using ultrasound image data in a medical procedure. The method involves acquiring ultrasound image data of a target tissue, acquiring strain image data of the target tissue, generating a model from the strain image, utilizing the model as an input to a model based segmentation process, and generating segmentation data associated with the target tissue based on the strain image data.

[0022] In accordance with a fourth aspect of the present invention, the aforementioned and other advantages are achieved by a method of registering online ultrasound data to preoperative non-ultrasound. The method involves combining tissue/organ boundaries from 3D ultrasound image data, augmenting elasticity to generate a pseudo, non-ultrasound data that can be used to register with preoperative, non-ultrasound data, utilizing a strain component as a landmark to automate a first initial matching registration, utilizing anatomy data to fine-tune the registration, and incorporating anatomy information and elasticity in a registration metric.

[0023] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as set forth in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The accompanying drawings together with the description serve to explain the principles of the present invention. In the drawings:

[0025] **FIG. 1** is a block diagram of a robotic 5D ultrasound system in accordance with exemplary embodiments of the present invention;

[0026] **FIG. 2** is a flowchart of a method for rendering a 5D ultrasound based image in accordance with exemplary embodiments of the present invention;

[0027] **FIG. 3** is a flow chart of a method for providing segmentation based on ultrasound and strain image information, in accordance with exemplary embodiments of the present invention; and

[0028] **FIGS. 4-7** illustrate exemplary configurations associated with the medical robot, in accordance with exemplary embodiments of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0029] The focus of the present invention is a robotic 5D ultrasound system and method for use in the field of Image Guided Therapy (IGT) and, more generally, Computer Integrated Surgery (CIS). The robotic 5D ultrasound system and method, in accordance with exemplary embodiments of the present invention enhance "surgical CAD-CAM-TQM" systems by integrating over time 3D ultrasonic image data with strain (i.e., elasticity) image data.

[0030] "Surgical CAD" is analogous to computer-aided design (i.e., CAD) in manufacturing systems, wherein the CAD phase involves the design and/or planning of the intended treatment using an IGT system. In general, prior to such medical procedures, medical images, anatomical atlases and other information are combined for the purpose of generating a model of an individual patient. The model is then used for planning the treatment or intervention procedure. The present invention, however, offers new capabilities with respect to the planning based on more accurate information as a result of integrating elasticity and anatomical variation information simultaneously. More specifically, the present invention uses both elasticity (i.e., strain) image data and ultrasound image data to more accurately identifying the targeted lesions and surrounding critical structures and to more effectively plan optimized therapy patterns (CAD).

[0031] The following are examples illustrating some of the ways in which the robotic 5D ultrasound system and method of the present invention facilitate surgical CAD process.

[0032] Identifying lesion or tumor boundaries for both isoechoic and non-isoechoic tissue in planning treatment. Ultrasound cannot differentiate isoechoic tumors from surrounding tissue, as the tumor tissue and the surrounding tissue have the same scattering/acoustic signature. Regardless, tumors tend to have different elastic (i.e., mechanical) characteristics compared to normal tissue. The 5D ultrasound system and method of the present invention exploits this difference, and is capable of identifying the tumor through the use of elasticity image data. In non-isoechoic scenarios (i.e., hyperechoic or hypoechoic), ultrasound images often suffer from a data incompleteness problem, due to the tissue boundary not being perpendicular to beam direction. However, once again, the the 5D ultrasound system of the present invention overcomes this problem as image data based on tissue elasticity properties can clearly delineate those boundaries.

[0033] Identifying organs and sub-organs from surrounding structure, such as prostate and its lobes. This capability is particularly beneficial in pre-planning EBRT (External Beam Radiation Therapy) treatment or Brachy therapy.

[0034] Defining realistic registration algorithms based on elasticity in addition to the anatomical variations. This leads to more accurate statistical atlases and, therefore, more accurate planning at the end.

[0035] "Surgical CAM" is analogous to computer-aided manufacturing. In the "surgical CAM" phase, data from the preoperative planning phase (i.e., the images, models, plan geometry, etc.) is made available to the attending technician or physician, for example, in the operating room. Real time image and other sensor data are used to update the information during the course of the procedure. The actual surgical procedure is performed by the surgeon with the assistance of the CIS system. In this surgical CAM phase, the 5D ultrasound system and method, in accordance with the present invention, enhance surgical CAD-CAM-TQM" systems in the following ways.

[0036] Segmenting (i.e., defining with particularity the contours of the target lesion or tumor). The 5D ultrasound system and method provides this capability even where the lesion or tumor is isoechoic, as stated above. In addition, the segmentation data is more reliable, as it is based on two reliable sources of information, the anatomy information as well as the elasticity information.

