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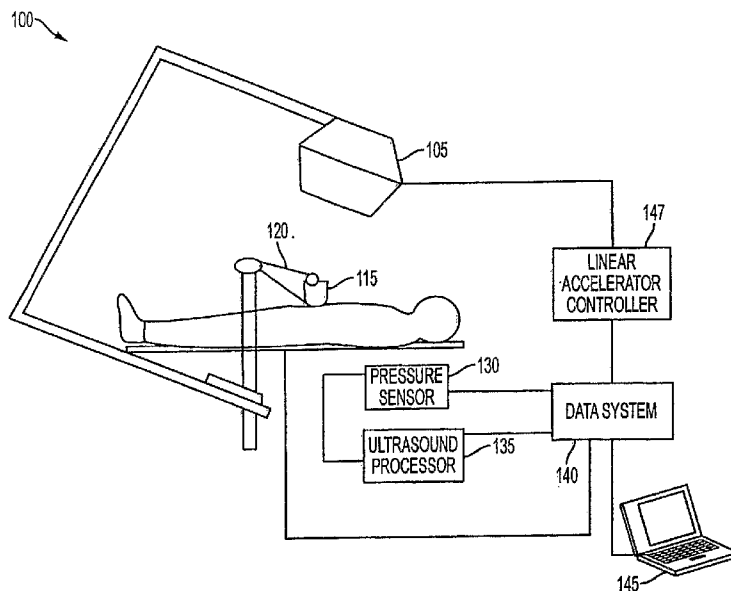
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[Continued on next page]

(54) Title: ULTRASOUND STRAIN IMAGING IN TISSUE THERAPIES



(57) Abstract: Disclosed is a system and method for providing ultrasound strain imaging of a soft tissue, such as a prostate, so that the soft tissue may be more precisely targeted during radiation treatment. The system includes a mechanical arm with a pressure interface for applying incremental pressure to the patient's abdomen, and a data system for correlating the ultrasound signals acquired before and after each application of incremental pressure. By correlating the pre and post-pressure ultrasound signals, acoustic interfaces corresponding to the prostate, which define the contours of the prostate, may be identified and displayed. Further, data corresponding to the contours of the prostate may be provided to a linear accelerator to enable the linear accelerator to more precisely target the prostate.

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## **ULTRASOUND STRAIN IMAGING IN TISSUE THERAPIES**

[0001] This application claims the benefit of United States Provisional Patent Application No. 60/569,003, filed on May 7, 2004; United States Provisional Patent Application No. 60/577,789, filed on June 8, 2004; and United States Non-provisional Application No. 10/895,397 titled ROBOTIC 5D ULTRASOUND SYSTEM, which claims priority to United States Provisional Application No. 60/488,941, filed July 21, 2003, all of which are 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**

#### **Field of the Invention**

[0003] The present invention relates primarily to the field of radiation oncology. More particularly, the present invention involves a system and method to provide more precise targeting of radiation by improving ultrasound imaging of the target tissue.

#### **Discussion of the Related Art**

[0004] Linear accelerators are commonly used in the treatment of cancer, particularly breast and prostate cancer. Breast cancer and prostate cancer patients typically undergo 25 and 40 radiation treatments, respectively, as part of a treatment

regimen. In providing radiation treatment, linear accelerators typically deliver electromagnetic radiation dosages on the order of 20 million electron volts into a target area. Given such high levels, there is a need to precisely deliver that energy into the target (*e.g.*, the tumor) in order maximize the dosage delivered to the tumor while minimizing radiation exposure to healthy tissue.

**[0005]** In order to precisely target the tumor, it is necessary to know its location while the patient is lying on the linear accelerator table. Various imaging techniques have been developed to meet this need. One method involves the use of Electronic Portal Image Detectors (EPIDs), which are integrated into the linear accelerator. EPIDs provide X-Ray images of the target area while the patient is lying on the linear accelerator table. However, one problem with EPIDs is that they do not provide imagery of soft tissue. Instead, EPIDs typically provide imagery of bone in the vicinity of the target tissue, which the linear accelerator technician may use as a “landmark” reference for estimating the location of the tumor.

**[0006]** As used herein, the term “tumor” generally refers to any target feature within a patient. The term “linear accelerator” may include any external beam radiotherapy device. The term “imagery” generally refers to one or more images acquired by an imaging system, such as a CT, MRI, or ultrasound system. However, imagery may also refer to data values in “raw” electronic form, such as binary data, or may refer to one or more images displayed on a computer screen or printed in a hardcopy form.

**[0007]** To facilitate the description of the present invention, the present invention is described below with reference to the treatment of prostate cancer.

However, it will be apparent to one of ordinary skill that the present invention is applicable to other treatments, such as breast cancer.

[0008] Another imaging method for assisting in the targeting of tumors involves the use of transcutaneous ultrasound, in which a linear accelerator technician applies a transcutaneous ultrasound probe onto the patient's abdomen between radiation dosages. The problem with this approach is that intervening acoustic interfaces, such as the bladder, bone, etc., make such images unreliable for locating the tumor. Related art systems that use this approach include ultrasound systems manufactured by NOMOS Corp., Varian Corp., Computerized Medical Systems, Inc., and Resonant Corp.

[0009] Yet other related art solutions have emerged. One such solution involves implanting electromagnetic transponders into the prostate, which are then located using a radar-like scanning mechanism, such as the Calypso® product line by Calypso® Medical Technologies, Inc. of Seattle Washington. Still other approaches include implanting gold markers, which are visible in X-Ray imagery using EPIDs. A disadvantage of such solutions is that the implanted devices are mere surrogates for the prostate, and they do not provide information that specifically defines the contours of the prostate. In addition, these devices must be invasively implanted. Further, swelling of the prostate may occur during treatment, which could cause the surrogate implants to move relative to the location of the tumor. Either way, targeting by use of surrogates involves foreign objects placed in the vicinity of the tumor whereby the linear accelerator technician does not actually see the prostate. The technician must

therefore estimate the contours of the prostate and the location of the tumor relative to the surrogates.

### **SUMMARY OF THE INVENTION**

[0010] Accordingly, the present invention is directed to ultrasound strain imaging in tissue therapies that substantially obviates one or more of the aforementioned problems due to limitations and disadvantages of the related art. In general, the present invention achieves this by providing imagery that contains the contours of the targeted anatomical structure (*e.g.*, the prostate). The present invention provides this imagery by providing increasing pressure in the vicinity of the targeted anatomical structure while acquiring ultrasound images, identifying boundaries of differential strain as revealed in the images, and reconstructing the contours of the targeted anatomical structure from the images.

[0011] An advantage of the present invention is that it maximizes radiation dosages to tumors while reducing the exposure of surrounding healthy tissue to the radiation.

[0012] Another advantage of the present invention is that it provides more accurate imagery of the targeted anatomical structure (*e.g.*, the prostate) during radiation therapy, which it does by taking advantage of the differences in strain properties between the targeted anatomical structure and its surrounding tissue.

