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(54) Title of the Invention: **Ultrasound imaging**
Abstract Title: **Generating a 3D ultrasound image from a series of images based on a measured orientation of the probe**

(57) A subject 150 is imaged by capturing a series of images with an ultrasound probe 100, determining a respective orientation of the probe 100 for each image with an accelerometer (110, fig 1a), and arranging the series of images into a three dimensional image based on the probe orientation. The ultrasound system may determine whether there are any gaps (330, fig 3) between the arranged images (320, fig 3), and if the gaps 330 exceed a threshold instructions are output for further imaging. The accelerometer 110 may be positioned at the acoustic lens end 120 of the probe 100. One of the images (310, fig 3) may be selected as a reference image and the remaining images 320 arranged relative to the reference image 310 based on the difference in orientation. The system may identify a feature within the images, compare the position of the feature in each image, determine a lateral offset between the images and translate one or more of the images to compensate for the offset.

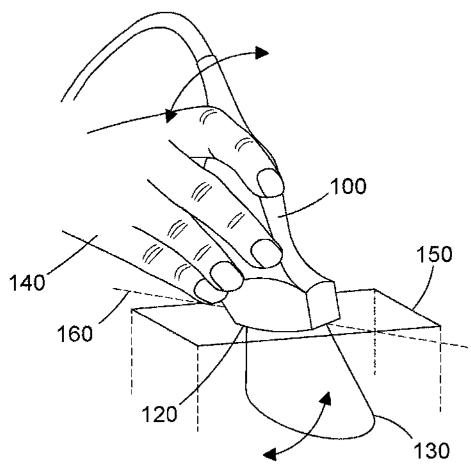

FIG. 1b

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

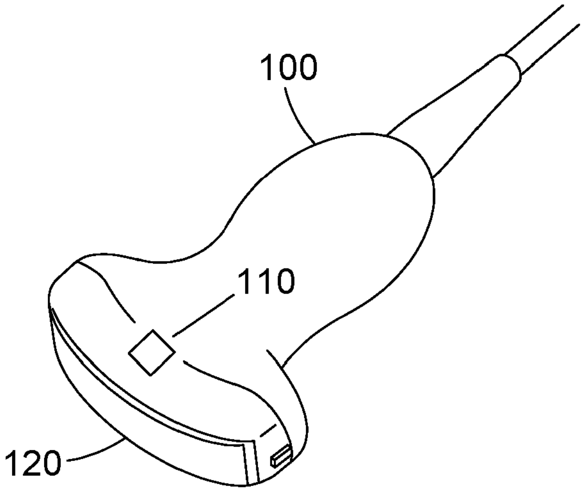


FIG. 1a

25 01 24

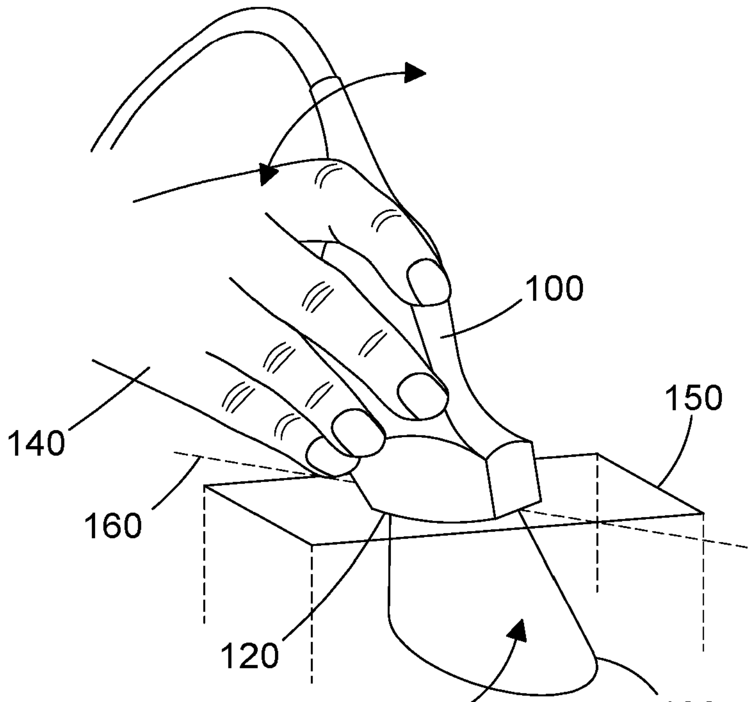


FIG. 1b

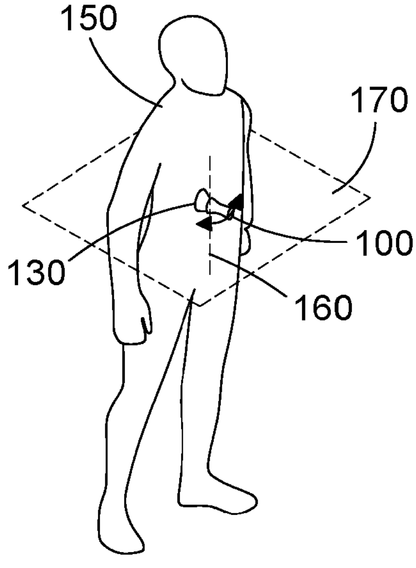


FIG. 1c

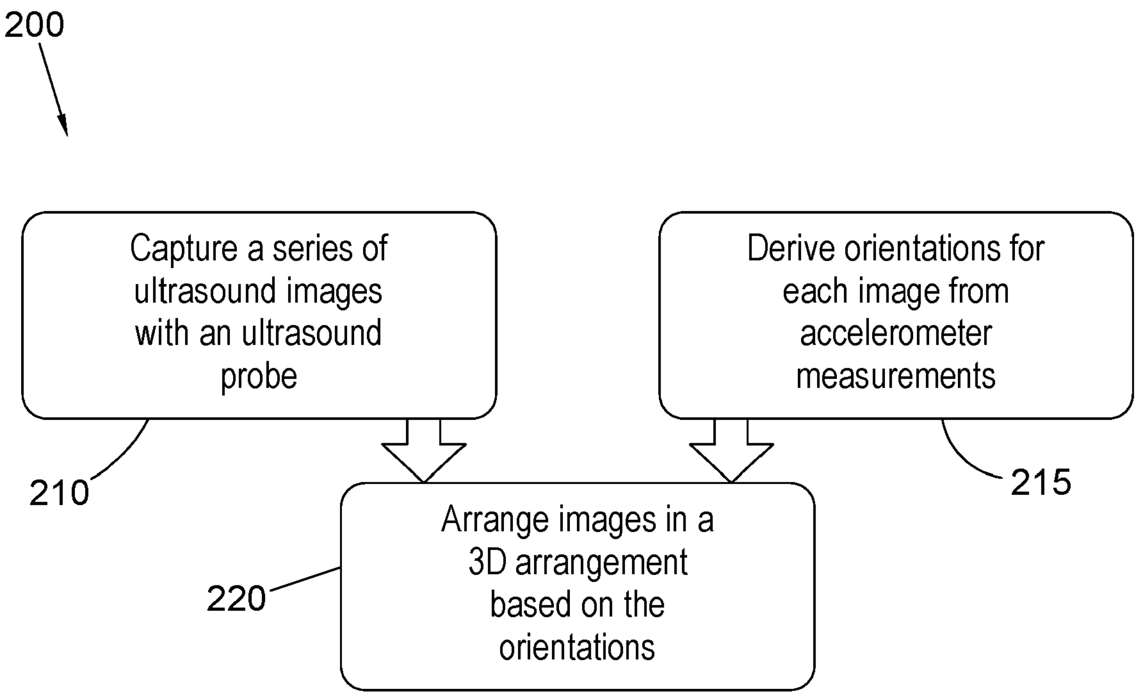

200
Capture a series of ultrasound images with an ultrasound probe
Derive orientations for each image from accelerometer measurements
210
215
220
Arrange images in a 3D arrangement based on the orientations

