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Acoustic registration of internal and external ultrasound probes

Abstract

An acoustically registerable probe includes a transducer (**212**) to generate acoustic pulses, and a beamformer (**222**) coupled to the transducer to adjust a field of view of the acoustic pulses. The transducer is configured to iteratively send and receive acoustic energy with a decremented field of view angles to identify a position of the transducer (**216**) to other transducers and to reveal positions of the other transducers to the transducer through a medium carrying the acoustic pulses to register the transducer to the other transducers coupled to the medium.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4249539	12/1980	Vilkomerson	600/461	A61B 8/0833
5349262	12/1993	Grenon	310/334	G01S 15/8927
6128958	12/1999	Cain	N/A	N/A
9282946	12/2015	Vignon	N/A	N/A
2004/0225218	12/2003	Guracar	600/443	G01S 15/8911
2006/0009695	12/2005	Mathew	600/437	G16H 40/67
2012/0071758	12/2011	Lachaine	600/443	A61N 5/1049
2012/0237102	12/2011	Savitsky	382/131	G09B 23/286
2013/0041252	12/2012	Vignon	600/424	A61B 8/5207
2014/0276003	12/2013	Wang	N/A	N/A
2016/0242746	12/2015	Rao	N/A	A61B 6/56

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2001516075	12/2000	JP	N/A
2012172458	12/2011	WO	N/A
2013038217	12/2012	WO	N/A

OTHER PUBLICATIONS

University of Washington Lecture 6—Ultrasound; https://courses.washington.edu/bioen508/Lecture6-US.pdf (Year: 2007). cited by examiner
Ortega et al. Automatic Definition of an Anatomic Field of View for Volumetric Cardiac Motion Estimation at High Temporal Resolution; Published on Jul. 24, 2017; Applied Sciences 2017, 7,

752 (Year: 2017). cited by examiner
Merdes, Christine L. et al “Locating a Catheter Transducer in a Three-Dimensional Ultrasound Imaging Field”, IEEE Transactions on Biomedical Engineering, vol. 48, No. 12, Dec. 2001. cited by applicant
Mung, Jay et al “Design and in vitro Evaluation of a Real-Time Catheter Localization System using Time of Flight Measurements from Seven 3.5 MHz Single Element Ultraound Transducers towards Abdominal Aortic Aneurysm Procedures”, Ultrasonics, Vpl. 51, pp. 768-775. 2011. cited by applicant
Szmigielski, Cezary et al “Real-Time 3D Fusion Echocardiography”, JACC: Cardiovascular Imaging, vol. 3, No. 7, 2010, pp. 682-690. cited by applicant

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Background/Summary

BACKGROUND
Technical Field
(1) This disclosure relates to ultrasound devices and more particularly to acoustic registration of ultrasound probes.
Description of the Related Art
(2) Several technologies may be employed for spatially registering ultrasound probes for the purpose of image fusion between the images generated using the probes. These technologies include image-based image registration, mechanical sweeping devices (e.g., a manual sweeping, brachytherapy stepper, intravenous ultrasound (IVUS) pull-back, early generations “rocking” 3D imaging probes, etc.), electromagnetic (EM) tracking, optical tracking, fiber-optic tracking (Fiber-Optical Real Shape™), optical-position-sensing-enabled ultrasound imaging, etc.
(3) These technologies may suffer from issues that may include some of the following. For example, image-based registration is computationally intensive and is not real-time due to computational delay. Mechanical devices are restrictive with respect to the range of probe motion, positions allowed and tracking accuracy. EM tracking has the disadvantage of requiring set up and calibration of an external tracking system. In addition, tracking accuracies (typically a few mm) are degraded by the presence of metallic objects. Optical (external, interferometric, fiber-optic) are high resolution but require the setup of an external system, and may be expensive.
SUMMARY
(4) In accordance with the present principles, an acoustically registerable probe includes a transducer to generate acoustic pulses, and a beamformer coupled to the transducer to adjust a field of view of the acoustic pulses. The transducer is configured to iteratively send and receive acoustic energy with a decremented field of view angles to identify a position of the transducer to other transducers and to reveal positions of the other transducers to the transducer through a medium carrying the acoustic pulses to register the transducer to the other transducers coupled to the medium.
(5) A system for acoustically registering probes includes a first probe coupled to a medium to transmit and receive acoustic pulses and a second probe coupled to the medium to transmit and receive acoustic pulses such that when the first and second probes are in a field of view of each other, registration is provided by acoustic communication therebetween. The first and second probes are configured to iteratively send and receive acoustic energy with decremented field of view angles to identify a position of each other through the medium carrying the acoustic pulses to

