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(54) SYSTEMS AND METHODS OF REGISTRATION USING AN ULTRASOUND PROBE

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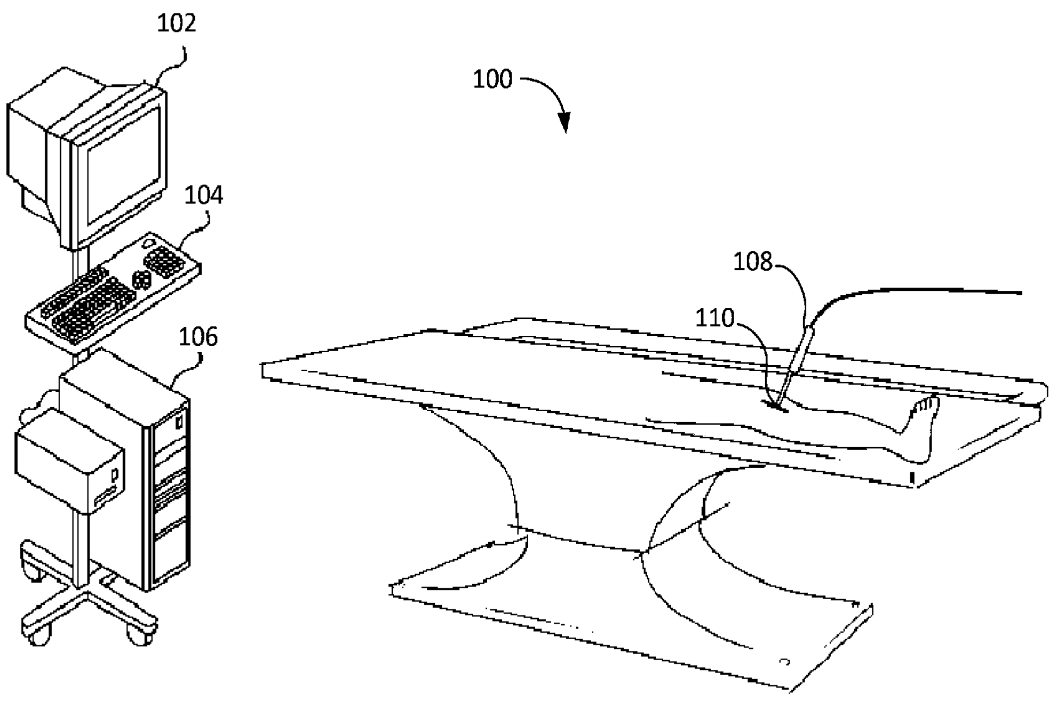
(57) **ABSTRACT**

A system for registration of a bone structure includes a registration probe and a processing circuit. The registration probe includes a two-dimensional array of a plurality of ultrasonic transducers coupled to a rounded tip of the probe, wherein the ultrasonic transducers are configured to provide ultrasonic data. The processing circuit is configured to receive ultrasonic data from the ultrasonic transducers, determine which of the ultrasonic transducers are in contact with anatomy of a patient, generate registration points based on the ultrasonic data and the determination of which of the ultrasonic transducers are in contact with the anatomy of the patient, and register the anatomy of the patient to a model of bone using the registration points.