[0013] Additional advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the

invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

[0014] The aforementioned and other advantages of the present invention are achieved with a system that provides ultrasound strain imaging. The system comprises an ultrasound probe; a pressure actuator connected to the ultrasound probe; and a data system having a computer readable medium encoded with a program for controlling the pressure actuator to apply pressure on a patient's anatomy, and for determining the contours of a target anatomical structure based on a difference between an elasticity of the target anatomical structure and an elasticity of a surrounding tissue.

[0015] In another aspect of the present invention, the aforementioned and other advantages are achieved by a method for identifying the contour corresponding to an anatomical structure using ultrasound imagery. The method involves positioning an ultrasound probe relative to the anatomical structure; acquiring a first ultrasound signal from the ultrasound probe; applying pressure to the anatomical structure; acquiring a second ultrasound signal from the ultrasound probe; identifying the contour based on the first and second ultrasound signal.

[0016] 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 claimed.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0017] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this

specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention.

[0018] FIG. 1 illustrates an exemplary ultrasound strain imaging system according to the present invention;

[0019] FIG. 2 illustrates an exemplary ultrasound strain imaging system, which includes a linear accelerator for cancer treatment;

[0020] FIG. 3 illustrates a bladder and a prostate subject to strain, along with multiple fields of view projected by an ultrasound probe;

[0021] FIG. 4A illustrates exemplary echo signals for given field of view with and without strain exerted on the prostate;

[0022] FIG. 4B illustrates exemplary echo signals for a different field of view with and without strain exerted on the prostate;

[0023] FIG. 5 illustrates another exemplary ultrasound strain imaging system using an ultrasound transmitter and a rectal balloon; and

[0024] FIG. 6 illustrates an exemplary process for performing ultrasound strain imaging according to the present invention.

#### **DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS**

[0025] As used herein, ultrasound strain imaging refers to acquiring ultrasound imagery of an anatomical region, which includes a targeted anatomical structure and its surrounding tissue, while precisely applying incremental amounts of pressure against an area of patient's body in the vicinity of the anatomical region. The applied pressure exerts strain on the tissue within the anatomical region, including the targeted anatomical structure and its surrounding tissue. The

surrounding tissue and the targeted anatomical structure respond differently to the exerted strain such that the tissue and the targeted anatomical structure will compress at different rates. By correlating the ultrasound data acquired with and without strain, the contours of the targeted anatomical structure may be identified based on its different response to the strain.

[0026] For purposes of illustration and not limitation, the present invention as illustrated in FIGs. 1 and 2 is described in terms of a system for providing images of the prostate. However, it will be readily evident to those skilled in the art that the imaging system described herein below and illustrated in FIGs. 1 and 2 could be employed to provide images of anatomical structures other than the prostate.

[0027] FIG. 1 illustrates an exemplary strain imaging system 100 according to the present invention. The system 100 includes a transcutaneous ultrasound probe 115; a pressure interface 125 connected to the transcutaneous ultrasound probe 115; a mechanical arm 120 connected to the transcutaneous ultrasound probe 115; a pressure sensor 130 connected to the pressure interface 125; an ultrasound processor 135 for providing and receiving signals and data to and from the transcutaneous ultrasound probe 115; a data system 140; and a user interface 145.

[0028] FIG. 2 illustrates an exemplary strain imaging system 100, as described above, further including a linear accelerator 105, and a linear accelerator controller 147 connected to the data system 140.

[0029] The transcutaneous ultrasound probe 115 may have a plurality of elements (referred to herein as “N” elements) for providing imagery of the bladder 150 and the prostate 155 within the patent. The ultrasound probe may be connected to

the mechanical arm 120, or may be held and applied to the patient manually. For the purposes of illustration, this embodiment of the present invention may employ a Siemens C7F2 3D “wobbler” probe for the transcutaneous ultrasound probe 115, which is manufactured by Siemens Medical Solutions, USA, Inc., Ultrasound Division, Issaquah, WA. However, it will be readily apparent to one skilled in the art that other commercially available ultrasound probes may be used. The transcutaneous ultrasound probe 115 may operate in pulse/echo mode, whereby the probe transmits acoustic energy and detects the reflected acoustic energy.

[0030] The pressure interface 125 may have a substantially flat lower surface for applying substantially planar pressure against the patient’s abdomen. The pressure interface 125, which is connected to the transcutaneous ultrasound probe 115 may have an opening through which the transcutaneous ultrasound probe 115 may be inserted for contacting the patient. Alternatively, the pressure interface may be integrated into the transcutaneous ultrasound probe 115 and be acoustically coupled to the probe. Depending on the shape of the transcutaneous ultrasound probe 115, if the probe is capable of providing substantially planar pressure against the abdomen, the pressure interface 125 may not be necessary.

[0031] The data system 140 may include one or more computers, which may be connected together either locally or over a network. The data system 140 includes a memory encoded with software (hereinafter “the software”) for implementing processes according to the present invention. The software may be stored and run on the data system 140, or may be stored and run in a distributed manner between the data system 140 the ultrasound processor 135, and the user interface 145.

[0032] The pressure sensor 130 measures the pressure exerted by the pressure interface 125 against the patient's abdomen. The pressure sensor 130 may measure the pressure as exerted by the pressure interface 125, or may measure the pressure as exerted by the transcutaneous ultrasound probe 115 if the pressure interface 125 is not used. The pressure sensor 130 is connected to the data system 140 so that pressure measurements made by the pressure sensor 130 may be acquired and stored by the software.

[0033] The ultrasound processor 135 is for sending control signals to, and receiving data from, the transcutaneous ultrasound probe 115. For the purposes of illustration, this embodiment of the present invention may employ a SONOLINE™ Antares system for the ultrasound processor 135, which is manufactured by Siemens Medical Solutions, USA, Inc., Ultrasound Division, Issaquah, WA. However, it will be readily apparent to one skilled in the art that other commercially available ultrasound processors may be used. The ultrasound processor 135 is connected to the data system 140 for receiving control signals and providing ultrasound image data.

[0034] The mechanical arm 120 may provide at least one degree of freedom of motion to the transcutaneous ultrasound probe 115 and the pressure interface 125. The mechanical arm 120 is connected to the data system 140 for receiving control signals and sending data regarding its position, orientation, rate of motion, and acceleration for each degree of freedom. The mechanical arm 120 may be controlled by commands issued by an operator via the user interface 145. The mechanical arm 120 may also be controlled robotically by the software using motion control algorithms that are known to the art. It will be understood by one skilled in the art

that other types of pressure actuators, other than a mechanical arm, are possible and within the scope of the invention.

[0035] The user interface 145 may include one or more computers that communicate with the data system 140. The user interface may also include computers that are connected remotely over a network to allow for remote operation and monitoring of operation.