register the first and second probes in a common coordinate system.
(6) A method for acoustically registering probes includes transmitting a first acoustic pulse at a first field of view angle from a first probe; receiving the first acoustic pulse at a second probe to measure time of flight and signal strength of the first pulse; transmitting a second acoustic pulse at a second narrower field of view angle than the first field of view angle from the second probe; receiving the second acoustic pulse at the first probe to measure time of flight and signal strength of the second pulse; and computing positions of the first probe and the second probe based upon measured times of flight and signal strengths to register the first probe and the second probe to a common coordinate system.
(7) These and other objects, features and advantages of the present disclosure will become apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

Description

BRIEF DESCRIPTION OF DRAWINGS
(1) This disclosure will present in detail the following description of preferred embodiments with reference to the following figures wherein:
(2) FIG. **1** is a block/flow diagram showing a system for acoustically registering ultrasound probes in accordance with one embodiment;
(3) FIG. **2**A is a diagram showing acoustic communication between an external and an internal probe for acoustically registering the probes in accordance with one embodiment;
(4) FIG. **2**B is a diagram showing acoustic communication between probes where one probe includes multiple elements for acoustically registering the probes in accordance with another embodiment;
(5) FIG. **3** is a diagram showing acoustic communication between probes for acoustically registering the probes in accordance with one embodiment;
(6) FIG. **4** shows ultrasound images having compound images obtained by fusing or stitching together image data from multiple probes in accordance with the present principles;
(7) FIG. **5** shows ultrasound images stitched together from multiple probes to form a larger view in accordance with the present principles;
(8) FIG. **6** is a block/flow diagram showing an ultrasound system for acoustically registering ultrasound probes in accordance with one embodiment; and
(9) FIG. **7** is a flow diagram showing a method for acoustically registering ultrasound probes in accordance with illustrative embodiments.
DETAILED DESCRIPTION OF EMBODIMENTS
(10) In accordance with the present principles, simple and accurate tracking methods and systems are provided for two or more ultrasound probes concurrently employed. The present embodiments are based on the use of the same ultrasound waves employed to form pulse-echo images from a tracked probe(s). In useful embodiments, the tracking is low-cost and does not interfere with existing workflows. In one embodiment, multiple ultrasound probes are employed in conjunction with one another to provide improved anatomy visualization. These probes can be registered acoustically with one another and to a common coordinate system to provide a comprehensive image of an area of interest or greater detail of a specific region within the area of interest. In one example, in the discipline of echocardiography, internal transesophageal echo (TEE) can provide detailed small fields of view within a heart while an external transthoracic echo (TTE) probe can provide anatomical context for improved visualization. Registration of the multiple probes is provided using ultrasound signaling for synchronized acquisition and visualization.
(11) Ultrasound positioning of intra-body instruments equipped with transducers are employed to

track 3D positions of one or more ultrasound transmitter/receivers. This can be used to determine and track a 2D or 3D pose (e.g., position and orientation) of one or several probes with respect to each other. Once registered to a common coordinate system, image processing may be employed to expand the visualization capabilities of the system. The present principles enable real-time registration of multiple ultrasound probes in space and time permitting multi-perspective imaging. This leads to improved visualization of soft tissue anatomy and reduced artifacts from device shadowing or reverberation. The present principles can be applied to any combination of ultrasound probes and for a multitude of applications such as, e.g., cranial imaging, breast imaging, renal imaging, etc.

(12) It should be understood that the present invention will be described in terms of medical instruments; however, the teachings of the present invention are much broader and are applicable to any acoustic instruments. In some embodiments, the present principles are employed in tracking or analyzing complex biological or mechanical systems. In particular, the present principles are applicable to internal and/or external tracking procedures of biological systems and procedures in all areas of the body such as the lungs, gastro-intestinal tract, excretory organs, blood vessels, etc. The elements depicted in the FIGS. may be implemented in various combinations of hardware and software and provide functions which may be combined in a single element or multiple elements.