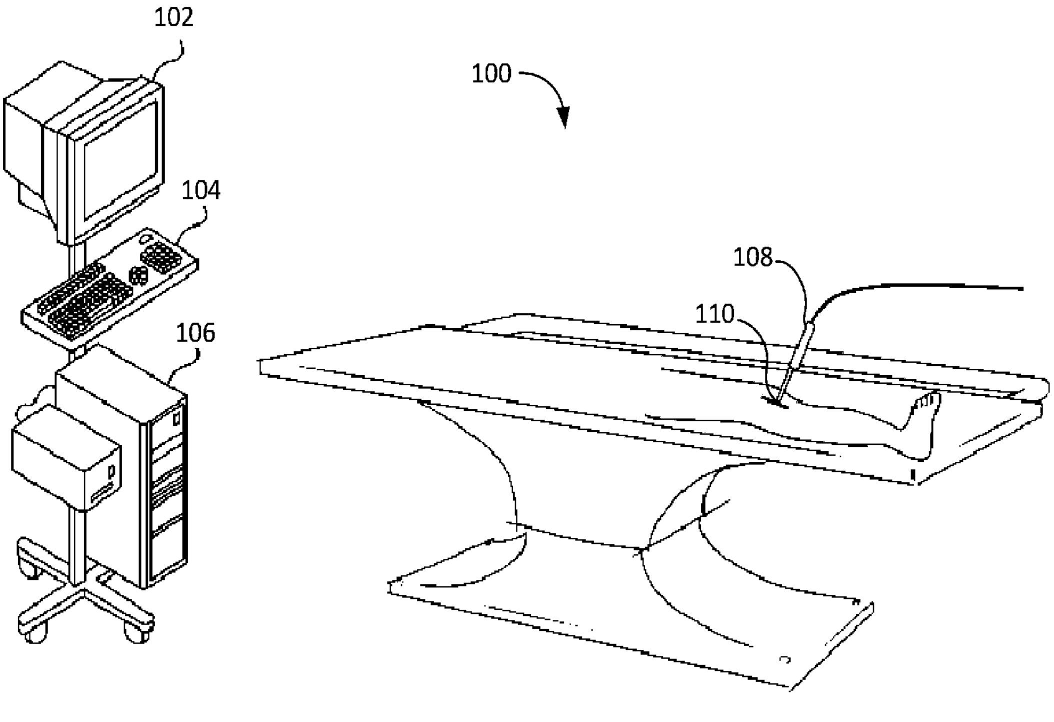


FIG. 1

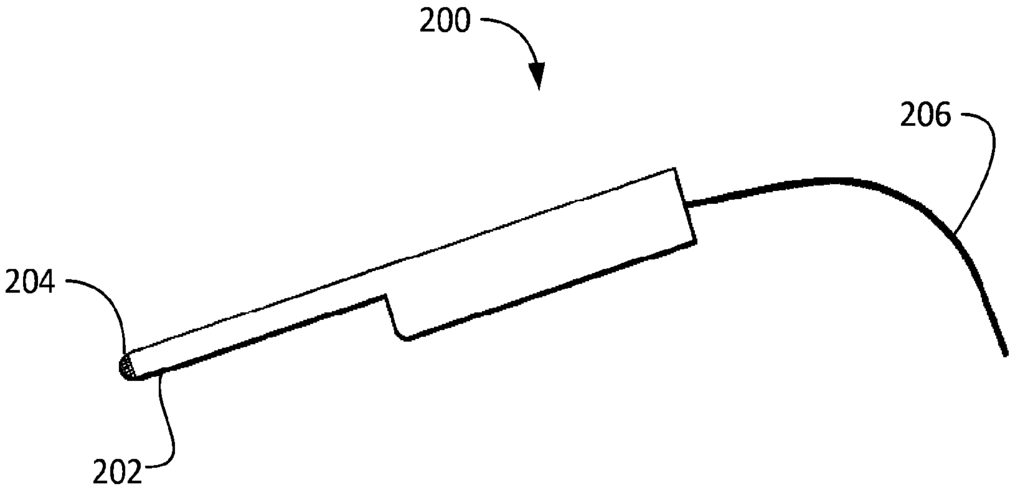


FIG. 2

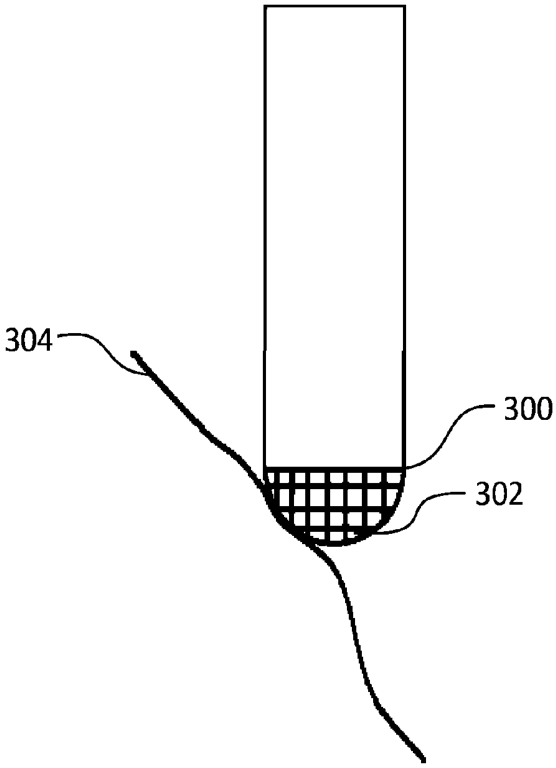


FIG. 3

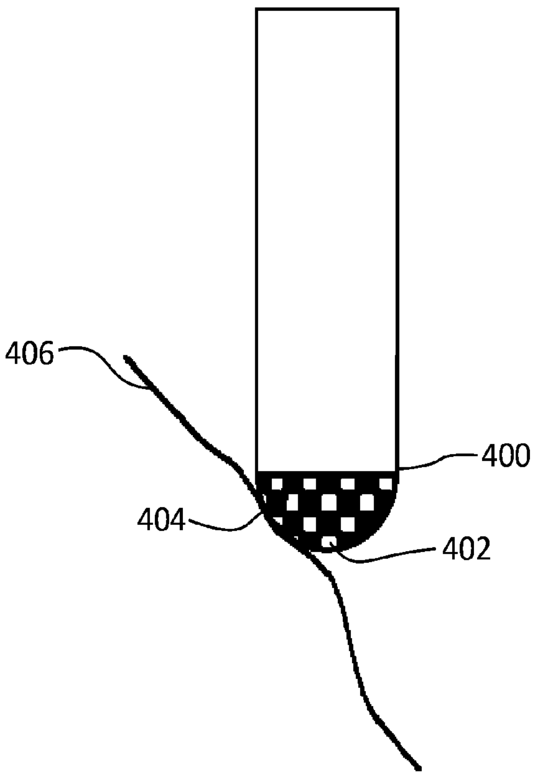


FIG. 4

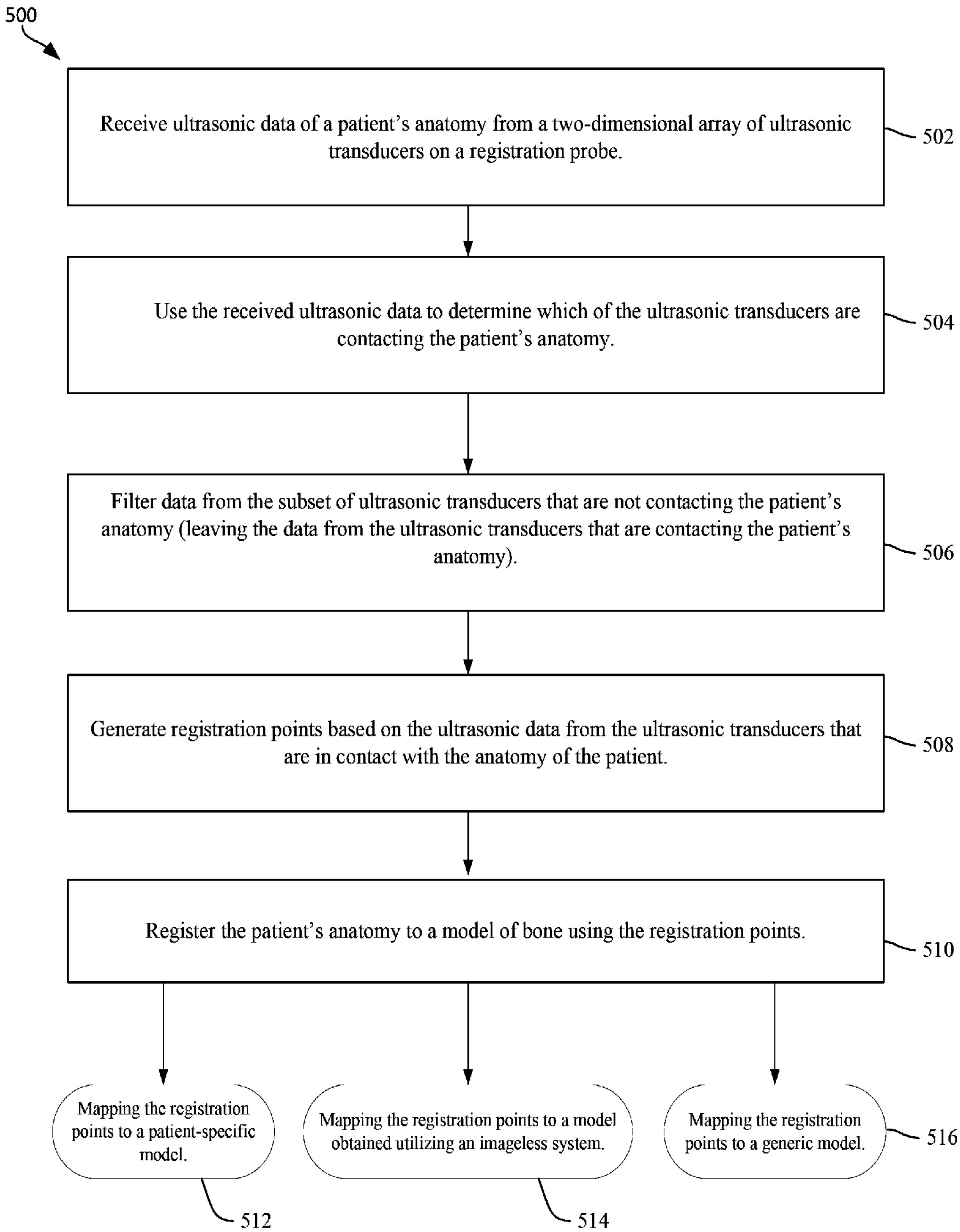

500
Receive ultrasonic data of a patient's anatomy from a two-dimensional array of ultrasonic transducers on a registration probe.
502
Use the received ultrasonic data to determine which of the ultrasonic transducers are contacting the patient's anatomy.
504
Filter data from the subset of ultrasonic transducers that are not contacting the patient's anatomy (leaving the data from the ultrasonic transducers that are contacting the patient's anatomy).
506
Generate registration points based on the ultrasonic data from the ultrasonic transducers that are in contact with the anatomy of the patient.
508
Register the patient's anatomy to a model of bone using the registration points.
510
Mapping the registration points to a patient-specific model.
512
Mapping the registration points to a model obtained utilizing an imageless system.
514
Mapping the registration points to a generic model.
516