[0036] The linear accelerator 105 may be one of a number of external beam radiotherapy devices that are used in cancer treatment. The linear accelerator 105 may have the capability of fine-tuning the focusing of radiation based on commands issued by the linear accelerator controller 147. The linear accelerator controller 147 may have data inputs for accepting commands from the data system 140, or may have a separate user interface by which commands may be entered manually.

[0037] FIG. 3 illustrates a transcutaneous ultrasound probe 115 connected to a pressure interface 125. Together, the transcutaneous ultrasound probe 115 and the pressure interface 125 are exerting strain on a patient's bladder 150 and prostate 155. Also illustrated are two fields of view, represented by dashed lines 305 and 310. The two different fields of view may be achieved through the use of two different elements within the transcutaneous ultrasound probe 115. Once a strain corresponding to a few millimeters to a few centimeters of displacement is exerted on the bladder 150, the bladder 150 may conform around the prostate 155, as illustrated in FIG. 3. The amount of strain required to make the bladder 150 conform around the prostate 155 may vary depending on the patient, the pressure within the bladder 150,

and the size of the prostate 155. In conforming around the prostate 155, the bladder 150 substantially stabilizes the prostate 155 and may prevent it from moving.

[0038] Pressure exerted by the pressure interface 125 will exert strain on the prostate 155. Once the prostate 155 experiences strain, the contours of the prostate may become more visible in the imagery acquired by the transcutaneous ultrasound probe 115 and processed according to the present invention.

[0039] FIG. 4A illustrates two exemplary signals 410 and 420 from a single transcutaneous ultrasound probe 115 element having field of view 305; and FIG. 4B illustrates two exemplary signals 440 and 450 from a single transcutaneous ultrasound probe 115 element having field of view 310.

[0040] Referring to FIG. 4A and FIG. 3, signal 410 depicts the acoustic energy received by an element of the transcutaneous ultrasound probe 115 having field of view 305 when no pressure is applied by pressure interface 125 and the transcutaneous ultrasound probe 115. Signal 415 depicts the acoustic energy received by the same element when pressure is being applied by pressure interface 125 and transcutaneous ultrasound probe 115, and the prostate 155 is under strain. Signals 410 and 415 have a signal response feature 420, which represents that portion of the acoustic energy emitted by transcutaneous ultrasound probe 115, which reflects back from acoustic interface 320 that corresponds to the near surface of the bladder. The portion of signal 410 and signal 415 following signal feature 420 is generally faint since it reflects the acoustic energy propagating through fluid in the bladder 150, which is substantially free of acoustic scatterers. Signal response feature 425

represents the energy reflected back from acoustic interface 325, which corresponds to the flat surface of bladder 150.

[0041] Signal response feature 430 represents the energy that reflects back from acoustic interface 330, which corresponds to the near surface of the prostate 155. Similarly, signal response feature 435 represents the energy reflected back from acoustic interface 335, which corresponds to the far surface of the prostate 155. Signal response features 430 and 435 may have a sufficiently large amplitude that makes them distinguishable from the background signal, as illustrated in FIG. 4A. However, this is not always the case. In this instance, speckle correlation (to be described later) may be required to identify these features in the form of temporal shifts in the ultrasound imagery that may be retrieved via correlation techniques that are known in the art.

[0042] Referring to FIG. 4B and FIG. 3, signals 440 and 445 are respectively similar to signals 410 and 415, but correspond to acoustic energy received by an element of transcutaneous ultrasound probe 115 having field of view 310. Signal 440 represents the acoustic energy received when no pressure is being exerted by the transcutaneous ultrasound probe 115 and the pressure interface 125. Signal 445 represents the acoustic energy received when pressure is being applied by the transcutaneous ultrasound probe 115 and the pressure interface, and whereby the prostate 155 is under strain. Given the orientation of field of view 310, signal response features 450 and 455 respectively correspond to acoustic interfaces 330 and 335 (*i.e.*, the near and far surfaces of the prostate 155). As illustrated in FIG. 4B, signal response features 450 and 455 are closer to each other, as compared to response

features 430 and 435 of FIG. 4A. This is expected as the near and far surfaces of the prostate 155 are closer along field of view 310 than they are along field of view 305.

[0043] FIGs. 4A and 4B refer to signals detected by two elements of transcutaneous ultrasound probe 115. A transcutaneous ultrasound probe 115 may have N elements. Given N elements, with each having a field of view that provides a different “slice” of prostate 155, there will be N signals similar to the signals illustrated in FIG. 4A. Each of the N signals may provide information regarding the near and far surfaces of the prostate 155, depending on the orientation of a particular element’s field of view. The software may determine the near and far surfaces of the prostate 155 for each field of view, and then assemble the corresponding near and far surface information to reconstruct the contours of the prostate 155. The value of N depends on the transcutaneous ultrasound probe 115 used. As transcutaneous ultrasound probe technology develops to include more elements, this may enable reconstructing the contours of the prostate 155 with greater spatial resolution, since there will be more fields of view intersecting the prostate 155.

[0044] FIG. 5 illustrates another exemplary embodiment of the ultrasound strain imaging system 100, which further includes a rectal balloon 510, a balloon actuator 530, and an ultrasound transmitter 530 disposed on the rectal balloon. The ultrasound transmitter 520 may be connected to the ultrasound processor 135 to operate in conjunction with the transcutaneous ultrasound probe 115. The balloon actuator 530 enables an operator to control the strain exerted on the prostate 155 by controlling the pressure within the rectal balloon 510. The balloon actuator 530 may

be connected to the data system 140, and may receive control signals from and transmit data to the software running on the data system 140.

[0045] In this embodiment, the ultrasound transmitter 520 and the transcutaneous ultrasound probe 115 act in conjunction as a transmission-based ultrasound imaging system, also referred to as transmission mode. Transmission-based ultrasound is an alternative mode of operation to the pulse/echo mode of operation. In transmission-based ultrasound, one ultrasound probe transmits acoustic energy and another probe receives it. This contrasts with pulse/echo mode, in which one ultrasound probe serves as both transmitter and receiver.

[0046] In this embodiment, the ultrasound transmitter 520 transmits acoustic energy that is received by each element of the transcutaneous ultrasound probe 115. By operating in this manner, the flux of the acoustic energy received by each element of the transcutaneous ultrasound probe 115 is much greater than that received in a conventional pulse/echo mode. In pulse/echo mode, which is the conventional operating mode for a typical ultrasound probe, the same probe transmits and receives the same acoustic energy, which is reflected off of acoustic scatterers in the propagation medium. For each scattering event, only a small portion of the reflected energy falls within the field of view of the ultrasound probe elements. Accordingly, only a small portion of the transmitted acoustic energy is received.