(13) The functions of the various elements shown in the FIGS. can be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions can be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which can be shared. Moreover, explicit use of the term “processor” or “controller” should not be construed to refer exclusively to hardware capable of executing software, and can implicitly include, without limitation, digital signal processor (“DSP”) hardware, read-only memory (“ROM”) for storing software, random access memory (“RAM”), non-volatile storage, etc.

(14) Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future (i.e., any elements developed that perform the same function, regardless of structure). Thus, for example, it will be appreciated by those skilled in the art that the block diagrams presented herein represent conceptual views of illustrative system components and/or circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams and the like represent various processes which may be substantially represented in computer readable storage media and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

(15) Furthermore, embodiments of the present invention can take the form of a computer program product accessible from a computer-usable or computer-readable storage medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer readable storage medium can be any apparatus that may include, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk—read only memory (CD-ROM), compact disk—read/write (CD-R/W), Blu-Ray™ and DVD.

(16) Reference in the specification to “one embodiment” or “an embodiment” of the present principles, as well as other variations thereof, means that a particular feature, structure,

characteristic, and so forth described in connection with the embodiment is included in at least one embodiment of the present principles. Thus, the appearances of the phrase “in one embodiment” or “in an embodiment”, as well any other variations, appearing in various places throughout the specification are not necessarily all referring to the same embodiment.

(17) It is to be appreciated that the use of any of the following “/”, “and/or”, and “at least one of”, for example, in the cases of “A/B”, “A and/or B” and “at least one of A and B”, is intended to encompass the selection of the first listed option (A) only, or the selection of the second listed option (B) only, or the selection of both options (A and B). As a further example, in the cases of “A, B, and/or C” and “at least one of A, B, and C”, such phrasing is intended to encompass the selection of the first listed option (A) only, or the selection of the second listed option (B) only, or the selection of the third listed option (C) only, or the selection of the first and the second listed options (A and B) only, or the selection of the first and third listed options (A and C) only, or the selection of the second and third listed options (B and C) only, or the selection of all three options (A and B and C). This may be extended, as readily apparent by one of ordinary skill in this and related arts, for as many items listed.

(18) It will also be understood that when an element such as a layer, region or material is referred to as being “on” or “over” another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” or “directly over” another element, there are no intervening elements present. It will also be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, there are no intervening elements present.

(19) Referring now to the drawings in which like numerals represent the same or similar elements and initially to FIG. **1**, a system **100** for acoustically registering two or more probes is illustratively shown in accordance with one embodiment. System **100** may include one or more workstations or consoles **112** associated with each probe **12**, **14**. In one embodiment, a single workstation **112** may be employed for multiple probes **12**, **14**. Workstation **112** preferably includes one or more processors **114** and memory **116** for storing programs and applications. Memory **116** stores programs for acoustically registering one or more ultrasound probes with respect to each other. A position calibration module **150** is stored in memory **116** and is configured to register all ultrasound probes **12** and **14** to a single coordinate system. In addition, the position calibration module **150** updates new positions and orientations of the probes **12** as they dynamically change positions during a procedure or training session. While FIG. **1** depicts that all probes **12**, **14** can be controlled by a single ultrasound system or workstation **112** such that all beam transmission and reception can be performed synchronously, the present principles may also include multiple beam transmission and reception systems that report positions to a single or distributed position calibration module **150**.

(20) In one embodiment, multiple ultrasound probes **12**, **14** are employed in conjunction with one another to provide improved anatomy visualization. For example, in echocardiography, an internal transesophageal echo (TEE) probe **14** can provide detailed small fields of view within a heart (volume **130**) while an external transthoracic echo (TTE) probes **12** can provide anatomical context for improved visualization. These probes **12**, **14** can be registered to each other to using ultrasound signaling therebetween to synchronize acquisition and visualization.

(21) The registration process relies on signal exchanges between the probes **12**, **14**. The position calibration module **150** computes the probes' positions based on transmitted/received signals between the probes **12**, **14**. The locations are updated by the position calibration module **150** to generate transformation matrices or other position indicators to register multiple image volumes in a common reference space or coordinate system **132** for incoherent volume compounding or side-by-side display.