FIG. 5

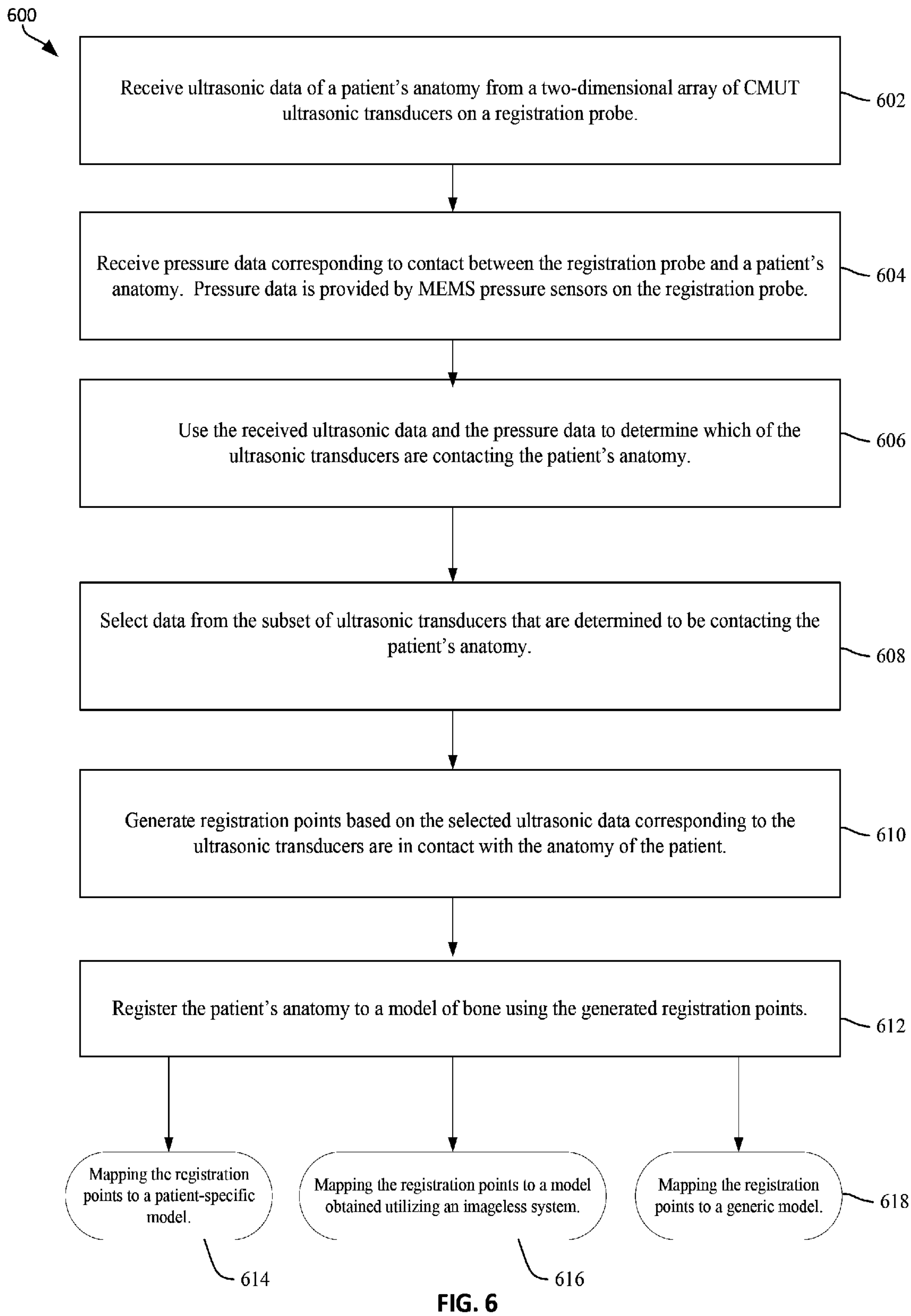

600
Receive ultrasonic data of a patient's anatomy from a two-dimensional array of CMUT ultrasonic transducers on a registration probe.
602
Receive pressure data corresponding to contact between the registration probe and a patient's anatomy. Pressure data is provided by MEMS pressure sensors on the registration probe.
604
Use the received ultrasonic data and the pressure data to determine which of the ultrasonic transducers are contacting the patient's anatomy.
606
Select data from the subset of ultrasonic transducers that are determined to be contacting the patient's anatomy.
608
Generate registration points based on the selected ultrasonic data corresponding to the ultrasonic transducers are in contact with the anatomy of the patient.
610
Register the patient's anatomy to a model of bone using the generated registration points.
612
Mapping the registration points to a patient-specific model.
614
Mapping the registration points to a model obtained utilizing an imageless system.
616
Mapping the registration points to a generic model.
618