[0047] By operating in transmission mode, the system illustrated in FIG. 5 may provide higher quality imagery since signal strength is strong. Further, since the received signal is strong, the software may be able to resolve distances corresponding

to the acoustic interfaces corresponding to the prostate 155 to high precision, resulting in precise definition of the contours of the prostate 155.

[0048] In order to operate the system transmission-based system illustrated in FIG. 5, the signals corresponding to the ultrasound transmitter 520 and transcutaneous ultrasound probe 115 must be synchronized. The signals corresponding to the ultrasound transmitter 520 and the transcutaneous ultrasound probe 115 must be synchronized because the time between the transmission of acoustic energy (by the ultrasound transmitter 520) and its reception (by the transcutaneous ultrasound probe 115) must be determined so that the software may use this information to reconstruct signals similar to those illustrated in FIGs. 4A and 4B. Once the software has reconstructed the signals accordingly, it may determine the near and far surfaces of the prostate 155 in a manner similar to that described earlier. It will be apparent to one skilled in the art how to synchronize these signals and reconstruct them in order to operate the system illustrated in FIG. 5.

[0049] Variations to the exemplary embodiment illustrated in FIG. 5 are possible. For instance, the rectal balloon 520 may be the sole source of pressure on the prostate 115, whereby the mechanical arm 120 and the pressure interface 125 may be optional. Further, the ultrasound transmitter 520 may be an ultrasound probe that operates in pulse/echo mode, in which case ultrasound transmitter 520 and the transcutaneous ultrasound probe 115 may operate independently or in conjunction. The ultrasound transmitter 520 may be a pulse/echo mode ultrasound probe, and the transcutaneous ultrasound probe 115 may be optional. In this case, the pressure interface 125 provides pressure, and the ultrasound transmitter 520 may be the sole

ultrasound probe. Other permutations are possible and within the scope of the invention.

[0050] FIG. 6 illustrates an exemplary process 600 for performing ultrasound strain imaging according to the present invention. Process 600 may be implemented by the software, may run in an automated fashion, and may involve operator interaction.

[0051] In step 605, the transcutaneous ultrasound probe 115 is positioned over the patient lying on the table of the linear accelerator 105. An operator may position the mechanical arm 130 in such a way that the transcutaneous ultrasound probe 115 and the pressure interface 125 are in contact with, but generally not applying pressure to, the patient's abdomen. Once the transcutaneous ultrasound probe 115 is in contact with the patient's abdomen, the ultrasound processor 135 may begin acquiring ultrasound imagery, and the user interface 145 may begin displaying the acquired ultrasound imagery.

[0052] The mechanical arm 120 should be positioned such that a vector normal to the surface of the pressure interface 125 (hereinafter "pressure vector") is directed toward the prostate 155 such that as pressure is applied (in a later step), the bladder 150 may conform around the prostate 155 and substantially stabilize the prostate 155 in a manner described above.

[0053] In step 610, the mechanical arm 130 moves the transcutaneous ultrasound probe 115 and the pressure interface 125 along the pressure vector. The motion may be incremental or continuous. If the motion is incremental, an increment size may be selected based on factors such as the pressure of the bladder 150 and the

size of the prostate 155. The increment may vary from fractions of millimeters to many millimeters, depending on the patient. As the pressure interface 125 and the transcutaneous ultrasound probe 115 translate along the pressure vector, they exert strain on the bladder and the prostate commensurate with their translation. The mechanical arm 120 may be commanded directly by an operator through the user interface 145, or the software may issue commands to the mechanical arm 120 according to a pre-programmed motion profile.

[0054] In step 615, as the pressure interface 125 and the transcutaneous ultrasound probe 115 move along the pressure vector, the ultrasound processor 135 acquires image data from the transcutaneous ultrasound probe 115, and transmits the data to the data system 140, wherein the software receives and stores the data values corresponding to the signals acquired by each element in the transcutaneous ultrasound probe 115. As used in exemplary process 600, the transcutaneous ultrasound probe 115 has N elements, and the data from each may be processed and stored independently. Each of the N stored signals may be like those illustrated in FIG. 4A, whereby the most recently stored signal may correspond to signal 415 and a previously stored signal corresponds to signal 410.

[0055] In step 620, the software correlates each of the N signals with the most recently stored corresponding signal. If this is the first incremental motion of the pressure interface 125 and the transcutaneous ultrasound probe 115, then step 620 may be bypassed, since there may be no previous data with which to correlate.

[0056] The software correlates the two N signals using processing techniques that are known to the art, such as circular cross correlation algorithms that are

available as functions within commercial mathematical software packages. The result of the correlation may include an N-dimensional array of correlation amplitudes and phases corresponding with each signal data point. The correlation phase corresponds to a time shift between a data point of the current signal and its strongest correlated counterpart in the previous signal; and the correlation amplitude corresponds to the degree of correlation.

[0057] If more than one previous signal is stored, the software may repeat the correlation process between the current signal and each of the previous signals independently. This may provide for trending information or allow for the identification and removal of outlier correlation results.

[0058] In correlating the current and previous signals, the software generally correlates the speckle present in the signal data. Speckle refers to the texture-like features present in ultrasound data, which results from small acoustic scatterers present in the tissue. The observed speckle is in part due to constructive and destructive interference of the acoustic wavefront as it propagates through tissue. Speckle is stable, such that a point in a target tissue that presents speckle in ultrasound imagery will continue to do so for repeated images. Accordingly, speckle results from a spatially distributed low intensity reflecting medium that provides “texture” through which multiple signals may be correlated. In other words, speckle is used to correlate the signals.

[0059] If the correlation yields portions of substantially zero correlation between the current and previous signal, it may be due to out-of-plane motion of a speckle scatterer. Since speckle is used to correlate the current and previous signals,

if a speckle scatterer undergoes out-of-plane motion, the absence (or sudden presence) of the scatterer from one signal to the next may corrupt the correlation, and result in outliers in the resulting prostate contour. Out-of-plane motion is substantially mitigated by incrementing the pressure interface 125 and transcutaneous ultrasound probe 115 depending on the length of the increment or the speed by which the transcutaneous ultrasound probe 115 and the pressure interface 125 are translated.

[0060] In step 625, the acoustic interfaces 330 and 335 are identified by the software. The software searches for sudden changes in correlation phase computed in step 620, and assesses the degree of correlation corresponding to these phase changes by evaluating the correlation amplitude. Since the prostate will respond to strain differently than the surrounding tissue, the difference in response to strain may be apparent in abrupt correlation phase changes at the acoustic interfaces 330 and 335. The software may identify these abrupt changes and store the corresponding distances. The software may identify the abrupt phase changes by comparing the phase differences in phase to a preset threshold, or may be identified by selecting the two highest phase changes within a certain window of time. It will be readily apparent to one of ordinary skill how to implement an algorithm for selecting the phase changes corresponding to acoustic interfaces 330 and 335. Doing this for N signals (one per element) may yield an array of distances corresponding to the contours of the prostate.