(22) Image configuration preferences may be input by a user into the system **100** through an image generation module **148**. The image generation module **148** may stitch or fuse images obtained from multiple probes **12**, **14** to create a single view or may generate more detailed views of a particle area or areas of interest sequentially or concurrently (multi-views).

(23) In one embodiment, the probe **14** may be positioned internally within the volume **130** within a subject **152**, while the probes **12** are positioned externally on the subject **152**. External probes **12** are more easily tracked in the common space **132**. The external probes **12** can be registered to one another using one or more methods. These methods may include spatial encoding, electromagnetic (EM) tracking, or other methods to generate a standard reference coordinate space **132**. Such tracking is optional since the probes **12**, **14** can be acoustically registered in accordance with aspects of the present principles. In one example, if EM tracking is employed, one or more probes **12** may include an EM sensor **16** that tracks movement of the probes **12** in an EM field created by an EM generator (not shown). With the positions of the external probes **12** known, the internal probe(s) **14** transmit a series of directed acoustic pulses, e.g., over a large field of view, while the probes **12** passively receive the pulses. This is repeated with the external probes **12** actively transmitting while the internal probe(s) passively receive.

(24) Based on signal strength, time of flight and/or other acoustic wave characteristics of the received echoes, the probes **12**, **14** can identify a rough direction in which the other probes **12**, **14** are located. In the next iteration or cycle, focused pulses will again be transmitted, but over a smaller and more directed field of view. This can be repeated iteratively and synchronously until each probe has zeroed in on the location of the other probes **12**, **14**. The position calibration module **150** stores the positions and orientations of each probe **12**, **14** at each iteration. Once the locations (e.g., distance and direction) of the probes **12**, **14** are known with respect to one another, a coordinate transformation can be generated by the position calibration module **150** to register all probes in the same coordinate space **132**.

(25) The probes **12**, **14** need to include overlap in their operating bandwidth to ensure that the probes **12**, **14** can acoustically recognize one another. For example, the bandwidths of the probes **12**, **14** preferably include a same central frequency as the other probes such that the transmitted pulses can be detected. If the probes **12**, **14** are to perform compounded imaging (e.g., two or more probes contributing to a single compound or stitched image) the probes **12**, **14** need to be within imaging frustums of the each other.

(26) In one embodiment, the external probes **12** may remain fixed and the internal probe **14** may be moved. However, the present principles are not limited to this configuration, and one or more probes may be fixed and one or more probes may be moving at any time. In a particularly useful embodiment, the external probes **12** may include transthoracic probes that remain fixed on a chest wall of the subject **152**, while the internal probe of probes **14** can move within the volume **130** of the subject **152**. If the internal probe is a TEE probe, the TEE probe may move up and down the gut, and at each position of the TEE probe, a re-registration may be needed. If the TEE probe (**14**) moves out of view of one of the external probes **12** (e.g., a TTE probe), another TTE probe (**12**) could be activated for the procedure, if it is in a better position (within view).

(27) In one embodiment, the image generation module **148** may be configured to setup up different viewing configurations. These may include a single compound view, which combines received data from multiple probes, multiple pane views including separate images for each probe, fused images from the probes or any combination thereof. The images may be directly displayed or processed prior to display. The images can be displayed on a display device **118** for viewing the internal images of the subject **152**. Display **118** may also permit a user to interact with the workstation **112** and its components and functions, or any other element within the system **100**. This is further facilitated by an interface **120** which may include a keyboard, mouse, a joystick, a haptic device, or any other peripheral or control to permit user feedback from and interaction with the workstation **112**.

(28) It should be understood that the present principles may be employed using different types of probes and different types of acoustic technologies (e.g., intravenous ultrasound (IVUS), endoscopic ultrasound (EUS), intracardiac echocardiography (ICE), endobronchial ultrasound (EBUS), TEE, TTE, etc. In some embodiments, probes **12**, **14** may include a single element with an A-mode, M-mode, etc. scanner. The probes **12**, **14** may image in Doppler™, SonoCT™ or other modes with any combination being displayed. The probes **12**, **14** may employ combinations of any sensor technology, e.g., piezoelectric (PZT), capacitive micromachined ultrasonic transducers (cMUT), optical sensors, etc. in each probe **12**, **14**.