FIG. 6

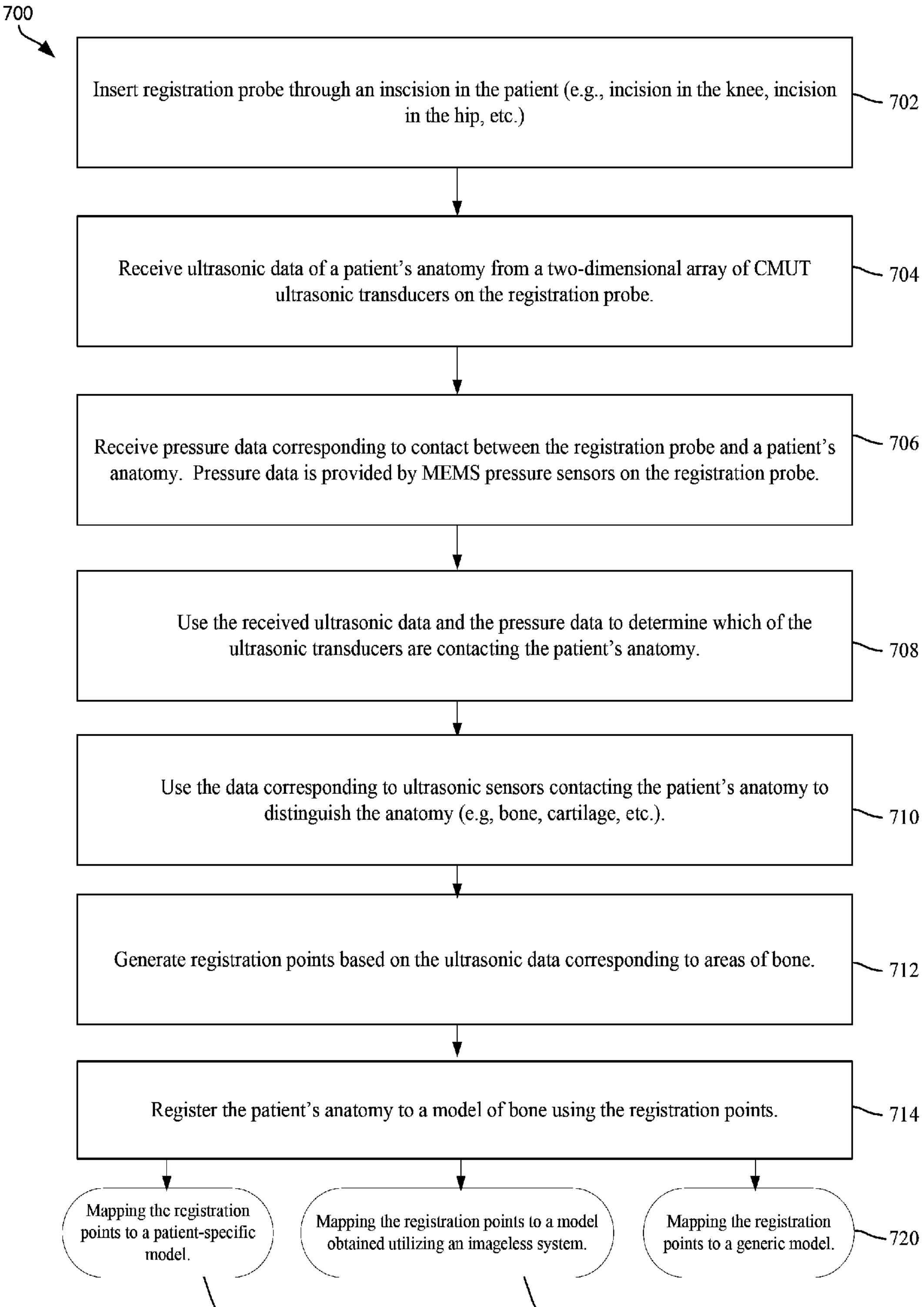

700
Insert registration probe through an inscision in the patient (e.g., incision in the knee, incision in the hip, etc.)
702
Receive ultrasonic data of a patient's anatomy from a two-dimensional array of CMUT ultrasonic transducers on the registration probe.
704
Receive pressure data corresponding to contact between the registration probe and a patient's anatomy. Pressure data is provided by MEMS pressure sensors on the registration probe.
706
Use the received ultrasonic data and the pressure data to determine which of the ultrasonic transducers are contacting the patient's anatomy.
708
Use the data corresponding to ultrasonic sensors contacting the patient's anatomy to distinguish the anatomy (e.g, bone, cartilage, etc.).
710
Generate registration points based on the ultrasonic data corresponding to areas of bone.
712
Register the patient's anatomy to a model of bone using the registration points.
714
Mapping the registration points to a patient-specific model.
716
Mapping the registration points to a model obtained utilizing an imageless system.
718
Mapping the registration points to a generic model.
720

FIG. 7

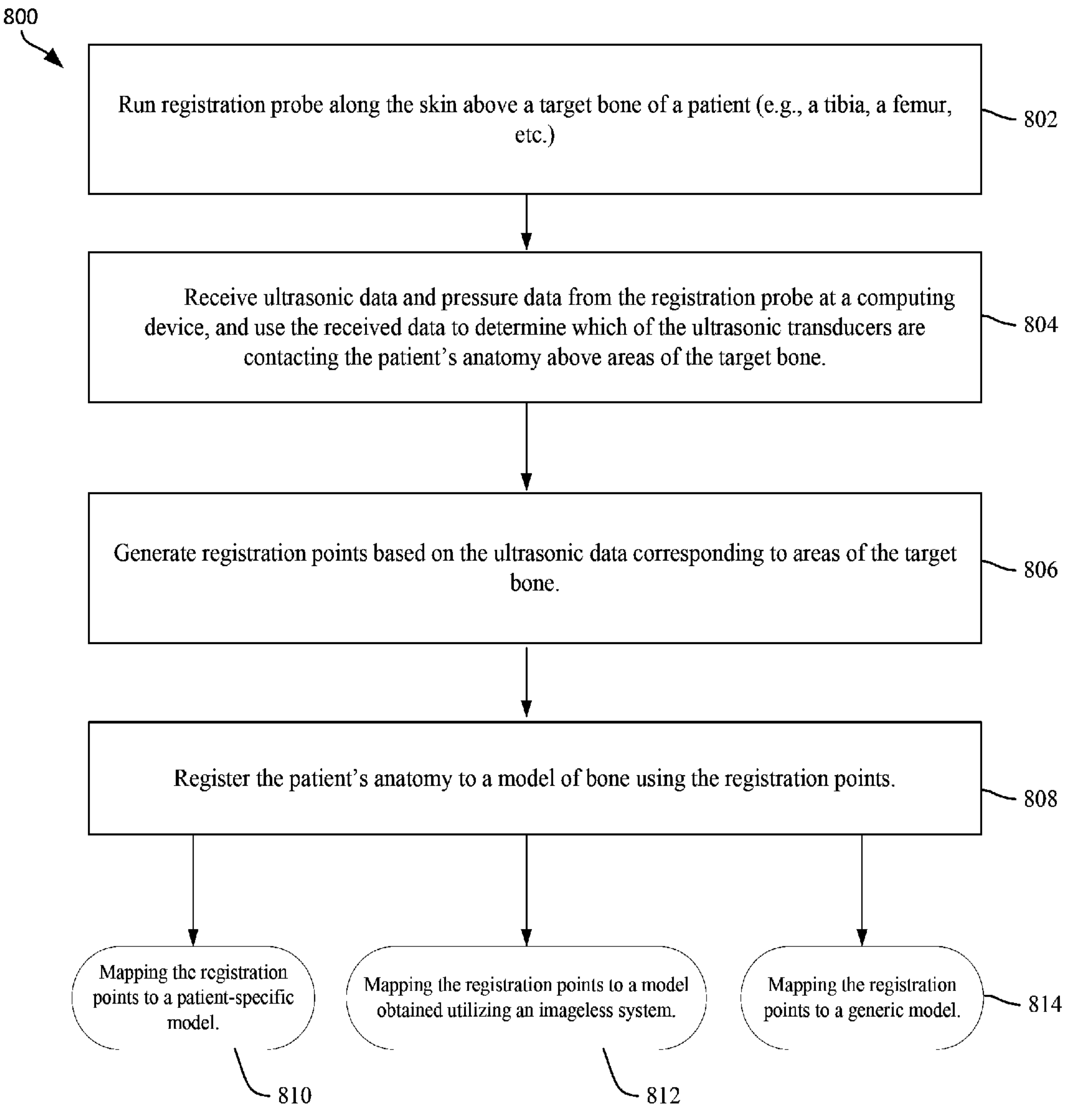

800
Run registration probe along the skin above a target bone of a patient (e.g., a tibia, a femur, etc.)
802
Receive ultrasonic data and pressure data from the registration probe at a computing device, and use the received data to determine which of the ultrasonic transducers are contacting the patient's anatomy above areas of the target bone.
804
Generate registration points based on the ultrasonic data corresponding to areas of the target bone.
806
Register the patient's anatomy to a model of bone using the registration points.
808
Mapping the registration points to a patient-specific model.
810
Mapping the registration points to a model obtained utilizing an imageless system.
812
Mapping the registration points to a generic model.
814

FIG. 8

SYSTEMS AND METHODS OF REGISTRATION USING AN ULTRASOUND PROBE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This application claims the benefit of and priority to U.S. Provisional Application No. 61/747,784, filed Dec. 31, 2012, which is incorporated by reference herein in its entirety.