[0061] Although steps 625 and 630 illustrate the use of speckle correlation to identify changes in elasticity corresponding to the contours of the prostate, other methods are possible and within the scope of the invention. For example, techniques

that art known in the art, such as vibro-acoustography may be employed to discriminate the contours of the prostate instead of speckle correlation. In vibro-acoustography, the transcutaneous ultrasound probe 115 transmits continuous acoustic energy in frequencies ranging from 100Hz to 1kHz. Each of the N elements in the transcutaneous ultrasound probe 115 receives acoustic energy reflected from the speckle scatters within each of the N fields of view. The software may spectrographically analyze the signals received from each of the N elements to identify Doppler-related shifts in the signals. Doppler-related shifts correspond to changes in elasticity that occur at the near and far surfaces of the prostate 155.

[0062] As illustrated in FIG. 6, steps 610–624 may be repeated until the correlation in step 620 yields phase correlations with corresponding correlation amplitudes that are sufficiently high such that the software may decide that the acoustic interfaces 330 and 335 of the prostate have been determined for a sufficient number of the N signals.

[0063] The pressure is released in step 630, in which the mechanical arm reverses the translation of the pressure interface 125 and the transcutaneous ultrasound probe 115. This may be done by an operator through the user interface 145, or automatically by the software. On releasing pressure, contact between the transcutaneous ultrasound probe 115 and the abdomen may be such that acoustic coupling between the abdomen and the transcutaneous ultrasound probe 115 is maintained.

[0064] In step 635, which may be optional, the software stores and correlates N signals acquired in which the pressure was released with the N signals stored in the

last iteration of step 615, which occurred when the prostate 155 was subjected to the greatest strain. The purpose of this step is to confirm the contours of the prostate 155 in its un-strained state.

**[0065]** In step 640, the user interface displays the un-strained contours of the prostate. Additionally, the software may compute and issue commands to the linear accelerator controller 147 to fine tune its pointing so that the maximum dosage may be delivered to the prostate 155 and not to the surrounding tissue.

**[0066]** It may be the case that the prostate 155 may not be visible according to the above-described techniques, because the elasticity of the prostate 155 and its surrounding tissue may be the same. If this is the case, it may be possible to induce a change in elasticity of the prostate so that it may be visible, and its contours defined, by methods and systems according to the present invention. For example, lesions may be deliberately induced in the prostate whereby the lesions may have different strain characteristics that may make them visible under the systems and processes of the present invention. Alternatively, the prostate may be treated so that its elasticity may be made distinct from that of the surrounding tissue. Methods of achieving either of these results include High Intensity Focused Ultrasound (HIFU), which is a noninvasive ultrasound-based method known in the art for delivering focused high intensity acoustic energy to impart thermal energy in a localized region within a surrounding tissue.

**[0067]** Although the above description refers to prostate cancer treatment, it will be readily apparent to one of ordinary skill that the systems and processes of the present invention may be used for other medical procedures, such as breast cancer

treatment or ablative therapy of tumors in a liver. Although the techniques to be applied in these cases may not involve using the bladder as a stabilizing background, there may be geometries in the surrounding anatomy that may assist in stabilizing the tumor being treated, given the direction and force with which the strain is exerted.

[0068] 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 system for providing ultrasound strain imaging comprising:  
an ultrasound probe;  
a pressure actuator connected to the ultrasound probe; and  
a data system having a computer readable medium encoded with a program for controlling the pressure actuator to apply pressure on a patient's anatomy, and for determining the contours of a target anatomical structure based on a difference between an elasticity of the target anatomical structure and an elasticity of a surrounding tissue.
2. The system of claim 1, further comprising a pressure interface mechanically connected to the ultrasound probe.
3. The system of claim 2, further comprising a pressure sensor mechanically connected to the pressure interface.
4. The system of claim 1, further comprising a linear accelerator having a linear accelerator controller.
5. The system of claim 1, wherein the ultrasound probe is a transcutaneous ultrasound probe.
6. The system of claim 1, further comprising:  
a rectal balloon; and  
an ultrasound transmitter disposed on the rectal balloon.

7. The system of claim 6, wherein the computer readable medium is encoded with a program for synchronizing a signal corresponding to the ultrasound probe and a signal corresponding to the ultrasound transmitter.
8. The system of claim 1, wherein the pressure actuator is a mechanical arm.
9. The system of claim 1, wherein the program for controlling the pressure actuator to apply pressure on a patient's anatomy, and for determining the contours of a target anatomical structure based on a difference between an elasticity of the target anatomical structure and an elasticity of a surrounding tissue includes:
  - translating the mechanical arm by plurality of increments;
  - acquiring ultrasound signals from the ultrasound processor before and after each increment;
  - correlating the ultrasound signals; and
  - identifying features in the correlated ultrasound signals corresponding to the target anatomical structure.
10. The system of claim 1, wherein the patient's anatomy is the patient's abdomen.
11. The system of claim 1, wherein the target anatomical structure is a prostate.
12. A method for identifying the contour corresponding to an anatomical structure using ultrasound imagery, the method comprising:
  - positioning an ultrasound probe relative to the anatomical structure;
  - acquiring a first ultrasound signal from the ultrasound probe;

applying pressure to the anatomical structure;  
acquiring a second ultrasound signal from the ultrasound probe;  
identifying the contour based on the first and second ultrasound signal.

13. The method of claim 12, wherein the anatomical structure is a prostate.

14. The method of claim 13, wherein applying pressure to the anatomical structure includes commanding a pressure actuator to apply pressure along a direction from the patient's abdomen toward the prostate.

15. The method of claim 14, wherein commanding a pressure actuator to apply pressure along a direction from the patient's abdomen toward the prostate includes commanding the mechanical arm to translate by an increment corresponding to a pressure of the patient's bladder and a size of the prostate.

16. The method of claim 12, further comprising displaying the contour.

17. The method of claim 12, further comprising commanding a linear accelerator according to the contour.

18. The method of claim 12, wherein identifying the contour based on the first and second signal includes:

correlating the first ultrasound signal and the second ultrasound signal; and  
identifying an abrupt change in phase in the result of the correlation.

19. The method of claim 12, further comprising treating the anatomical structure to change its elasticity relative to an elasticity of a surrounding tissue.
  
20. The method of claim 12, wherein acquiring a first ultrasound signal from the ultrasound probe includes acquiring the first ultrasound signal corresponding to acoustic energy transmitted by a first ultrasound probe and acoustic energy received by a second ultrasound probe.