FIG. 2a

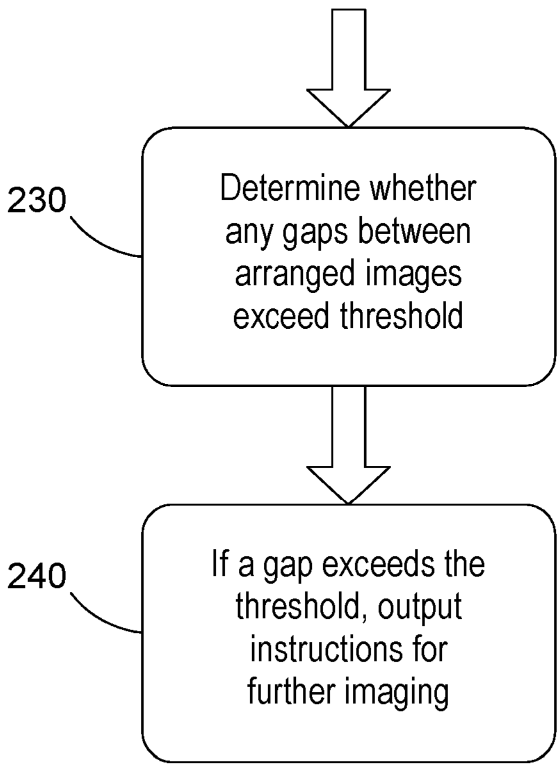
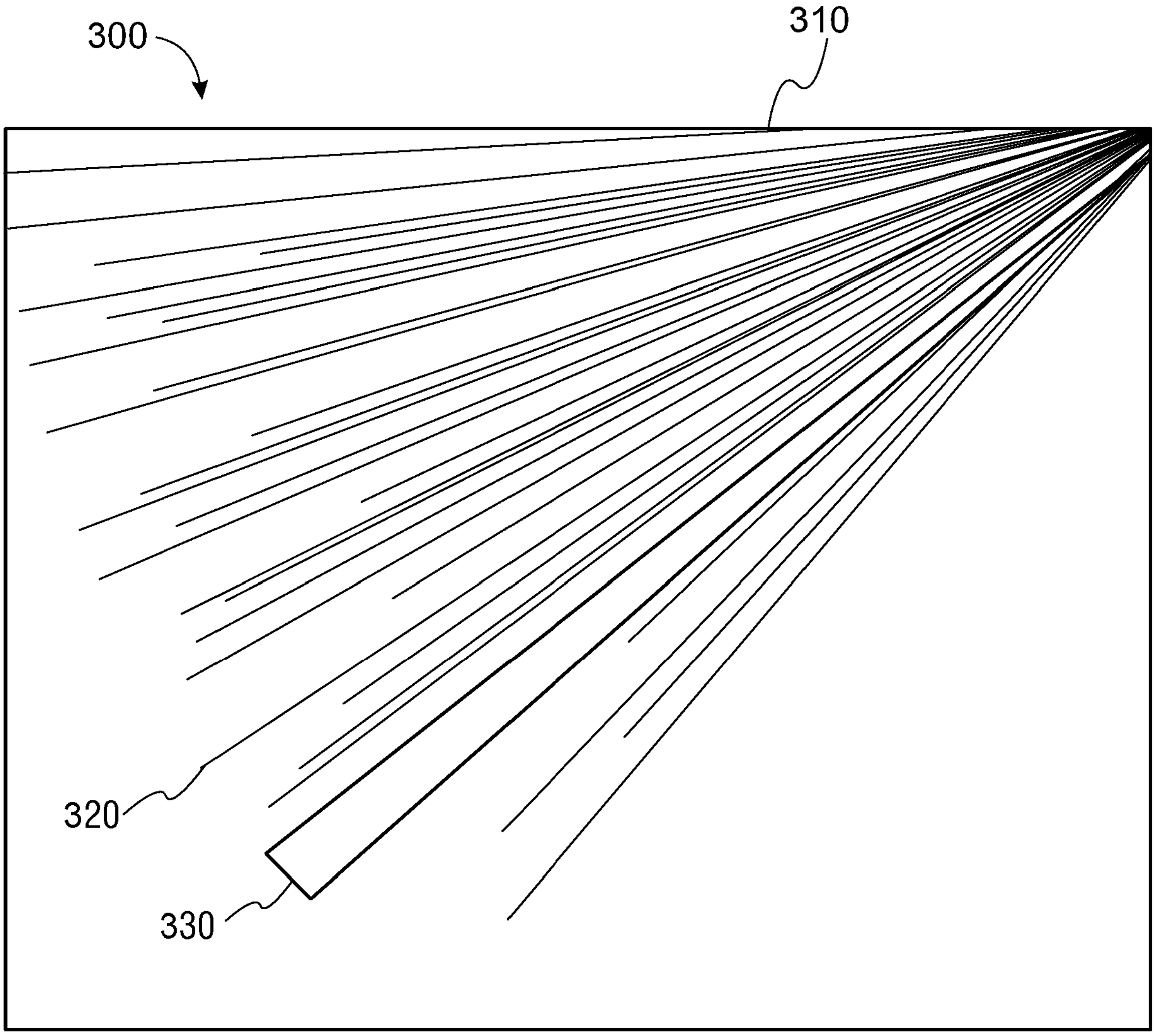

230
Determine whether any gaps between arranged images exceed threshold
240
If a gap exceeds the threshold, output instructions for further imaging

FIG. 2b



25 01 24

FIG. 3

Ultrasound Imaging

FIELD

[0001] Embodiments described herein relate to methods and systems for three-dimensionally imaging a subject.

BACKGROUND

[0002] Three dimensional ultrasound is a medical imaging technique which is often used in foetal, cardia or intra-vascular applications. Existing three-dimensional ultrasound imaging techniques involve controlling the direction of a sequence of ultrasound images using a beam steering means or a motorised gimbal that is integrated with an ultrasound probe. Such sophisticated methods may be expensive, cover only limited angular ranges, and require a specially trained medical professional to perform them, limiting their accessibility.

[0003] An aim of the present invention is to provide cost-effective means for reliably obtaining a high field-of-view three-dimensional ultrasound image without requiring a specialised medical professional.

SUMMARY OF THE INVENTION

[0004] According to an embodiment, there is provided a method of imaging a subject, the method comprising: capturing a series of ultrasound images using an ultrasound probe; determining a respective orientation of the ultrasound probe when each of the series of ultrasound images is captured, each orientation being derived from measurements of an accelerometer comprised by the ultrasound probe; arranging each of the series of captured ultrasound images in a three-dimensional arrangement based on the orientation of the ultrasound probe when that ultrasound image was captured.

[0005] Such a method may enable a three-dimensional representation of the subject to be captured by arranging the three-dimensional images in their associated orientations. By varying the orientation of the ultrasound probe a larger amount as the series of images are captured, a three-dimensional representation with a larger field of view may be obtained.

[0006] In some embodiments, the method further comprises determining whether any gaps between the arranged ultrasound images exceed a threshold separation; and if one or more gaps between the arranged ultrasound images exceed the threshold separation are identified, outputting instructions to perform further imaging.

[0007] Identifying gaps and outputting instructions to perform further imaging if they are identified may ensure the obtained three-dimensional representation is not limited by ineffective manipulation of the ultrasound probe while the images are captured.

[0008] In some embodiments, the instructions to perform further imaging are output by or to a graphical user interface.

[0009] In some embodiments, the instructions to perform further imaging comprise instructions indicating one or more orientations in which to position the ultrasound probe while performing the further imaging, the one or more orientations in which to position the ultrasound prove corresponding to orientations of the one or more gaps.

[0010] In some embodiments, the method further comprises positioning the ultrasound probe on a region of interest of the subject before capturing the series of ultrasound images and reorienting the ultrasound probe while holding it on the region of interest while the series of ultrasound images are captured.