[0002] This application is related to U.S. application Ser. No. 13/710,955, titled "Registration Using Phased Array Ultrasound," filed Dec. 11, 2012, which is incorporated by reference herein in its entirety.

BACKGROUND

[0003] When performing computer-assisted surgery (CAS) and/or robotically-assisted surgery (RAS), it is often desirable to perform a registration step to align the computerized bone model with the actual patient bone. Existing systems achieve this goal by measuring point locations on the physical bone surface with a calibrated probe and feeding the point locations to the CAS/RAS system. Drawbacks of this approach include the need to use a sharp probe to penetrate the soft tissue surrounding the bone and the need to collect numerous intra-incision points.

SUMMARY

[0004] One embodiment of the invention relates to a system for registration of a bone structure. The system for registration of a bone structure includes a registration probe and a processing circuit. The registration probe includes a two-dimensional array of a plurality of ultrasonic transducers coupled to a rounded tip of the probe, wherein the ultrasonic transducers are configured to provide ultrasonic data. The processing circuit is configured to receive ultrasonic data from the ultrasonic transducers, determine which of the ultrasonic transducers are in contact with anatomy of a patient, generate registration points based on the ultrasonic data and the determination of which of the ultrasonic transducers are in contact with the anatomy of the patient, and register the anatomy of the patient to a model of bone using the registration points.

[0005] Another embodiment of the invention relates to a method of registration of a bone structure. The method includes receiving ultrasonic data of a patient's anatomy from a registration probe that includes a two-dimensional array of a plurality of ultrasonic transducers coupled to a rounded tip of the registration probe, wherein the ultrasonic transducers are configured to provide ultrasonic data of the patient's anatomy, determining which of the ultrasonic transducers are contacting the patient's anatomy, generating registration points based on the ultrasonic data of the patient's anatomy and the ultrasonic transducers that are contacting the patient's anatomy, and registering the patient's anatomy to a model of bone using the registration points.

[0006] Another embodiment of the invention relates to a non-transitory computer-readable medium having instructions stored thereon for execution by a processing circuit. The instructions include instructions to receive ultrasonic data of a patient's anatomy from a registration probe that includes an array of a plurality of ultrasonic transducers coupled to a rounded tip of the probe, wherein the ultrasonic transducers are configured to provide ultrasonic data of the patient's anatomy, instructions to determine which of the ultrasonic transducers are contacting the patient's anatomy, instructions to generate registration points based on the ultrasonic data of the patient's anatomy and the ultrasonic transducers that are contacting the patient's anatomy, and instructions to register the patient's anatomy to a model of bone using the registration points.

[0007] Alternative exemplary embodiments relate to other features and combinations of features as may be generally recited in the claims.

BRIEF DESCRIPTION OF THE FIGURES

[0008] The disclosure will become more fully understood from the following detailed description, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements, in which:

[0009] FIG. **1** is a diagram of a registration system in accordance with an exemplary embodiment.

[0010] FIG. **2** is a schematic diagram of a registration probe in accordance with an exemplary embodiment.

[0011] FIG. **3** is a schematic diagram of a registration probe tip including an ultrasound transducer array in accordance with an exemplary embodiment.

[0012] FIG. **4** is a schematic diagram of a registration probe tip including an ultrasound transducer array in accordance with an exemplary embodiment.

[0013] FIG. **5** is a flow diagram of a registration process in accordance with an exemplary embodiment.

[0014] FIG. **6** is a flow diagram of a registration process in accordance with an exemplary embodiment.

[0015] FIG. **7** is a flow diagram of a registration process in accordance with an exemplary embodiment.

[0016] FIG. **8** is a flow diagram of a registration process in accordance with an exemplary embodiment.

DETAILED DESCRIPTION

[0017] Before turning to the figures, which illustrate the exemplary embodiments in detail, it should be understood that the application is not limited to the details or methodology set forth in the description or illustrated in the figures. It should also be understood that the terminology is for the purpose of description only and should not be regarded as limiting.

[0018] Referring to FIG. **1**, a bone structure registration system **100** is shown according to an exemplary embodiment. Registration system **100** includes a processing circuit, depicted as computing device **106**, and an ultrasound probe **108** having rounded tip. The rounded tip of the probe includes a two-dimensional array of ultrasonic transducers **110**. Although any suitable ultrasound transducer technology, such as piezoelectric transducers, may be used in implementing the described systems and methods herein, in an exemplary embodiment, ultrasonic transducers **110** include capacitive micromachined ultrasound transducers (CMUTs). A CMUT includes two plate electrodes which are DC biased. One plate is driven with an additional AC signal. In addition to the substrate, the body of each CMUT includes a cavity, a membrane, and the electrode. Other layers may be included as needed, e.g., an insulating layer may also be included to prevent the two electrodes from coming into contact. A single transducer may be made up of multiple CMUTs in parallel, with the transducer elements then being arranged to form a desired array. An exemplary two-dimensional array of ultrasound transducers is described in detail in U.S. application Ser. No. 13/710,955, incorporated by reference above. The ultrasonic transducers provide ultrasonic data relating to the anatomy of a patient to computing device **106**, which processes the received ultrasonic data. Transmission of ultrasonic data from ultrasound probe **108** to computing device **106** may be implemented via wired or wireless communications according to any protocol(s) known to those of skill in the art. Computing device **106** generates registration points based on received ultrasonic data, determines which of the ultrasonic transducers are providing acceptable signals (e.g., which transducers are in contact with bone, cartilage, or other soft tissue), and registers the anatomy of the patient to a model of bone.

[0019] The processing circuit of bone structure registration system **100**, which is represented in FIG. **1** as computing device **106**, includes a processor and memory device. The processor can be implemented as a general purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable electronic processing components. The memory device (e.g., memory, memory unit, storage device, etc.) is one or more devices (e.g., RAM, ROM, Flash memory, hard disk storage, optical storage, etc.) for storing data and/or computer code for completing or facilitating the various processes and functions described in the present application. The memory device may be or include volatile memory or non-volatile memory. The memory device may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present application. According to an exemplary embodiment, the memory device is communicably connected to the processor via the processing circuit and includes computer code for executing (e.g., by the processing circuit and/or processor) one or more processes described herein.

[0020] In an exemplary embodiment, computing device **106** is configured to communicate with ultrasound probe **108**. Furthermore, computing device **106** may receive information related to surgical procedures and may perform various functions related to performance of surgical procedures. For example, computing device **106** may have software modules as necessary to perform functions related to image analysis, surgical planning, registration, and navigation (e.g., of the probe or other surgical elements). As another example, computing device **106** may have software modules as necessary to control the operation of ultrasound probe **108**. This includes the command set and protocol required to control the operation of the two-dimensional array of ultrasonic transducers **110** of ultrasound probe **108**. The command set includes commands for enabling and disabling particular ultrasonic transducers of two-dimensional array of ultrasonic transducers **110**, enabling and disabling subsets of two-dimensional array of ultrasonic transducers **110**, and steering and focusing beams generated by the ultrasonic transducers.