[0037] Volume-rendering. The present invention is capable of providing a clear and accurate projection of the 4D image data (i.e., 3D anatomy in addition to elasticity) in real-time. This capability is particularly beneficial for thermal ablation, for example, liver ablation under interaoperative or laparoscopic ultrasound guidance.

[0038] Registering online ultrasound data to preoperative non-ultrasound data, such as computer-tomography (CT) data, magnetic resonance imaging (MRI) data and X-ray data. The present invention can achieve this in a more reliable manner through the use of unified elasticity imaging framework. The elasticity component from the 5D ultrasound data can be used to register the ultrasound data to non-ultrasound data in the following ways: 1) by combining the tissue/organ boundaries from the 3D ultrasound image data and augment elasticity to generate a pseudo CT/MRI that can be used to register with non-ultrasound data, 2) using the strain component as a landmark (hard/soft regions) to help automate a first initial matching registration, and continue using anatomy data, and 3) incorporating both anatomy information and elasticity in the registration metric (i.e. energy function, correlation based metrics, mutual information etc. . . .).

[0039] Providing fast and reliable motion tracking. The present invention is capable of providing this based on elasticity and/or speckle correlation. For example, tumors with distinct elasticity parameters can be easily tracked, and undesired motions can then be compensated for.

[0040] "Surgical TQM" refers to "total quality management," and it reflects the important role that the a CIS system can play in reducing surgical errors and promoting better, more consistent outcomes. It is always a crucial goal to ensure that the planned therapeutic intervention has in fact been completely and successfully performed before the patient leaves the operating room. In this phase, the assessment process must be integrated with planning and therapy delivery systems to permit interactive re-planning based on this feedback (TQM). The present invention facilitates the TQM phase in a number of ways for a wide variety of clinical/surgical applications.

[0041] With respect to ablative procedures, the present invention is capable of identifying the ablation region in 3D and in real-time. Knowing the elasticity of the growing hard necrosis helps define the termination of the procedure, the need for a second intervention, and ablation parameters to be modified according to the delivered monitored therapy.

[0042] With respect to needle interventions, the present invention provides an elasticity map of the soft tissue under intervention that could be used to predict future needle deflection and compensate for it.

[0043] **FIG. 1** is a block diagram of a robotic 5D ultrasound CIS system **100** that is capable of processing RF data, raw 3D ultrasound data and strain image data in interactive or real-time, in accordance with exemplary embodiments of the present invention. As shown, the robotic 5D ultrasound CIS system **100** includes an ultrasound sensor **105**, an optical tracker **110**, a surgical robot **115** and a 5D ultrasound workstation **120**. The 5D ultrasound workstation **120**, in turn, contains several components or modules, each of which will now be described in greater detail.

[0044] First, the 5D ultrasound workstation **120** includes a video capture board **125**. The video capture board **125** receives and processes the B-mode 2D ultrasound video data generated by the ultrasound sensor **105**. The video capture board **125** is a standard piece of equipment that may be purchased "of-the-shelf." An example of a suitable video

capture board is the MeteorII video processing board made by Matrox Inc. Alternatively, the video capture board **125** could be replaced by a digital video processing board if the ultrasound sensor **105** supported digital link (e.g., DV firewire, optical link etc. . . .). In another alternative, the B-mode video data can be derived from the raw RF data.

[**0045**] Second, the workstation **120** includes an RF capture board **130**. The RF capture board **130** receives and digitizes the raw RF data that corresponds to the 2D ultrasound data generated by the ultrasound sensor **105**. The RF capture board **130**, like the video capture board **125**, is standard, and it can be implemented using almost any high frequency digitizer card, where it would be preferable that the digitizer card is capable of operating at a frequency 10× that of the ultrasound probe operating frequency.

[**0046**] In addition, the workstation **120** includes a CIS tracker module **135**. The CIS tracker module **135** receives and processes signals from the optical tracker **110**, from which, the position of the ultrasound probe and the robot end-deflector may be determined. A suitable device for the CIS tracker module **135** would be the tracker module developed by ERC CISST Lab.

[**0047**] The workstation **120** further includes a robot client module **140**. The robot client module **140** communicates with the robot **115** and, more specifically, provides control commands to the robot **115**. The robot client **140** may be the Medical Robot Control (MRC) device developed by the ERC CISST Lab.