[0011] The ultrasound probe may be manually positioned and reoriented by a user manipulating the probe, while other steps may be performed by an ultrasound system, for example, by executing computer instructions.

[0012] In some embodiments, positioning the ultrasound probe on the region of interest comprises positioning the probe on the subject, capturing an initial ultrasound image using the ultrasound probe, identifying one or more features of the subject in the initial image, and using the one or more identified features to determine whether the probe is correctly positioned on the region of interest.

[0013] Such steps may assist a non-medical-professional user in positioning the ultrasound probe to image the region of interest. Whether the probe is correctly positioned on the region of interest may be performed using an artificial intelligence or machine learning model which may be configured and/or trained to perform semantic segmentation. The identity, position, orientation and/or absence of features from the one or more identified features may be used to determine whether the probe is correctly positioned. In some embodiments, a series of initial ultrasound images may be captured, have features identified therein and used to determine whether the probe is correctly positioned, for example, until the probe is determined to be correctly positioned.

[0014] In some such embodiments, the method further comprises, when the probe is determined not to be correctly positioned, outputting instructions to reposition the ultrasound probe.

[0015] In some embodiments, arranging the series of captured ultrasound images in the three-dimensional arrangement comprises selecting one of the images as a reference image and arranging the remaining images relative to the reference image in the arrangement, based on the differences in the orientations in which they were captured and the orientation in which the reference image was captured.

[0016] In some such embodiments, the method further comprises identifying a feature of the subject in a plurality of the captured ultrasound images, comparing the position of the identified feature in the plurality of the captured ultrasound images to determine a lateral offset between the plurality of captured ultrasound images, and translating one or more of the plurality of captured ultrasound images to compensate for the lateral offset.

[0017] According to embodiments of the invention, there is provided a system for imaging a subject, the system comprising: an ultrasound probe configured to capture a series of ultrasound images; an accelerometer, comprised by the ultrasound probe; an output device for providing instructions to a user; and a processor, the processor configured to: use measurements of the accelerometer to derive a respective orientation of the ultrasound probe when each of the series of ultrasound images is captured; arrange each of the series of captured ultrasound images in a three-dimensional arrangement based on the orientation of the ultrasound probe when that ultrasound image was captured.

[0018] In some embodiments, the processor is further configured to: determine whether any gaps between the arranged ultrasound images exceed a threshold separation; and when one or more gaps between the arranged ultrasound images exceed the threshold separation are identified, outputting instructions to perform further imaging using the output device.

[0019] In some embodiments, the output device is an electronic display configured to display the instructions using a graphical user interface.

[0020] In some embodiments, the instructions to perform further imaging comprise instructions indicating one or more orientations in which to position the ultrasound probe while performing the further imaging, the one or more orientations in which to position the ultrasound prove corresponding to orientations of the one or more gaps.

[0021] In some embodiments, the ultrasound probe is further configured to capture an initial ultrasound image before capturing the series of ultrasound images, and wherein the processor is further configured to identify one or more features of the subject in the initial image, and use the identify and/or position of the one or more features to determine whether the probe is correctly positioned on the region of interest.

[0022] In some embodiments, arranging the series of captured ultrasound images in the three-dimensional arrangement comprises selecting one of the images as a reference image and arranging the remaining images relative to the reference image in the arrangement, based on the differences in the orientations in which they were captured and the orientation in which the reference image was captured.

[0023] In some embodiments, the system is further configured to: identify a feature of the subject in a plurality of the captured ultrasound images; compare the position of the identified feature in the plurality of the captured ultrasound images to determine a lateral offset between the plurality of captured ultrasound images, and translate one or more of the plurality of captured ultrasound images to compensate for the lateral offset.

[0024] According to embodiments of the invention, there is provided storage medium comprising computer instructions executable by one or more processors, the computer instructions when executed by the one or more processors causing the one or more processors to perform a method according as described above. The method may comprise any of the optional features described herein.

BRIEF DESCRIPTION OF THE FIGURES

[0025] Fig. 1a shows an ultrasound probe for use in imaging a subject;

[0026] Fig. 1b shows a user holding the ultrasound probe of Fig. 1a against a subject and rotating it through a range of orientations;

[0027] Fig. 1c is a diagram showing a range of motion through which the ultrasound probe of Fig. 1 may be moved in use;

[0028] Fig. 2a is a flowchart of an embodiment of a method for imaging a subject;

[0029] Fig. 2b shows additional optional steps of the method of Fig. 2a; and

[0030] Fig. 3 shows a cross sectional view of a three-dimensional arrangement.

DETAILED DESCRIPTION

[0031] Referring to figures 1 to 3 generally, embodiments of methods and systems for three-dimensionally imaging a subject are described, in which an ultrasound probe comprising an accelerometer captures both ultrasound images and orientation data, from which a three-dimensional image is constructed.

[0032] In such embodiments, an ultrasound probe comprises at least one accelerometer, configured to detect changes in the orientation of the probe. The accelerometer may be arranged adjacent an end of the probe at which ultrasonic acoustic waves are emitted and detected, for example proximate to, or adjacent, an acoustic lens of the probe.

[0033] In example embodiments described herein, the accelerometer is configured to detect changes in orientations of the probe in three or more dimensions, for example, the accelerometer may be a three-degrees of freedom (3DoF) accelerometer. The accelerometer may be configured to record orientations of the probe, or changes therein, as sets of associated pitch, yaw and roll angles thereof.