[0021] In an exemplary embodiment, computing device **106** contains software for determining which specific ultrasonic transducers of two-dimensional array of ultrasonic transducers **110** are in contact (or are sufficiently close) to the anatomy of a patient (e.g., bone, cartilage, other soft tissue, etc.) to provide adequate ultrasonic signals. Computing device **106** may utilize filtering algorithms to filter signals from the two-dimensional array based on intensity. When the ultrasound probe **108** is contacting the anatomy of a patient, some portions of the two-dimensional array will contact the anatomy of the patient and other portions of the two-dimensional array will not. The portions that are not touching the anatomy of the patient will not be in direct acoustical contact with the patient. Without direct acoustical contact, an ultrasonic signal generated by an ultrasonic transducer will not result in a high quality return signal. An exemplary filtering algorithm may apply a threshold or high-pass filter to received signals in order to filter out lower intensity signals provided from transducers that are not in contact the patient's anatomy. In this manner, computing device **106** may determine which transducers are providing higher quality signals and are therefore contacting the patient's anatomy. Computing device **106** may utilize or otherwise prioritize this information in selecting a subset of transducers to receive data from, in generating registration points, and in registering the anatomy of the patient to a model of bone. It should be noted that the scope of the present application is not limited to a particular method of filtering. Additionally, an acoustic coupling medium may be disposed between the two-dimensional array of ultrasonic transducers **110** and a patient's skin to facilitate reliable transmission and receipt of ultrasound signals.

[0022] In an exemplary embodiment, computing device **106** contains software for registering the anatomy of the patient to a model of bone. Registration is based on the ultrasonic data received from ultrasound probe **108**. In some embodiments, registration may also be supplemented by pressure data, in addition to location and tracking data. Computing device **106** may generate registration points using any received data from ultrasound probe **108** (e.g., by analyzing collected delay and amplitude data to identify a surface of the underlying bone structure). The registration points may correspond to certain locations or an identified surface of the patient to be mapped (or otherwise correlated or registered) to a model of bone. The registration point may then be mapped, e.g., via a best fit or otherwise, to a patient-specific model based on a prior imaging scan, such as a CT, MRI, or other scan type known to those of skill in the art. Alternatively, the registration points may be mapped to a model obtained utilizing an imageless system known to those of skill in the art, such as systems utilizing statistically shaped models and methods of bone morphing. In yet another embodiment, the registration points may be mapped to a general bone model.

[0023] A tracking system (such as an optical tracking system) can be used to track the location of the bone structure and the ultrasound probe **108**. The tracking system may include trackable markers, such as optical arrays, which are fixed to the patient's bone structure, to the ultrasound probe **108**, and to any other tracked objects within the registration system **100**. Data related to the location of the tracked objects is received by computing device **106**. The tracking data is used to determine the actual, physical location of the bone structure such that the physical location can be registered to the model of bone (which is in virtual, software space). Once the physical bone structure is registered to the virtual model of bone, the tracking system is able to accurately track the location of the bone structure during a surgical procedure.

[0024] In an exemplary registration process, computing device **106** determines the location and orientation of the two-dimensional array of ultrasonic transducers **110** of the ultrasound probe **108** (obtained by tracking a trackable marker fixed to the ultrasound probe **108**) relative to the location and orientation of the trackable marker fixed to the bone structure. Computing device **106** causes each ultrasonic transducer to produce a signal and records the echo amplitude and delay of the signal. The echo amplitude and delay may be recorded in conjunction with a targeted location to produce a listing of associated locations and amplitudes/delays. Computing device **106** can then use the collected amplitude and delay data to register the underlying bone structure to a model of the structure.

[0025] FIG. **1** further includes display **102** and interface **104**. Interface **104** may be a user interface that allows a clinician or other operator to interact with computing device **106** and ultrasound probe **108**. Interface **104** may include a keyboard, a mouse, display **102**, a touch screen, etc. Interface **104** allows a clinician to send and receive commands and control signals to ultrasound probe **108** for use as described herein. Computing device **106** may format data for use on display **102** (e.g., a CRT monitor, an LCD screen, etc.). For example, computing device **106** may generate appropriate signals such that received ultrasonic information is displayed as real time images.

[0026] Referring to FIG. **2**, a registration probe **200** is shown in accordance with an exemplary embodiment. Registration probe **200** may be configured for use internally (e.g., through an incision) or externally (e.g., on a patient's skin). Registration probe **200** includes a rounded (or otherwise curved) tip **202**, which may be rigid or flexible in nature. Rounded tip **202** includes an array of ultrasonic transducers **204**. The array of ultrasonic transducers **204** may be a two-dimensional array of ultrasonic transducers **110** as described in connection with FIG. **1**. The array of ultrasonic transducers **204** is operably coupled to rounded tip **202**. The array of ultrasonic transducers **204** may be coupled to rounded tip **202** using any manner known to those of skill in the art. In some embodiments, array of ultrasonic transducers **204** may also be removable, or otherwise replaceable. For example, a particular array of ultrasonic transducers **204** with certain dimensions or sensor characteristics may be selected for a particular purpose. In an exemplary embodiment, the array of ultrasonic transducers **204** is formed from an array of capacitive micromachined ultrasonic transducer (CMUT) devices.

[0027] In another embodiment, the array of ultrasonic transducers **204** may also include pressure sensing devices. Exemplary pressure sensing devices include microelectromechanical systems (MEMS) pressure sensors, although other pressure sensing devices are envisioned. Such pressure sensing devices are configured to provide pressure data (e.g., force data) to a computing device (e.g., computing device **106** of FIG. **1**). Pressure data is used by the computing device to supplement the determination of which transducers are in contact with a patient's anatomy. As an example, the magnitude of a pressure signal provided may be evaluated to determine which transducers are in contact with the patient. The magnitude may be evaluated in light of values representing the rigidity of bone, cartilage, or other patient contact surface. In one embodiment, pressure sensing devices are interspersed between ultrasonic transducers. In another embodiment, pressure sensing devices may be part of a separate array coupled to array of ultrasonic transducers **204** (e.g., underneath the array of ultrasonic transducers **204**).

[0028] In the exemplary embodiment shown in FIG. **2**, the registration probe further includes communication interface **206**. Communication interface **206** may be a cord or wireless transmission mechanism for connecting registration probe **200** to a computing device. Communication interface **206** facilitates the transmission and reception of data between registration probe **200** and the computing device. Data may include control signals, commands, ultrasonic information, pressure data, etc.