[**0048**] The next components in workstation **120** are the strain imaging module **145** and the incremental 3D ultrasound module **150**. The strain imaging module **145** generates the strain characteristics of the captured 2D ultrasound data, which can be estimated as quickly as the B-mode acquisition. The strain estimation algorithm may be correlation-based, as shown, for example, in **FIG. 3**, or information based, as described in greater detail below. The incremental 3D ultrasound module **150** is responsible for reconstructing the 2D ultrasound data into 3D volumes. It interfaces with the video capture board **125**, the tracker **135** and the robot client **140**. It is referred to here as incremental 3D as it is possible to use a 1D array or an array that produces 2D ultrasound image data, where the probe is moved and the data is acquired incrementally. It is possible to employ a 3D ultrasound probe as well as a 2D array capable of producing 3D ultrasound data in an interactive way. Of particular importance, is the fact that the acquisition of the strain characteristics and the acquisition of the 3D ultrasound data is synchronized, where that synchronization is, at lest in part, controlled by the robot subsystem.

[**0049**] The workstation **120** also includes a 5D visualization and volume rendering module **155**. This module provides a volume rendering pipeline that merges both 3D ultrasound anatomy information with elasticity data. The pipeline provides a projection of the 4D data (i.e., 3D anatomy and 1D elasticity) into 3D scenes over time. The projections can be implemented in many ways. In general, however, and in accordance with exemplary embodiments of the present invention, the elasticity data is blended with the anatomy data.

[**0050**] **FIG. 2** is a flowchart illustrating an exemplary method for achieving the volume rendering pipeline described above, where elasticity is the controlling parameter. More specifically, **FIG. 2** shows a technique for volume rendering ultrasound data with opacity reflecting the strain data. Volume rendering is always a challenge with respect to ultrasound data. However, using elasticity data makes it possible to generate a more useful and more meaningful 3D image where, for example, the boundaries appear in a non-uniform way due to the change in angle between the boundary points and the ultrasound beam direction. Such images are particularly meaningful in IGT and CIS applications. It should be noted that volume rendering can easily be carried out in real-time using a volume rendering card, such as the Volume Pro 1000, made by Terarecon Inc.

[**0051**] Finally, the workstation **120** includes the deformable model segmentation module **160**. As stated, the present invention provides a useful tool for IGT and CIS applications. One main challenge in this field is to have a reliable real-time tracking mechanism. This is easily with the present invention for a wide variety of surgical interventions due to the integration of elasticity information, as well as the use of feedback data and control which is generally provided by the segmentation module **160**, as shown in **FIG. 1**.

[**0052**] Referring now to **FIG. 3**, this flow diagram illustrates an implementation for achieving strain imaging estimation. In general, the implementation illustrated in **FIG. 3** comprises two main stages. The first stage involves normal strain generation, in accordance with a correlation based technique. This is followed by stage two, which involves a model based segmentation technique. More specifically, the implementation starts with the acquisition of two frames, each having different compression states, followed by companding (i.e., signal processing preconditioning) to compensate for the compression. This results in better correlation. Next, a correlation technique (i.e., Normalized Cross-Correlation, SSD, SAD, Mutual Information, etc. . . .). From the estimated motion, we can get the strain by getting the gradient according to continuum mechanics.

[**0053**] With regard to the Phase **2** in **FIG. 3**, elasticity data can be used, for a wide variety of clinical applications, to provide a first approximation for model based segmentation. This is not a trivial task with conventional systems, particularly where the target tissue is isoechoic, as explained above. In many conventional systems, this first approximation is simply a best guess that is provided by the physician. Here the first approximation is automatically and accurately generated as a function of the elasticity data. In Phase **2** of **FIG. 3**, the segmentation process is implemented using the basic energy formula for 2D "snake model." However, one of skill in the art will understand that this could be extended to 3D, or that implementation may be achieved using any model based segmentation technique.

[**0054**] As stated above, the strain estimation may be correlation based, as set forth, for example, in the first stage of the process illustrated in **FIG. 3**. Alternatively, the strain estimation may be derived using an information based technique as described herein below.

[**0055**] Estimating the local strain is an essential step, which requires a high level of accuracy, since the amplitude of tissue deformation is relatively small. In accordance with exemplary embodiments of the present invention, two techniques are primarily considered. The first technique utilizes the maximization of normalized cross-correlation between

the pre- and post-compression RF signal after applying ID companding. This is illustrated in **FIG. 3**. This is considered a primitive delay estimation algorithms that is implemented in time-domain. Most advanced time delay estimation algorithms are implemented in frequency-domain; for example the generalized cross-correlation method. The spectral estimation in case of short signal segments is the most important weakness of the frequency-domain implementations. Others have searched for a time-domain implementation of an advanced delay estimation algorithm, and in doing so, found the "information theoretic delay criterion". A detailed description of the information based algorithm is set forth in R. Moddemeijer, *Delay-Estimation with Application to Electroencephalograms in Epilepsy*, Universiteit Twente, 1989, Enschede (NL), ISBN: 90:9002668-1, the contents of which are incorporated herein by reference.