(29) Referring to FIG. **2**A, the probe **12** may include a large external ultrasound probe and the probe **14** may include a smaller ultrasound probe (e.g., a 2D ICE). A 2D ICE image from probe **14** can be registered to probe **12** (e.g., a 3D TEE image). A subset or all individual elements of the probe **12** are tracked in the coordinate system of the probe **14** (or vice versa). Tracking of any single element of the probe **12** can be done using emitted signals from the probe **14**. Focused beams **20**, **22** between the probes **14** and **12** are transmitted and received by one another in sequence while altering the angular fields of view. The positions of the probes **12**, **14** are revealed by analysis of: time of flight (yields range), and the angular information (yields beam directions and provides the signal strength). A position accuracy of 0.4 mm or less and angular accuracy of 1.2° or less can be achieved for elements separated by about 20 mm.

(30) Each probe **12**, **14** needs to be inside the field of view of the other probe (**14**, **12**). While two elements, patches or beacons may be employed to estimate the pose and position of the ultrasound elements (probes) (two elements can define a vector in space that fully characterizes the six degrees of freedom (3 translations, 3 rotations) of the object), tracking more elements is beneficial for the robustness of the estimate. Once the relative positions and orientations of the probes **12**, **14** are known, the images from both probes **12**, **14** can be displayed in the same coordinate system. The individual images can be superimposed on a single display, with each probe providing a resolution in a small area or wider area.

(31) Referring to FIG. **2**B, the probe **14** (and/or probe **12**) may include a few discrete sensors/elements **30** doing, e.g., A-mode/M-mode single sensor imaging. The sensor positions are known for the given probe and the array arrangements of sensors/elements **30** makes time of flight, position and pose information more easily computed due to the known spatial relationships of the sensors **30** on the probe **14**.

(32) Referring to FIG. **3**, acoustic registration of multiple probes may include a single TEE probe **14** with multiple TTE probes **12** constituting of a large area TTE (or LATTE probe). As illustratively depicted in FIG. **3**, a plurality of transthoracic and transesophageal probes are registered for, e.g., an interventional cardiology procedure. The registration process may include the following. A TEE probe **14** (e.g., a wire or catheter) is positioned within the esophagus or other volume in a subject, while two TTE probes **12** that are positioned on the chest wall in different intercostal spaces (e.g., between the ribs). These provide opposing groups of probes. The external probes **12** can be registered to one another using a spatial encoding, EM tracking, etc. to generate a standard reference coordinate space. In a first instance **160** of a first iteration **180**, the TTE probes **12** transmit a series of directed acoustic pulses **161** over a large field of view, while the TEE probes **14** passively receive the pulses **161**. The same process is repeated in instance **162**, with the TEE probe **14** actively transmitting pulses **163** while the TTE probes **12** passively receive the pulses **163**. Based on the strength and time of flight of the received echoes from the pulses **161** and **163**, the probes **12** or **14** can identify a rough direction in which the other probes **14** or **12** are located.

(33) In a next iteration **182**, more focused pulses **165** and **167** are transmitted over a smaller and more directed field of view. In a first instance **164** of the iteration **182**, the TTE probes **12** transmit a series of directed acoustic pulses **165** over a narrower field of view, while the TEE probes **14** passively receive the pulses **165**. The same process is repeated in instance **166**, with the TEE probe **14** actively transmitting pulses **167** while the TTE probes **12** passively receive the pulses **167**.

Based on the strength and time of flight of the received echoes from the pulses **165** and **167**, the probes **12** or **14** can identify a direction in which the other probes **14** or **12** are located.

(34) The process continues iteratively and synchronously until each probe has zeroed in on the location of the other probes. For example, in iteration **184**, even greater focused pulses **169** and **171** are transmitted over a more directed field of view. In a first instance **168** of the iteration **184**, the TTE probes **12** transmit a series of directed acoustic pulses **169** over a narrower field of view (e.g., 5-10 degrees per iteration, although other amounts may be employed), while the TEE probes **14** passively receive the pulses **169**. The same process is repeated in instance **170**, with the TEE probe **14** actively transmitting pulses **171** while the TTE probes **12** passively receive the pulses **171**. Based on the strength and time of flight of the received echoes from the pulses **169** and **171**, the probes **12** or **14** can further identify a direction in which the other probes **14** or **12** are located.