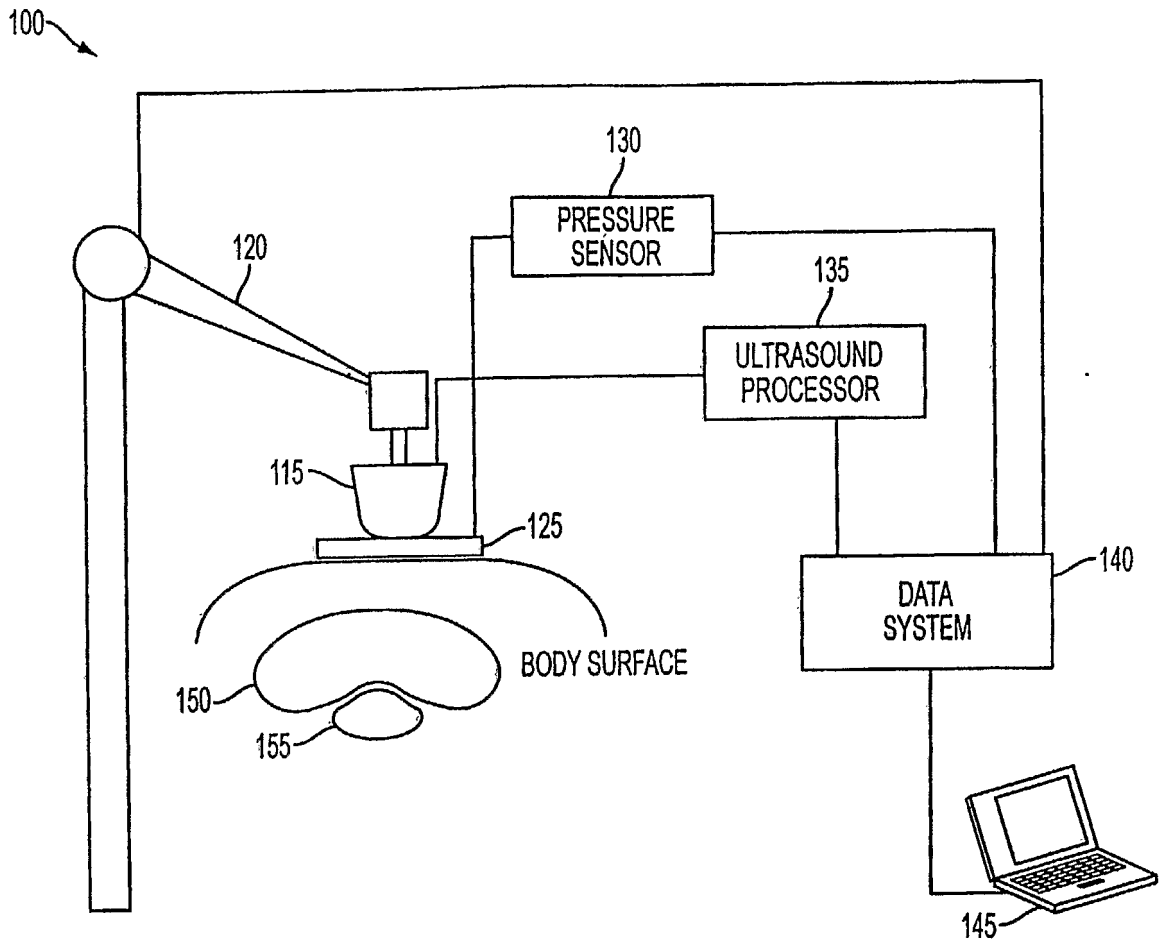


FIG. 1

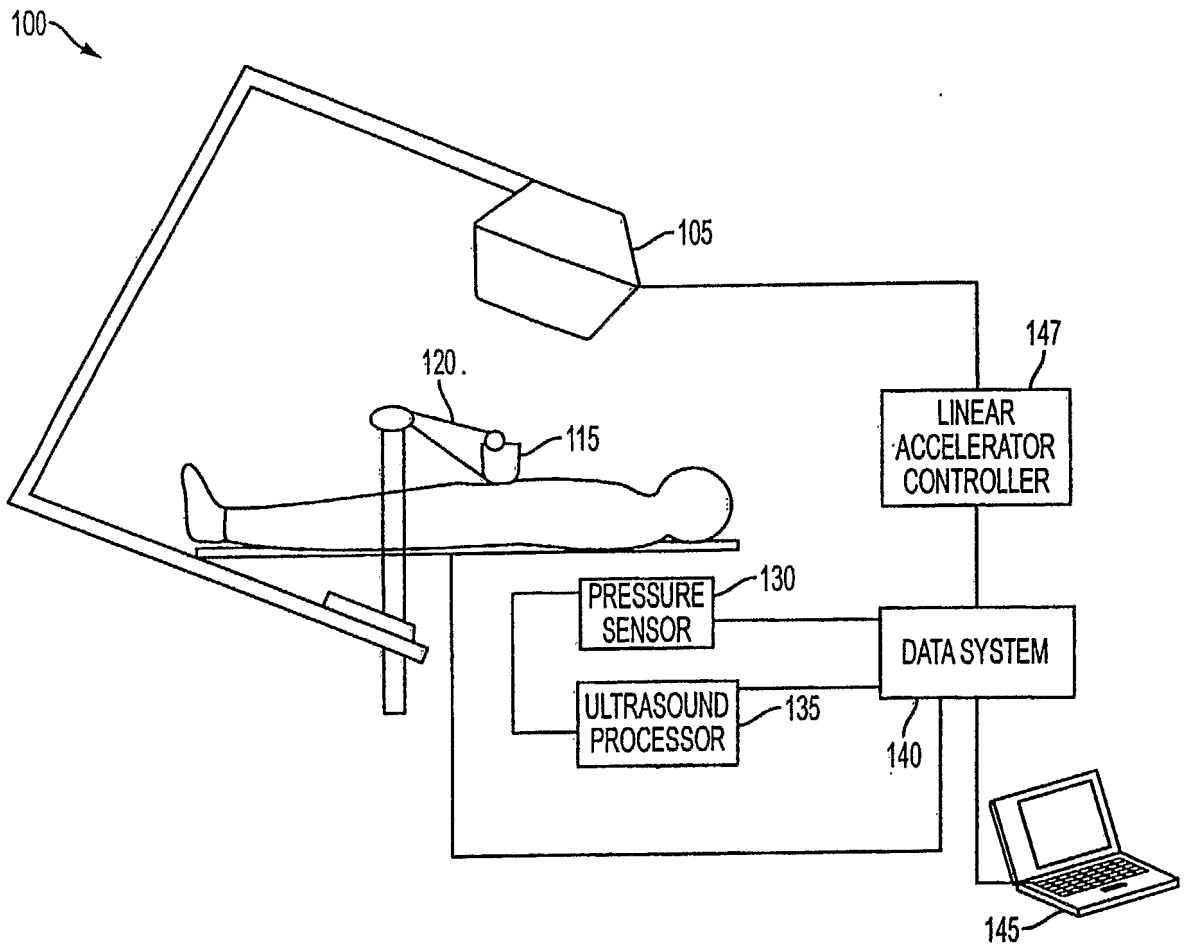


FIG. 2

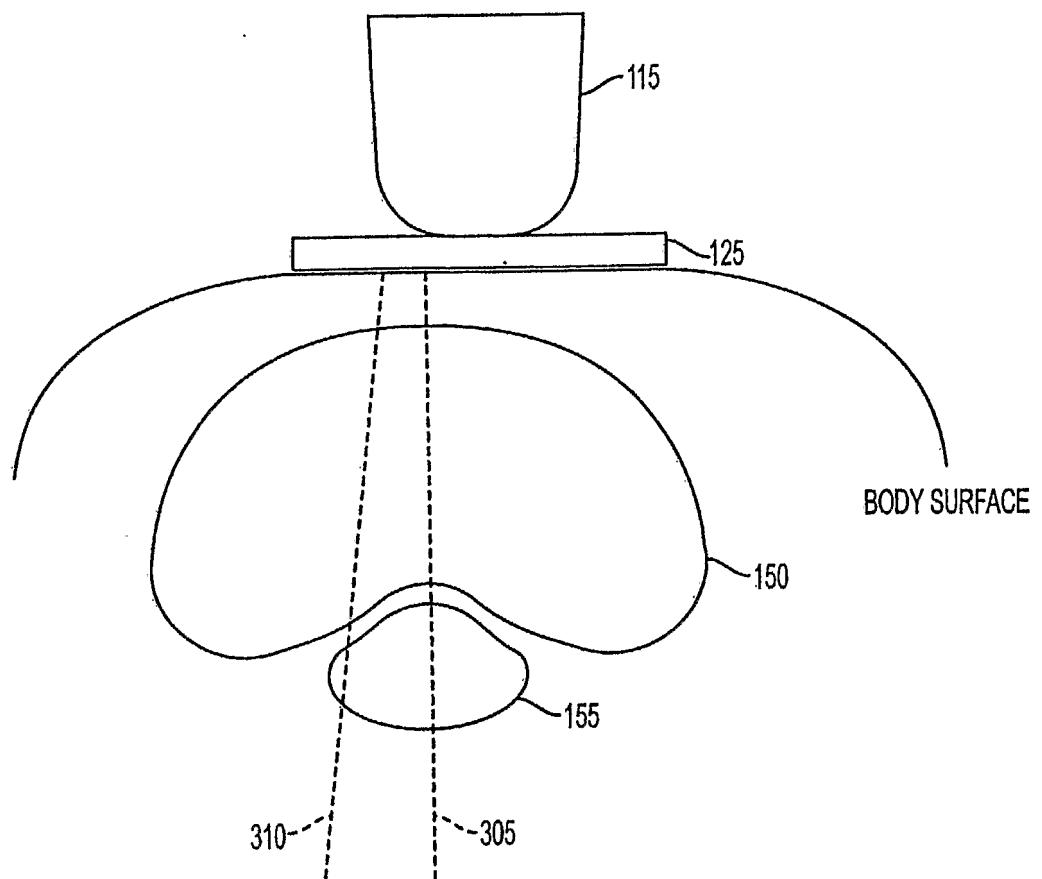


FIG. 3

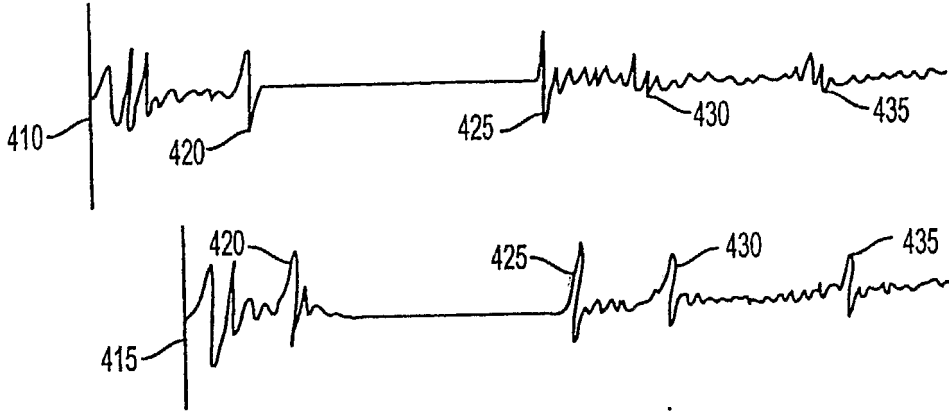


FIG. 4A

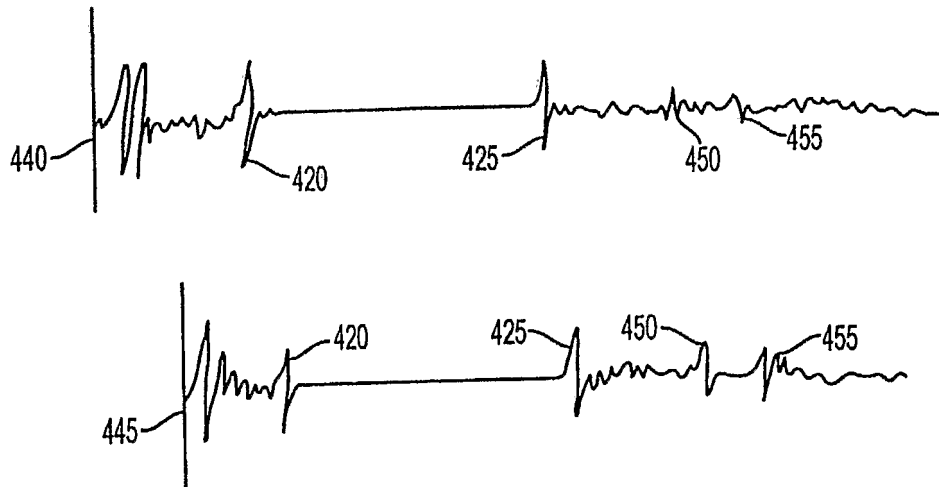


FIG. 4B

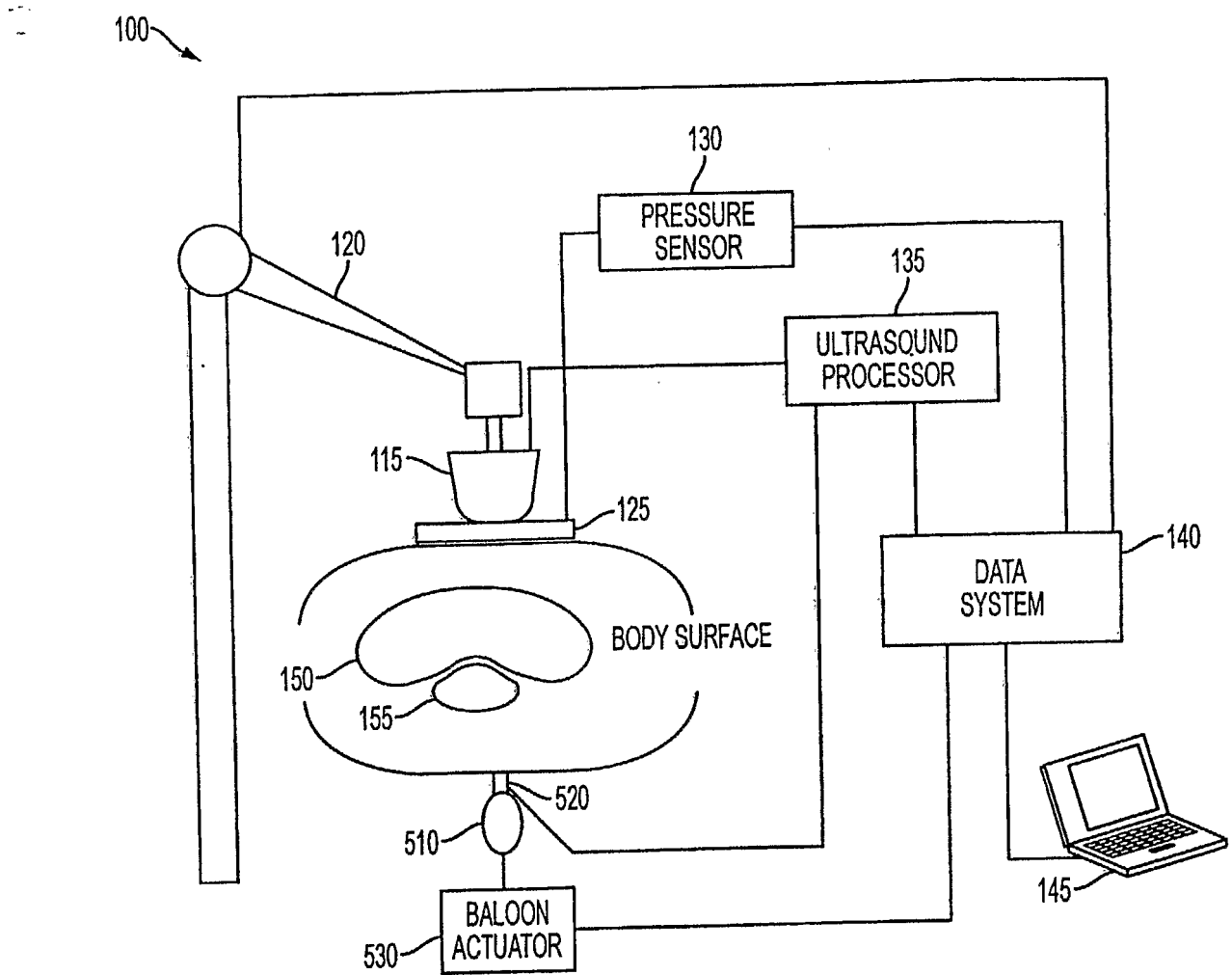


FIG. 5

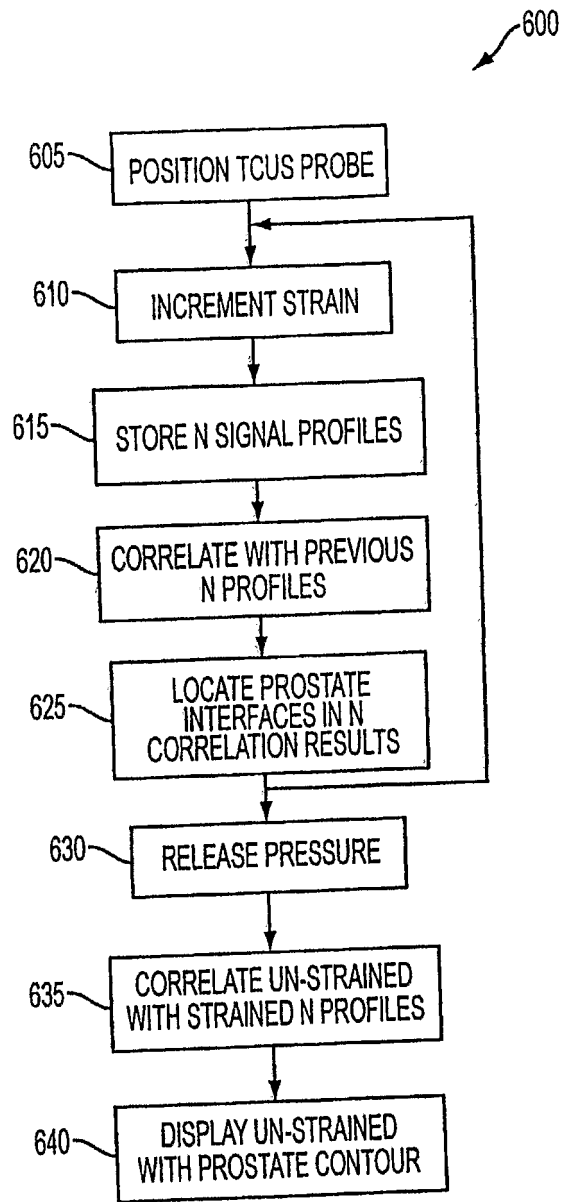


FIG. 6

专利名称(译)	组织疗法中的超声应变成像		