[0029] Referring to FIG. **3**, a registration probe tip **300** is shown in accordance with an exemplary embodiment. The registration probe tip **300** includes an array of ultrasonic transducers **302**. The array of ultrasonic transducers **302** may be an array of ultrasonic transducers as described herein (e.g., a two-dimensional array of ultrasonic transducers **110** of FIG. **1**). Registration probe tip **300** is depicted as curved in nature, and may be flexible or rigid. The array of ultrasonic transducers **302** is operably coupled to registration probe tip **300**. In an exemplary embodiment, the array of ultrasonic transducers **302** includes capacitive micromachined ultrasonic transducer (CMUT) devices configured in a two-dimensional array. Each of the CMUT devices provides ultrasonic signals (e.g., source signals, echo, and reflection information) that may be used by a computing device in registering the anatomy of the patient to a model of bone. Each of the CMUT devices may be controlled by a computing device individually, in subsets, or as entire array. Such an array of CMUT devices is capable of sending and receiving signals at high frequencies, which is useful in allowing a clinician to quickly gather a high number of registration points. A computing device may process received ultrasonic information as described herein to determine which of the CMUT devices are in contact with the anatomy of a patient. Based on the amplitude and corresponding delay of ultrasonic reflections detected by the CMUT devices, the computing device may further determine the nature of the patient anatomy being scanned (e.g., bone, cartilage, other soft tissue, etc.). In another embodiment, piezoelectric transducers may be used in implementing the described systems and methods herein.

[0030] FIG. **3** also depicts patient anatomy **304** in contact with a portion of registration probe tip **300**. Patient anatomy **304** is shown as curved in nature, but may also be flat, and may relate to any anatomy being scanned. Patient anatomy **304** may include bone, cartilage, or other soft tissue. Due to the curved nature of registration probe tip **300**, at a point of contact (such as that shown with patient anatomy **304**), there will be ultrasonic transducers that are in proper contact with the patient anatomy **304** for imaging purposes. The curved probe tip in combination with the two-dimensional array of transducers thus ensures the sufficient transducer contact to adequately image the bone surface. By implementing the contact detection systems discussed herein, a computing device may eliminate data from or disable ultrasonic transducers that are not in proper contact with the anatomy (e.g., ultrasonic transducers with signals indicating attenuation or loss). The computing device may continue to receive data from ultrasonic transducers indicating strong signals with minimal attenuation. In this manner, the computing device may obtain the points required to perform registration with an improved accuracy and precision. Such enabling and disabling of ultrasonic transducers may be controlled by a computing device in real time. In another embodiment, a computing device may receive data from all transducers, but may accept or ignore data from specific ultrasonic transducers in real time to achieve the same effect as enabling or disabling transducers.

[0031] Referring to FIG. **4**, registration probe tip **400** is shown in accordance with an exemplary embodiment. Registration probe tip **400** includes an array of ultrasonic transducers **402**. The array of ultrasonic transducers **402** is similar to the other arrays described herein (e.g., the two-dimensional array of ultrasonic transducers **110** of FIG. **1**), but includes pressure sensors **404** interspersed among the ultrasonic transducers **402**. Pressure sensors **404** are configured to provide pressure data corresponding to forces generated via contact with a patient's anatomy. Each of the pressure sensors may provide data to a computing device individually, in subsets, or as entire array. Pressure data is transmitted to the computing device (e.g., computing device **106** of FIG. **1**) and evaluated to determine which ultrasonic transducers, or which portions of registration probe tip, are in contact with the anatomy of a patient. Contact detection using pressure data may supplement or replace contact detection processes that utilize filtering techniques as described above. In one embodiment, registration probe tip **400** includes a pressure sensor for each ultrasonic transducer. In another embodiment, registration probe tip **400** includes pressure sensors configured to provide force data corresponding to a subset of ultrasonic transducers. Pressure sensors may include such devices as pressure transducers, pressure transmitters, pressure senders, pressure indicators and piezometers, manometers, or micro electromechanical systems (MEMS).

[0032] In an exemplary embodiment, pressure sensors **404** are MEMS devices. Such MEMS devices are typically constructed using layers of polysilicon and layers of metals, and may be configured as pressure sensors as known to those of skill in the art. A MEMS pressure sensor may provide data relating to capacitance changes, which result from contact of a mechanical structure with a patient's anatomy. The data from the MEMS pressure sensor may be further processed to determine pressure values. As depicted in FIG. **4**, pressure data provided by pressure sensors **404** may be used by a computing device in determining contact points on patient anatomy **406**. Although pressure sensors **404** are shown as interspersed between the array of ultrasonic transducers **402**, other embodiments may include other configurations, such as placing pressure sensors behind the array of ultrasonic transducers.

[0033] Referring to FIG. **5**, a flow diagram of a bone structure registration process **500** is shown in accordance with an exemplary embodiment. In step **502**, ultrasonic data corresponding to a patient's anatomy is received from a two-dimensional array of ultrasonic transducers on a registration probe, as described herein. In step **504**, the received ultrasonic data is processed to determine which of the ultrasonic transducers are contacting the patient's anatomy. In step **506**, the data is filtered to remove the data from the subset of ultrasonic transducers that are not contacting the patient's anatomy. In step **508**, registration points are generated based on the ultrasonic data from the ultrasonic transducers in contact with the anatomy of the patient. In step **510**, the patient's anatomy is registered to a model of bone using the generated registration points. Registration may be implemented using a variety of methods, including mapping the registration points to a patient-specific model (step **512**), mapping the registration points to model obtained by utilizing an imageless system (step **514**), or mapping the registration points to a generic model (step **516**). Other methods of registration, as known to those skilled in the art, are also envisioned.

[0034] Referring to FIG. **6**, a flow diagram of a bone structure registration process **600** is shown in accordance with an exemplary embodiment. In step **602**, ultrasonic data corresponding to a patient's anatomy is received from a two-dimensional array of CMUT ultrasonic transducers on a registration probe, as described herein. In step **604**, pressure data is received corresponding to contact between the registration probe and a patient's anatomy. The pressure data is provided by MEMS pressure sensors on the registration probe. In step **606**, the received ultrasonic data and the pressure data are used to determine which of the ultrasonic transducers are contacting the patient's anatomy. This determination may make use of filtering techniques as discussed herein. In step **608**, data is selected from the subset of ultrasonic transducers that are determined to be contacting the patient's anatomy. In step **610**, registration points are generated based on the selected ultrasonic data corresponding to the ultrasonic transducers that are in contact with the anatomy of the patient. In step **612**, the patient's anatomy is registered to a model of bone using the generated registration points. Registration may be implemented using a variety of methods, including mapping the registration points to a patient-specific model (step **614**), mapping the registration points to model obtained by using an imageless system (step **616**), or mapping the registration points to a generic model (step **618**). Other methods of registration, as known to those skilled in the art, are also envisioned.

[0035] Referring to FIG. **7**, a flow diagram of a bone structure registration process **700** is shown in accordance with an exemplary embodiment. In step **702**, a registration probe as described herein is inserted through an incision in the patient (e.g., incision in the knee, incision in the hip, etc.). In step **704**, ultrasonic data corresponding to a patient's anatomy is received from the two-dimensional array of CMUT ultrasonic transducers on the registration probe. In step **706**, pressure data is received corresponding to contact between the registration probe and a patient's anatomy. The pressure data is provided by MEMS pressure sensors on the registration probe. In step **708**, the received ultrasonic data and the pressure data are used (e.g., by a computing device) to determine which of the ultrasonic transducers are contacting the patient's anatomy. In step **710**, the data corresponding to ultrasonic sensors contacting the patient's anatomy is further processed to distinguish the anatomy (e.g., bone, cartilage, etc.). In step **712**, registration points are generated based on the ultrasonic data corresponding to areas of bone. In step **714**, the patient's anatomy is registered to a model of bone using the generated registration points. Registration may be implemented using a variety of methods, including mapping the registration points to a patient-specific model (step **716**), mapping the registration points to model obtained by using an imageless system (step **718**), or mapping the registration points to a generic model (step **720**). Other methods of registration, as known to those skilled in the art, are also envisioned.