(35) Once the location (e.g., distance and direction) of the probes **12**, **14** is known with respect to one another, a coordinate transformation needed to register all probes in a same coordinate space is determined.

(36) It should be understood that the present examples describe three iterations where the beam focus and field of view is adjusted; however, in some embodiments, a single iteration may be employed or a plurality of iterations may be employed depending on the application and the resolution needed. In addition, three probes are depicted; however, any number of probes **12** and/or probes **14** may be employed.

(37) Referring to FIG. **4**, six images **188-198** are illustratively shown of a heart phantom taken with multiple imaging probes in accordance with the present principles. Images **188**, **192** and **196** depict single-view images of the heart phantom. The images **190**, **194** and **198** show extended field of view (FOV), high quality images achieved by combining 6 images taken from different viewpoints separated in the azimuth direction. Images **188** and **190** show an azimuthal slice. Images **192** and **194** show an elevational slice. Images **196** and **198** show a transverse slice. The combination of several images from the TEE/TTE probes from different perspectives yields extended field of view imaging and the capability of spatial compounding for enhanced image quality in accordance with the present principles.

(38) Real-time registration of multiple ultrasound probes in space and time permits multi-perspective imaging, which improves visualization of soft tissue anatomy and reduces artifacts from device shadowing or reverberation. The present principles can be applied to any combination of ultrasound probes and for a multitude of applications such as, e.g., cranial imaging, breast imaging, renal imaging, etc.

(39) Referring to FIG. **5**, multiple images from one probe can be stitched into a reference frame of the other probe over time to create a larger image **200** with a larger field of view. Alternately, the stitching may be employed to aid in seeing tissue motion over time (e.g., cardiac or lung motion).

(40) Referring to FIG. **6**, an illustrative ultrasound imaging system **210** is shown in block diagram form. The ultrasound system **210** illustratively shows a single transducer device or probe **212**, but may include multiple probes **212** or may be employed with other single transducer device or probe **212** systems. The transducer device or probe **212** includes a transducer array **214** for transmitting ultrasonic waves and receiving echo information. The transducer array **214** may be configured as, e.g., linear arrays or phased arrays, and can include piezoelectric elements (PZT), capacitive micromachined ultrasonic transducers (cMUT) elements, etc. The transducer array **214**, for example, can include a two or three dimensional array of transducer elements capable of scanning in both elevation and azimuth dimensions for 2D and/or 3D imaging. The probe **212** may include a TTE probe, a TEE probe or any other probe.

(41) The transducer array **214** is coupled to a microbeamformer **216** in the probe **212**, which controls transmission and reception of signals by the transducer elements in the array. In this example, the microbeamformer **216** is integrated with the transducer device **212** and is coupled to a transmit/receive (T/R) switch **218**, which switches between transmission and reception and protects