[**0056**] As stated above, and as illustrated in **FIG. 1**, the CIS system **100** includes a medical robot **115**. The robot **115** is an important component as it provides several different yet important functions, such as controlling the rapid and frequent capture of pre and post compression ultrasound data, as well as synchronizing ultrasound scanning and compression so that it is possible to acquire rapid, accurate and synchronized strain and 3D ultrasound data. **FIGS. 4-7** illustrate exemplary configurations associated with the robot **115**, and the aforementioned functions provided the robot **115**.

[**0057**] **FIG. 4**, for example, shows the configuration of a robotic end-effector **400** which comprises, among other things, using linear actuators **402** and a compression plate **404**. The linear actuators **402** and the compression plate **404** move along an axial path in the direction of the ultrasound beam, where the ultrasound probe **405** is either rotated or translated within the volume. In accordance with the present invention, a 3D ultrasound probe can be fixed, where only the compression plate moves. Alternatively, the probe may be rotated to acquire multiple 3D ultrasound data sets for the same volume of interest using different lateral and elevation resolutions. This can, with careful compounding, enhance the signal-to-noise ratio and, in turn, enhance the 5D ultrasound data. In general, the motion scenarios can be either a) moving one part (i.e., either the ultrasound probe or the compression plate) or b) moving both the probe and the compression plate at the same time. Scenario "a" basically starts by moving the compression plate and then acquiring the 3D ultrasound data. The compression plate is then moved and 3D ultrasound data is once again acquired. If a strain image is generated from "n" compressions, the strain rate will be the rate of the 3D ultrasound acquisition divided by "n". Scenario "b" involves linearly moving the plate and rotating the ultrasound probe at the same time. This means that every two consecutive images will have different compression levels.

[**0058**] **FIG. 5** shows a more preferable design, also capable of delivering a high rate of strain. Here, the end-effector is based on a multi-parallel actuator design. The same motion scenarios described above, also apply here, as **FIG. 6**. **FIG. 7** shows that it is possible to compress the tissue obliquely while moving the 2D ultrasound probe. This means that every two consecutive ultrasound beam profiles will have a different compression level, thus, strain rate can be generated at the same 3D ultrasound volume acquisition rate. Moreover, it is no longer necessary to adjust the compression rate to accommodate tissue response. This results in a more reliable motion profile and greater accuracy. Additionally, the same volume under a different pressure profile can lead to better strain compounded volume.

[**0059**] It will be apparent to those skilled in the art that various modifications and variation can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A computer integrated surgical system comprising:

an ultrasound imaging system; and

a workstation configured for receiving ultrasound signals from the ultrasound imaging system, said workstation including:

an elasticity imaging module configured for deriving elasticity related parameters relating to target tissue, an ultrasound module configured for providing ultrasound image data reflecting the anatomical structure of the target tissue, and

a volume rendering module configured for integrating the strain distribution information and the ultrasound image data and generating a visualization of the target tissue based on both the strain distribution data and the ultrasound image data.

2. The system of claim 1, wherein the elasticity imaging module can be reconfigured to estimate elasticity parameters based on static imaging (i.e., strain based), dynamic imaging (i.e., wave based) and mechanical (i.e., stress based).

3. The system of claim 1, wherein the workstation further comprises:

a segmentation module, the segmentation module configured for feeding back segmentation data to the volume rendering module.

4. The system of claim 1 further comprising:

a medical robot, wherein the medical robot communicates with the workstation through a robot client; and wherein the medical robot comprises an end-effector.

5. The system of claim 4, wherein the end-effector comprises:

a linear actuator.

6. The system of claim 4, wherein the end-effector comprises:

parallel actuators.

7. The system of claim 4, wherein the medical robot comprises:

means for synchronizing between ultrasound acquisition and strain acquisition.

8. The system of claim 4, wherein the workstation further comprises:

a segmentation module, the segmentation module configured for feeding back segmentation data to the robot client, and wherein the robot client comprises means for generating robot control signals as a function of the feedback data provided by the segmentation module.

9. The system of claim 4, wherein the robot is configured for compressing the target tissue and inducing a strain distribution.