[0034] In alternative embodiments, the accelerometer may be configured to detect changes in orientations of the probe in fewer dimensions, for example, in only a single dimension. For example, in some embodiments the accelerometer may be configured to detect changes about only a single axis of the probe, in which case a user may only tilt the probe about such an axis in use. The accelerometer is preferably configured to detect rotation of the probe about at least a short transverse axis of the probe parallel to an imaging plane thereof.

[0035] Existing methods of 3D imaging a subject frequently require more sophisticated accelerometers with more than three degrees of freedom, such as six-degrees of freedom accelerometers that detect changes in their position as well changes in their orientation. However embodiments described herein allow changes in position of the accelerometer and associated ultrasound probe to be determined from features in captured ultrasound images and fewer-degree-of-freedom orientation changes, without requiring such accelerometers, which may be more expensive, complex and/or bulky.

[0036] Fig. 1a shows an example of an ultrasound probe 100 for use in embodiments described herein. The illustrated probe is a curvilinear phased array ultrasound probe, however it will be appreciated that any other ultrasound probe may be used, such as a linear ultrasound probe. The probe is configured to be held and manipulated by a user, and/or by other suitable machinery, enabling the orientation of the probe to be varied in use, for example while held in contact with a subject. In use, the probe captures ultrasound images in orientations corresponding to the orientation in which it is held.

[0037] The illustrated probe 100 comprises an accelerometer 110 arranged adjacent a distal end, or “nose end”, 120 of the probe 100, at which the acoustic lens of the probe 100 is located.

[0038] Such an ultrasound probe 100 defines or is comprised by a system configured to three-dimensionally image a subject. The system may further comprise a computing device, such as a terminal, which may be configured to control the ultrasound probe and/or to view, output or manipulate images captured by the probe, or composites thereof. The system may be configured to perform an imaging method as described herein, for example by executing computer instructions stored in one or more storage media comprised by or associated with the system using one or more processors comprised by the system, for example, a non-transitory storage media such as a memory comprised by the computing device.

[0039] In some embodiments, the ultrasound probe 100 and/or the computing device of the system is configured to output instructions and/or other information for a user. Such instructions and/or information may comprise visual, audio, haptic, and/or pictographic elements. The instructions may be output directly by the system, for example using an electronic visual display, graphical user interface (GUI), speaker or other output device comprised by, or connected to, the ultrasound probe and/or computing device, or may be output to another computing device in communication with the system, such as a personal computer or smartphone, in order to be output to a user by said other computing device.

[0040] Fig. 1b shows an example of the probe 100 being used to image a subject 150. A user 140 holds the probe, such that its acoustic lens end 120 is pressed against or into the exterior of the subject 150, such as a portion of their own body. In this position, an imaging plane 130 in which the probe 100 captures ultrasound images extends into the interior of the subject 150.

[0041] In use, the user holds the acoustic lens end 120 of the probe 100 in the same position on the subject 150 while tilting the probe 100 about an axis 160 parallel to the imaging plane 130 and tangential to the surface of the subject 150, such that tilting the probe 130 sweeps the imaging plane through the subject 150. In the illustrated example, this axis 160 is a lateral axis of the probe 100, perpendicular to the length of its handle. The reorientation of the probe 100 and the imaging plane 130 as the probe is tilted about the axis 160 are shown with double-headed arrows. Tilting an ultrasound probe 100 about lateral axis 160 of the probe 100 in this manner is sometimes referred to as “fanning” the probe 100. As the probe 100 is tilted, the accelerometer 120 measures the changes in orientation of the probe 100 (and by extension, of the imaging plane 130).

[0042] Fig. 1c shows an example of the probe 100 being used to image the abdomen of a human patient 150. As in the illustrated example, the probe 100 may be arranged such that its imaging plane 130 is parallel to a longitudinal axis or midline of the body 150, and the probe 100 may be rotated about an axis 160 substantially parallel to the longitudinal axis or midline, such that all of the series of images are substantially parallel to said longitudinal axis or midline, and such that the ultrasound probe is rotated within a transverse plane 170 substantially perpendicular to the probe's imaging plane throughout the motion. Capturing a series of ultrasound images in this arrangement may advantageously facilitate identifying, and compensating for, motion of organs of the patient 150 relative to the probe 100 within such planes, for example as a consequence of the patient's breathing or heartbeat. In other examples, the ultrasound probe may be rotated within other planes such as sagittal or coronal planes.

[0043] Fig. 2a is a flowchart 200 of a method of imaging a subject 150. In some embodiments, the subject 150 is a patient's body, such as a human patient's body, and the methods or systems are medical imaging methods or systems. However it will be appreciated that in alternative embodiments, the subject may be a non-human animal body or an inanimate device or object.

[0044] During measurement steps 210, 215, of the method 200, an ultrasound probe 100 comprising an accelerometer for detecting changes in its orientation is located on a region of interest on the subject 150. In some embodiments, the probe 100 is located in a target location on the region of interest, for example near a centre thereof. In some embodiments, the method 200 may comprise positioning the ultrasound probe 200 on the region of interest before the measurement steps 210, 215 are performed.