a main beamformer **222** from high energy transmit signals.
(42) The transmit controller **220**, microbeamformer **216** and/or the beamformer **222** control the strength and field of view of transmitted pulses. Adjustments to the strength and the field of view can be made with each cycle or iteration as described with reference to FIG. **3**. The calibration module **150** (FIG. **1**) in memory **242** provides control signals to the beamformer **222** and/or the transmit controller **220** for this probe **212** (and possibly other probes in the system). In this way, the angle of the field of view and other parameters can be controlled with the system of probes to provide the needed information for synchronously communicating between the probes.
(43) In some embodiments, the T/R switch **218** and other elements in the system can be included in the transducer probe rather than in a separate ultrasound system base. The transmission of ultrasonic beams from the transducer array **214** under control of the microbeamformer **216** is directed by the transmit controller **220** coupled to the T/R switch **218** and the beamformer **222**, which may receive input from the user's operation of a user interface or control panel **224** or be preprogrammed and stored in memory **242**.
(44) One function controlled by the transmit controller **220** is the direction in which beams are steered. Beams may be steered straight ahead from (orthogonal to) the transducer array, or at different angles for a wider field of view. The partially beamformed signals produced by the microbeamformer **216** are coupled to a main beamformer **222** where partially beamformed signals from individual patches of transducer elements are combined into a fully beamformed signal.
(45) The beamformed signals are coupled to a signal processor **226**. The signal processor **226** can process the received echo signals in various ways, such as bandpass filtering, decimation, I and Q component separation, and harmonic signal separation. The signal processor **226** may also perform additional signal enhancement such as speckle reduction, signal compounding, and noise elimination. The processed signals are coupled to a B mode (or other mode: A, M, etc.) processor **228**, which can employ amplitude detection for the imaging of structures in the body. The signals produced by the B mode processor are coupled to a scan converter **230** and a multiplanar reformatter **232**. The scan converter **230** arranges the echo signals in the spatial relationship from which they were received in a desired image format. For instance, the scan converter **230** may arrange the echo signal into a two dimensional (2D) sector-shaped format, or a pyramidal three dimensional (3D) image. The multiplanar reformatter **232** can convert echoes which are received from points in a common plane in a volumetric region of the body into an ultrasonic image of that plane.
(46) A volume renderer **234** converts the echo signals of a 3D data set into a projected 3D image as viewed from a given reference point. The 2D or 3D images are coupled from the scan converter **230**, multiplanar reformatter **232**, and volume renderer **234** to an image processor **236** for further enhancement, buffering and temporary storage for display on an image display **238**. A graphics processor **240** can generate graphic overlays for display with the ultrasound images. These graphic overlays or parameter blocks may include, e.g., standard identifying information such as patient name, date and time of the image, imaging parameters, frame indices and the like. For these purposes, the graphics processor **240** receives input from the user interface **224**, such as a typed patient name. The user interface **224** can also be coupled to the multiplanar reformatter **232** for selection and control of a display of multiple multiplanar reformatted (MPR) images.
(47) In accordance with the present principles, ultrasound data is acquired and stored in memory **242** along with position and orientation data with regards to the positions of the other probes as described, e.g., with the reference to FIG. **1**. The memory **242** is depicted as being centrally placed; however, the memory **242** may store data and interact at any position in the signal path.
(48) Referring to FIG. **7**, a method for acoustically registering probes to one another and a common coordinate system is illustratively shown. In block **302**, two or more probes (e.g., ultrasound) are coupled to a medium (e.g., a subject or volume). The probes may be different types (e.g., TEE, TTE, etc.) and may be located internally and/or externally to the subject or volume. In block **304**, a

first acoustic pulse has a first field of view angle set for a first ultrasound probe. The first field of view angle should be wide (the widest for the first iteration). The first field of view angle may be set using a beamformer in the ultrasound device. The first field of view angle may be set using a calibration module. The first field of view angle may be a default number or adjusted and set using user input.

(49) In block **306**, the first acoustic pulse is received at a second ultrasound probe (and other probes, if present). The time of flight and signal strength of the first pulse are measured at the first probe using the probes transducer. The time of flight is measured by determining the difference between a time that the first probe initiated the acoustic pulse and a time that the pulse arrived at transducer of the second probe. Signal strength is also measured by the transducer by measuring the power of the signal and comparing the measured power with the power when the acoustic pulse left the first probe.

(50) In block **308**, a second acoustic pulse is transmitted from the second ultrasound probe at a narrower field of view angle than the first acoustic pulse. In block **310**, the second acoustic pulse is received at the first ultrasound probe (and other probes if present) to measure time of flight and signal strength of the second pulse. In block **312**, the transmission and receive iterations between the probes can continue with narrower and narrower fields of view for each cycle. The first ultrasound probe and the second ultrasound probe can have the angle for field of view adjusted using a corresponding beamformer for the probe.

(51) In block **314**, the times of flight and signal strengths are recorded and employed to compute positions of the first ultrasound probe and the second ultrasound probe. The first and second probes (and any other probes) are registered to one another and located in a common coordinate system. In one embodiment, a transformation is computed for one or more probes to correlate the location of the probe to one or more other probes and the coordinate system. The first ultrasound probe and the second ultrasound probe (and any other probes) include bandwidths that share one or more frequencies to permit communication therebetween. In one embodiment, the probes may all share a common central frequency.

(52) In some embodiments, in block **316**, opposing probes may be grouped into two or more groups. For example, the first ultrasound probe may include a plurality of first ultrasound probes to collectively form a large area probe. Positions are computed for the plurality of the probes in the system based upon measured times of flight and signal strengths to register the probes to each other and the common coordinate system.