10. The system of claim 4, wherein the robot is configured for synchronizing ultrasound image data acquisition and the strain distribution information.

11. A workstation for use in a computer integrated surgical system, said workstation comprising:

a strain imaging module configured for deriving strain distribution information relating to target tissue,

an ultrasound module configured for providing ultrasound image data reflecting the anatomical structure of the target tissue, and

a volume rendering module configured for integrating the strain distribution information and the ultrasound image data and generating a visualization of the target tissue based on both the strain distribution data and the ultrasound image data.

12. The workstation of claim 11 further comprising:

a segmentation module, the segmentation module configured for feeding back segmentation data to the volume rendering module.

13. The workstation of claim 11 further comprising:

a robot client module configured for communicating with a medical robot associated with the computer integrated surgical system.

14. The workstation of claim 13, wherein the workstation further comprises:

a segmentation module, the segmentation module configured for feeding back segmentation data to the robot client module, and wherein the robot client comprises means for generating robot control signals as a function of the feedback data provided by the segmentation module.

15. Method for rendering an ultrasonic image comprising the steps of:

acquiring ultrasound image data of a target tissue;

acquiring strain image data of the target tissue;

integrating the ultrasound image data and the strain image data; and

generating a visualization of the target tissue based on both the ultrasound image data and the strain image data.

16. The method of claim 15 further comprising the step of:

synchronizing the acquisition of the ultrasound image data and the strain image data.

17. The method of claim 15, wherein the ultrasound image data reflects an anatomical structure of the target tissue and the strain image data reflects an elasticity distribution associated with the target tissue.

18. The method of claim 17, wherein said step of generating a visualization of the target tissue comprises the step of:

representing the anatomical structure using color shading.

19. The method of claim 15, step of generating a visualization of the target tissue comprises the step of:

representing the elasticity distribution by a level of opacity.

20. The method of claim 15 further comprising the step of:

compressing the target tissue.

21. The method of claim 20, wherein said step of acquiring ultrasound image data is accomplished before and after compressing the target tissue.

22. A method of generating segmentation data using ultrasound image data in a medical procedure comprising the steps of:

acquiring ultrasound image data of a target tissue;

acquiring strain image data of the target tissue;

generating a model from the strain image;

utilizing the model as an input to a model based segmentation process; and

generating segmentation data associated with the target tissue based on the strain image data.

23. The method of claim 22 further comprising the step of:

monitoring the medical procedure based on the segmentation data.

24. The method of claim 22 further comprising the step of:

controlling the medical procedure based on the segmentation data.

25. The method of claim 22 further comprising the step of:

generating a visualization of the target tissue based on both the ultrasound image data and the strain image data; and

updating the visualization based on the segmentation data.

26. A method of registering online ultrasound data to preoperative non-ultrasound data comprising the steps of:

combining tissue/organ boundaries from 3D ultrasound image data;

augmenting elasticity to generate a pseudo, non-ultrasound data that can be used to register with preoperative, non-ultrasound data;

utilizing a strain component as a landmark to automate a first initial matching registration;

utilizing anatomy data to fine-tune the registration; and

incorporating anatomy information and elasticity in a registration metric.

* * * * *

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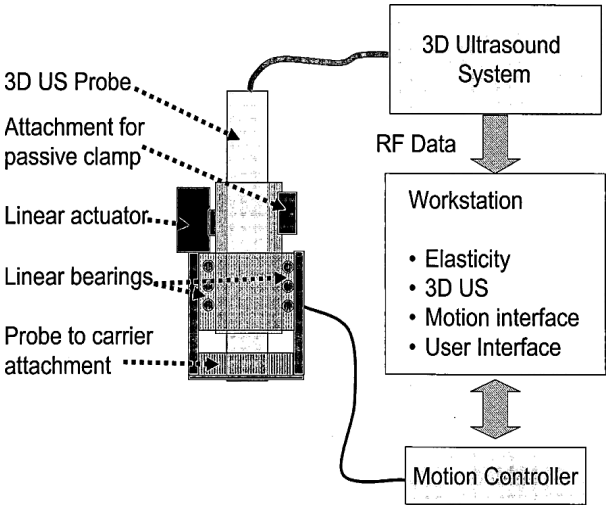
一种机器人5D超声系统和方法，用于计算机集成手术系统，其中3D超声图像数据随时间与应变（即弹性）图像数据整合。通过整合超声图像数据和应变图像数据，本发明能够准确地识别周围组织中的目标组织;在手术过程中分割，监测和跟踪目标组织;并且促进外科手术的适当规划和执行，即使手术环境有噪声且目标组织是等回声的。