[0045] In some embodiments, instructions on where to position the probe 100 on and/or within the region of interest are output by the system. For example, in image of a probe 100 in position may be presented to the user. Providing instructions on positioning the ultrasound probe 100 may enable a non-medical-professional user to use the ultrasound probe to obtain a three-dimensional ultrasound medical image by following them. The region of interest may be input or selected by a user, for example using a user interface comprised by the probe, or a terminal or computing device in communication therewith.

[0046] In some embodiments, positioning the ultrasound probe 100 comprises detecting that the ultrasound probe 100 is positioned on the region of interest of the subject 150, or on a target location thereof. For example, a user 140 may move the probe across the surface of the subject 150 until the probe 100 is detected to be on the region of interest and/or target location. The probe 100 may be moved across the surface by sliding it over the surface, with its acoustic lens end 120 held against the surface, and/or with a longitudinal axis of the probe 100 extending substantially perpendicularly to the surface.

[0047] In some such embodiments, as the probe 100 is in the process of being positioned on the region of interest, one or more initial ultrasound images are captured using the ultrasound probe 100 and whether the probe is correctly positioned or not may be determined based on the contents of such initial ultrasound images. In some embodiments, such initial ultrasound images may be captured continuously and/or at a pre-set frequency.

[0048] In some embodiments, the system is configured to identify the presence, absence, and/or position of one or more features of the subject in each of the initial ultrasound images captured during positioning of the ultrasound image. For example, using an image recognition artificial intelligence or machine learning model to identify any instances of the one or more features in the initial images. The system may be further configured to use the identity, position, and/or absence of the one or more identified features within an ultrasound image to determine/ whether the probe 100 was correctly positioned on the region of interest and/or a target location thereon when that ultrasound image was captured.

[0049] When the system determines that the probe 100 is not correctly positioned when an ultrasound image is captured, or after a pre-set period has elapsed and/or a pre-set number of images have been captured (for example, following initialisation of the system, provision of instructions to the user, or from some other initial time) it may output an indication that that the probe is incorrectly positioned and/or instructions to, or how to, move the probe 100 to the correct position. In some embodiments, the actual location of the probe is determined from the one or more features, and the instructions may indicate a direction in which to move the probe 100 from the determined location to the correct position. When the system determines that the probe 100 is correctly positioned, or that the probe has been correctly positioned for a pre-set time period and/or number of images, a confirmation or other indication may be provided to the user and/or the next stage 210, 215 of the method may be performed.

[0050] In measurement steps 210, 215 of the method 200, after the ultrasound probe 100 has been positioned on the region of interest, a measurement phase is performed, during which a series of ultrasound images are captured 210 and orientation data is collected 215.

[0051] The measurement phase may be initiated when the system determines that the probe 100 has been correctly positioned as described above. In alternative embodiments, the measurement phase is initiated by a user, for example using one or more controls on the ultrasound probe or on a terminal or computing device in communication therewith.

[0052] Each captured 210 ultrasound image may be a two-dimensional planar image or “slice” in a plane corresponding to the orientation of the probe 100 while it was captured. As the series of ultrasound images are captured 210, a user 140 manipulates the probe 100 to reorient it relative to the subject 150. When reorienting the probe 100, the user 140 preferably holds the acoustic lens end 120 of the acoustic probe 100 on the same location on the subject 150.

[0053] In some embodiments, the probe may rotated in substantially a single direction, for example by fanning the probe as described above with reference to Fig. 1b. In other embodiments, the probe may be rotated in multiple different directions, thereby capturing images in a greater variety of different orientations.

[0054] In some embodiments in which the subject 150 is a patient's body, the probe 100 may be rotated about an axis parallel to the patient's midline. For example, as described above with reference to Fig. 1c.

[0055] When each of the series of ultrasound images is captured 210, a respective orientation in which the probe is arranged while said ultrasound image of the series is being captured is determined from measurements of the accelerometer and may be recorded. The determined orientations may be relative to an absolute coordinate system, relative to each other, and/or relative to some reference orientation, such as an initial orientation when the first image of the series was captured, or when the probe was activated. The respective orientation determined for each ultrasound image defines the plane in which each ultrasound image is located. The captured images and their respective orientations may be stored in a memory.

[0056] In some embodiments, ultrasound images of the series and their associated orientations are captured continuously, for example at a set frequency. In alternative embodiments, an ultrasound image may instead be captured whenever the orientation of the probe measured by the accelerometer 110 differs from any orientation in which a previous ultrasound image of the series was captured, for example, by more than a threshold amount. In some embodiments, each ultrasound image and/or its associated orientation may be timestamped.

[0057] During the measurement phase, a user may tilt or otherwise reorient the ultrasound probe, while holding it in contact with the region of interest. In some embodiments, instructions to reorient the probe 100, or a specific motion in which to reorient the probe 100 may be output by the system, for example, after the measurement phase is automatically initiated upon detection that the probe 100 has been correctly positioned as described above.

[0058] The measurement phase may continue for a fixed period of time, until a fixed number or range of orientations of ultrasound images have been captured, and/or until manually ended by a user, for example using one or more controls on the ultrasound probe 100 or on a terminal or computing device in communication therewith.

[0059] After the measurement phase 210, 215, in a second stage of the method 200, the series of captured ultrasound images are assembled 220 into a three-dimensional arrangement of images based on the recorded orientations in which they were captured.