(53) In block **318**, one of the probes in the system of probes may be tracked and may be employed to define the coordinate system. The probe may be tracked by any suitable technology, e.g., EM tracking, spatial encoding, etc.

(54) In block **320**, images are displayed for the data collected for the one or more probes. This may include side-by side displays or compound images generated by fusing or stitching together image data received from the probes into a single image (or multiple images) for display. Ultrasound images and/or information can be combined from all or some probes to display on screen. The images may be combined spatially or temporally depending on the application. For example, images may be stitched together, shown concurrently, shown dynamically (moving over time), etc. Stitching images from one probe into a reference frame of another probe over time can be performed to create a larger image with a larger field of view or to track motion of tissue, provide more detail in an area of interest, etc.

(55) In some alternative implementations, the functions noted in the blocks may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.

(56) In interpreting the appended claims, it should be understood that: a) the word “comprising” does not exclude the presence of other elements or acts than those listed in a given claim; b) the

word “a” or “an” preceding an element does not exclude the presence of a plurality of such elements; c) any reference signs in the claims do not limit their scope; d) several “means” may be represented by the same item or hardware or software implemented structure or function; and e) no specific sequence of acts is intended to be required unless specifically indicated.
(57) Having described preferred embodiments for acoustic registration of internal and external ultrasound probes (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the disclosure disclosed which are within the scope of the embodiments disclosed herein as outlined by the appended claims. Having thus described the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.

Claims

1. An acoustically registerable probe for generating images, comprising: a transducer array having a field of view defined by an adjustable field of view angle, the transducer array configured to send and receive acoustic pulses in the field of view; a beamformer coupled to the transducer array and configured, in each of a plurality of iterations, to: adjust the field of view of the transducer array by iteratively decrementing the field of view angle of the transducer array and adjust signal strength of the acoustic pulses, and control the transducer array to send and receive the acoustic pulses, at the decremented field of view angle and the adjusted signal strength, respective to a second acoustically registerable probe configured to generate second images; and a processor configured to determine a position of the second acoustically registerable probe based on the decremented field of view angle, time of flight, and the adjusted signal strength of the acoustic pulses in each of the plurality of iterations.
2. The acoustically registerable probe as recited in claim 1, wherein the transducer array is configured to form a large area probe.
3. The acoustically registerable probe as recited in claim 1, wherein the transducer array is configured to generate images that are stitched into a reference frame of the second acoustically registerable probe to create a larger image with a larger field of view.
4. The acoustically registerable probe as recited in claim 1, wherein the processor is configured to indicate a position of the acoustically registerable probe based on the time of flight and the adjusted signal strength of the acoustic pulses.
5. The acoustically registerable probe as recited in claim 4, wherein the processor is configured to decrement the field of view angle of the transducer array at each successive iteration to permit positional identification of the second acoustically registerable probe and/or the acoustically registerable probe.
6. The acoustically registerable probe of claim 1, wherein the beamformer is configured to, in a first iteration of the plurality of iterations, control the transducer array to send and receive the acoustic pulses at a first field of view angle, and wherein the processor is configured to determine a direction of the second acoustically registerable probe based on a signal response to the first iteration.
7. The acoustically registerable probe of claim 6, wherein the beamformer is configured to, in a second iteration of the plurality of iterations, control the transducer array to send and receive the acoustic pulses at a second field of view angle, wherein the second field of view angle is narrower than the first field of view angle, and wherein the processor is configured to control decrementing of the field of view angle from the first field of view angle to the second field of view angle based on the determined direction of the second acoustically registerable probe.
8. The acoustically registerable probe as recited in claim 1, wherein the second acoustically

registerable probe is spaced apart from the acoustically registerable probe in the medium.
9. The acoustically registerable probe as recited in claim 8, wherein a transducer array of the second acoustically registerable probe and the transducer array of the acoustically registerable probe each have a bandwidth that shares one or more frequencies to permit communication therebetween.
10. The acoustically registerable probe as recited in claim 8, wherein the acoustically registerable probe and the second acoustically registerable probe are acoustically registered to a common coordinate system.
11. The acoustically registerable probe as recited in claim 10, wherein the acoustically registerable probe and the second acoustically registerable probe are tracked by a tracking device to register to the common coordinate system.