[0036] Referring to FIG. **8**, a flow diagram of a bone structure registration process **800** is shown in accordance with an exemplary embodiment. In step **802**, a registration probe (e.g., ultrasound probe **108** of FIG. **1**) is guided along the skin above a target bone of a patient (e.g., a tibia, a femur, etc.). In step **804**, ultrasonic data and pressure data are received from the registration probe by a computing device. The computing device uses the received data to determine which of the ultrasonic transducers are contacting the patient's anatomy above areas of the target bone. In step **806**, registration points are generated based on the ultrasonic data corresponding to areas of the target bone. In step **808**, the patient's anatomy is registered to a model of bone using the generated registration points. Registration may be implemented using a variety of methods, including mapping the registration points to a patient-specific model (step **810**), mapping the registration points to model obtained by using an imageless system (step **812**), or mapping the registration points to a generic model (step **814**). Other methods of registration, as known to those skilled in the art, are also envisioned.

[0037] The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure may be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage, other magnetic storage devices, solid state storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a machine, the machine properly views the connection as a machine-readable medium. Thus, any such connection is properly termed a machine-readable medium. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

[0038] Although a specific order of method steps may be described, the order of the steps may differ from what is described. Fewer, additional, and/or different operations may be performed. Also, two or more steps may be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen and on designer choice. All such variations are within the scope of the disclosure. Likewise, software implementations could be accomplished with standard programming techniques with rule based logic and other logic to accomplish any connection steps, processing steps, comparison steps, and decision steps.

What is claimed is:

1. A system for registration of a bone structure, comprising:

a registration probe having a two-dimensional array of a plurality of ultrasonic transducers coupled to a rounded tip of the probe, wherein the ultrasonic transducers are configured to provide ultrasonic data; and

a processing circuit configured to:

receive ultrasonic data from the ultrasonic transducers;

determine which of the ultrasonic transducers are in contact with anatomy of a patient;

generate registration points based on the ultrasonic data and the determination of which of the ultrasonic transducers are in contact with the anatomy of the patient; and

register the anatomy of the patient to a model of bone using the registration points.

2. The system of claim **1**, wherein the ultrasonic transducers include capacitive micromachined ultrasonic transducer (CMUT) devices.

3. The system of claim **1**, wherein receiving ultrasonic data from the ultrasonic transducers comprises receiving ultrasonic data from a subset of the plurality of ultrasonic transducers.

4. The system of claim **3**, wherein the processing circuit is further configured to select the subset of the plurality of ultrasonic transducers from which to receive ultrasonic data.

5. The system of claim **1**, wherein determining which of the ultrasonic transducers are in contact with the anatomy of the patient includes filtering based on an intensity of an ultrasonic signal.

6. The system of claim **1**, wherein the registration probe further comprises a plurality of pressure sensors coupled to the rounded tip of the probe.

7. The system of claim **6**, wherein the pressure sensors are interspersed between the ultrasonic transducers.

8. The system of claim **6**, wherein the pressure sensors include microelectromechanical systems pressure sensors.

9. The system of claim **6**, wherein the pressure sensors are configured to provide pressure data, and wherein the processing circuit is further configured to receive pressure data from the pressure sensors.

10. The system of claim **9**, wherein determining which of the ultrasonic transducers are in contact with the anatomy of the patient is further based on the pressure data.

11. The system of claim **1**, wherein the model of bone is based on at least one of a CT scan or an MRI.

12. The system of claim **1**, wherein the model of bone is a model obtained utilizing an imageless system.

13. A method of registration of a bone structure, comprising:

receiving ultrasonic data of a patient's anatomy from a registration probe that includes a two-dimensional array of a plurality of ultrasonic transducers coupled to a rounded tip of the registration probe, wherein the ultrasonic transducers are configured to provide ultrasonic data of the patient's anatomy;

determining which of the ultrasonic transducers are contacting the patient's anatomy;

generating registration points based on the ultrasonic data of the patient's anatomy and the ultrasonic transducers that are contacting the patient's anatomy; and

registering the patient's anatomy to a model of bone using the registration points.

14. The method of claim **13**, wherein receiving ultrasonic data of the patient's anatomy from the ultrasonic transducers comprises receiving ultrasonic data from a subset of the plurality of ultrasonic transducers.

15. The method of claim **14**, further comprising selecting the subset of the plurality of ultrasonic transducers from which to receive ultrasonic data of the patient's anatomy.

16. The method of claim **13**, wherein determining which of the ultrasonic transducers are contacting the patient's anatomy is based on filtering an intensity of the ultrasonic data.

17. The method of claim **13**, further comprising receiving pressure data from pressure sensors, wherein the registration probe further includes a plurality of pressure sensors coupled to the rounded tip of the probe, wherein the pressure sensors are configured to provide pressure data, and wherein determining which of the ultrasonic transducers are contacting the patient's anatomy is further based on the pressure data.

18. A non-transitory computer-readable medium having instructions stored thereon for execution by a processing circuit, the instructions comprising:

instructions to receive ultrasonic data of a patient's anatomy from a registration probe that includes an array of a plurality of ultrasonic transducers coupled to a rounded tip of the probe, wherein the ultrasonic transducers are configured to provide ultrasonic data of the patient's anatomy;

instructions to determine which of the ultrasonic transducers are contacting the patient's anatomy;

instructions to generate registration points based on the ultrasonic data of the patient's anatomy and the ultrasonic transducers that are contacting the patient's anatomy; and

instructions to register the patient's anatomy to a model of bone using the registration points.

19. The non-transitory computer-readable medium of claim **18**, wherein the instructions to receive ultrasonic data of the patient's anatomy from the ultrasonic transducers comprise instructions to receive ultrasonic data from a subset of the plurality of ultrasonic transducers.

20. The non-transitory computer-readable medium of claim **18**, further comprising instructions to receive pressure data from pressure sensors, wherein the registration probe further includes a plurality of pressure sensors coupled to the rounded tip of the probe, wherein the pressure sensors are configured to provide pressure data, and wherein determining which of the ultrasonic transducers are contacting the patient's anatomy is further based on the pressure data.

* * * * *

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摘要(译)

用于配准骨骼结构的系统包括配准探针和处理电路。配准探针包括耦合到探针的圆形尖端的多个超声换能器的二维阵列，其中超声换能器配置成提供超声数据。处理电路被配置为从超声换能器接收超声数据，确定哪个超声换能器与患者的解剖结构接触，基于超声数据生成配准点以及确定哪个超声换能器与超声换能器接触。患者的解剖结构，并使用配准点将患者的解剖结构记录到骨骼模型中。