[0060] Assembling the series of captured images into the arrangement may comprise selecting one of the ultrasound images as a reference image for the arrangement. The selected reference image may be the image of a portion of the subject closest to one end or extreme of the subject, which may be determined based on the associated orientation of the probe 100 when it was captured. For example, in some embodiments in which the images are of a portion of a patient's body, the selected image is the most cranial (located closest towards the top of the patient's head) and medial (located closest to the midline of the patient's body, which extends from the top of the patient's head towards their feet).

[0061] After an image is selected as a reference image, the remaining images of the series may arranged 220 relative to the selected image in the arrangement, based on the difference between their orientations (corresponding to the orientations of the probe 100 when they were captured) and the orientation of the selected reference image.

[0062] Fig. 3 shows a cross section of an example a three-dimensional image arrangement 300 of ultrasound images constructed after a measurement phase as described above is performed, in which the probe is rotated in a single direction about a single axis. The arrangement comprises a reference image 310 which is arranged horizontally within the arrangement 300. The selected reference image is the most cranial (located closest towards the top of the patient's head) and medial (located closest to the midline of the patient's body) image of the series. The remaining images 320 are arranged below the reference image 310 relative thereto based on the differences in their orientations and the orientation of the reference image.

[0063] The example illustrated arrangement 300 comprises ultrasound images which are all separated by angles within a single plane, as captured by an ultrasound probe 100 only being rotated in a single direction during the measurement steps 210, 215. In other examples, the ultrasound probe may be rotated in multiple directions around multiple different axes, producing a more complex arrangement of ultrasound images.

[0064] Arrangements 300 of ultrasound images constructed using the method described herein can cover very large fields of view. In situations, such arrangements can have fields of view of greater than 180º, for example, where an ultrasound is pressed into a relatively soft or yielding portion of the subject.

[0065] As shown in Fig. 3, a constructed arrangement 300 of ultrasound images may comprise differently sized gaps between adjacent images. Fig. 2b shows additional steps 230, 240 that may be performed in some embodiments of a method 200 as described above, in order to prevent the image loosing quality or information as a result of excessively large such gaps.

[0066] After the arrangement is constructed 220, in a third stage of the method 200 any gaps between images 310, 320 within the arrangement 300 larger than a threshold separation may be identified 230. Such gaps may define areas of the region of interest of the subject that have been insufficiently imaged during the initial measurement phase and of which additional images are to be captured. The threshold separation may depend upon the region of interest and/or the subject that is being imaged.

[0067] The gaps between images 310, 320 within the arrangement may be one-dimensional angular separations between adjacent images, which may be compared to a threshold one-dimensional angular separation, or may two-dimensional solid angles, which may be bounded by images and/or edges of the region of interest, which may be compared to a threshold two-dimensional solid angle.

[0068] In the example three-dimensional image arrangement 300 shown in Fig. 3, the gaps are one-dimensional separations that can be compared to a one-dimensional threshold angle. The illustrated example arrangement 300 includes one gap 330 with a separation between adjacent images exceeds the threshold. Such a gap results in a lack of information and/or detail on this portion of the imaged region of interest of the subject.

[0069] When one or more gaps 330 between images 310, 320 within the arrangement 300 larger than a threshold separation are identified 230, instructions to perform further imaging may be output 240 by the system, in a fourth stage of the method 200. Such further imaging may then be performed in an additional measurement phase.

[0070] The instructions output 240 when a gap 330 exceeding the threshold may instruct a user to initiate and/or perform an additional measurement phase. For example, the instructions may comprise a user interface element enabling a user to initiate an additional measurement phase. Alternatively, or additionally, identifying one or more gaps 330 exceeding the threshold may automatically initiate an additional measurement phase if and/or when the ultrasound probe 100 is arranged to perform another measurement phase.

[0071] In some embodiments, the instructions output when one or more gaps 330 exceeding the threshold are identified 230 may simply instruct the user to perform additional measurements while moving the ultrasound probe or to repeat their previous movement with the ultrasound probe 100.

[0072] In other embodiments, the instructions may instruct a user to reorient the probe 100 to and/or through one or more specific orientations corresponding to the threshold-exceeding gaps 330, in one or more specific directions, and/or at specific speeds. For example, the instructions may indicate one or more orientations in which to hold the ultrasound probe while performing the further imaging, the one or more orientation in which to hold the ultrasound prove corresponding to orientations of the one or more gaps. In some embodiments, during the additional measurement phase, the system may output an indication when images have been captured covering each and/or all of the identified gaps 330.

[0073] When a gap 330 is identified in an arrangement 300 comprising ultrasound images with angular separations in a single dimension, as in the example shown in Fig. 3. The instructions may be to rotate the probe about the same axis as it was rotated about in the initial measurement steps 210, 215. In some examples, the instructions may specify to rotate the probe in the opposite direction about the axis, and/or to rotate the probe more slowly than in the initial measurement steps 210, 215.

[0074] In some embodiments, the system may be configured to identify one or more features of the subject in a plurality or all of the ultrasound images captured during the measurement phase, for example, using an artificial intelligence or machine learning model.

[0075] The identified features may be anatomical structures of an imaged patient's body, such as individual organs and/or blood vessels, and/or parts thereof. In some embodiments, identifying features may comprise identifying parts of said images showing any of a preselected group of structures, which may correspond to the region of the subject being imaged. Alternatively, identifying structures in the first and second images may comprise identifying geometric structures within the images, which may not be part of a preselected group.