公开(公告)号	<a href="#">EP1768567A2</a>	公开(公告)日	2007-04-04
申请号	EP2005760767	申请日	2005-05-09
[标]申请(专利权)人(译)	约翰霍普金斯大学		
申请(专利权)人(译)	约翰·霍普金斯大学		
当前申请(专利权)人(译)	约翰·霍普金斯大学		
[标]发明人	BOCTOR EMAD MOUSSA FICHTINGER GABOR		
发明人	BOCTOR, EMAD, MOUSSA FICHTINGER, GABOR		
IPC分类号	A61B8/00 A61B8/08 A61B17/00 A61B19/00		
CPC分类号	A61B8/485 A61B5/0048 A61B5/6843 A61B8/08 A61B8/0833 A61B8/4218 A61B8/4281 A61B90/50 A61B2017/00274 A61B2018/00547		
代理机构(译)	JOHNSON , TERENCE LESLIE		
优先权	60/569003 2004-05-07 US 10/895397 2004-07-21 US 60/577789 2004-06-08 US		
其他公开文献	EP1768567A4		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

公开了一种用于提供诸如前列腺的软组织的超声应变成像的系统和方法，使得在放射治疗期间可以更精确地靶向软组织。该系统包括具有压力接口的机械臂，用于向患者的腹部施加增量压力，以及用于关联在每次施加增压之前和之后获得的超声信号的数据系统。通过关联压力前和压力后超声信号，可以识别和显示对应于前列腺的声学界面，其界定前列腺的轮廓。此外，可以将对应于前列腺轮廓的数据提供给线性加速器，以使线性加速器能够更精确地瞄准前列腺。