[0076] An artificial intelligence or machine learning model with which the features are identified may be an artificial intelligence configured and/or trained to perform semantic segmentation.

[0077] After the one or more features are identified in the images, the positions of features that have been identified in more than one of the images may be compared between those images to determine a lateral offset between those images. Lateral motion herein refers to movement within the plane of the ultrasound image, such as in a direction towards or away from the ultrasound probe 100, or in a direction across the plane of the ultrasound image.

[0078] Such lateral offsets may be motion artefacts resulting from the the subject moving during the capturing of the images. For example, when a patient whose abdomen is being imaged breathes in and out, this may displace a probe held against their skin inwards and outwards relative to some of their internal organs, and/or may displace one or more imaged internal organs within their body. For example a patient's liver will move downwards within their body as they breathe in and will move upwards as they breathe out. This can result in organs or parts thereof being located in different positions within the patient's body in different ultrasound images of the series.

[0079] As described above, in some embodiments, the probe is arranged and pivoted such that its imaging plane remains parallel to the midline or longitudinal axis of the patient's body, for example, as shown in Fig. 1c. In such embodiments, movement of organs upwards, downwards, towards the probe, and/or away from the probe between images of the series will be visible.

[0080] After such a lateral offset between images has been identified, images that have been laterally offset with respect to each other may be translated within the three-dimensional arrangement to remove such lateral offsets.

[0081] In some embodiments, the three-dimensional arrangement may be, or may be reformatted into, a three-dimensional image format comprising an array of voxels. Such a format may facilitate isolation and/or analysis of individual parts of the subject, which may be represented by groups or clusters of voxels within the array. Alternatively, the three-dimensional arrangement may be reformatted into a three dimensional array or a point cloud.

[0082] Implementations of the subject matter and the operations described in this specification can be realized in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Implementations of the subject matter described in this specification can be realized using one or more computer programs, i.e., one or more modules of computer program instructions, encoded on computer storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively or in addition, the program instructions can be encoded on an artificially generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

[0083] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of methods and systems described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms of modifications as would fall within the scope and spirit of the inventions.

CLAIMS

1. A method of imaging a subject, the method comprising:

capturing a series of ultrasound images using an ultrasound probe;

determining a respective orientation of the ultrasound probe when each of the series of ultrasound images is captured, each orientation being derived from measurements of an accelerometer comprised by the ultrasound probe;

arranging each of the series of captured ultrasound images in a three-dimensional arrangement based on the orientation of the ultrasound probe when that ultrasound image was captured.

2. A method according to claim 1 further comprising:

determining whether any gaps between the arranged ultrasound images exceed a threshold separation; and

when one or more gaps between the arranged ultrasound images exceed the threshold separation are identified, outputting instructions to perform further imaging.

3. A method according to claim 2, wherein the instructions to perform further imaging are output by or to a graphical user interface.

4. A method according to claim 2 or claim 3, wherein the instructions to perform further imaging comprise instructions indicating one or more orientations in which to position the ultrasound probe while performing the further imaging, the one or more orientations in which to position the ultrasound prove corresponding to orientations of the one or more gaps.

5. A method according to any preceding claim, further comprising:

positioning the ultrasound probe on a region of interest of the subject before capturing the series of ultrasound images;

reorienting the ultrasound probe while holding it on the region of interest while the series of ultrasound images are captured.

6. A method according to claim 5, wherein positioning the ultrasound probe on the region of interest comprises positioning the probe on the subject, capturing an initial ultrasound image using the ultrasound probe, identifying one or more features of the subject in the initial image, and using the one or more identified

features to determine whether the probe is correctly positioned on the region of interest.

7. A method according to claim 6, the method comprising, when the probe is determined not to be correctly positioned, outputting instructions to reposition the ultrasound probe.

8. A method according to any preceding claim, wherein arranging the series of captured ultrasound images in the three-dimensional arrangement comprises selecting one of the images as a reference image and arranging the remaining images relative to the reference image in the arrangement, based on the differences in the orientations in which they were captured and the orientation in which the reference image was captured.

9. A method according to any preceding claim, further comprising:

identifying a feature of the subject in a plurality of the captured ultrasound images,

comparing the position of the identified feature in the plurality of the captured ultrasound images to determine a lateral offset between the plurality of captured ultrasound images, and

translating one or more of the plurality of captured ultrasound images to compensate for the lateral offset.

10. A system for imaging a subject, the system comprising:

an ultrasound probe configured to capture a series of ultrasound images;

an accelerometer, comprised by the ultrasound probe;

an output device for providing instructions to a user; and

a processor, the processor configured to:

use measurements of the accelerometer to derive a respective orientation of the ultrasound probe when each of the series of ultrasound images is captured;

arrange each of the series of captured ultrasound images in a three-dimensional arrangement based on the orientation of the ultrasound probe when that ultrasound image was captured.

11. A system according to claim 10, the processor further configured to:

determine whether any gaps between the arranged ultrasound images exceed a threshold separation; and

when one or more gaps between the arranged ultrasound images exceed the threshold separation are identified, outputting instructions to perform further imaging using the output device.

12. A system according to claim 11, wherein the output device is an electronic display configured to display the instructions using a graphical user interface.

13. A system according to any of claims 9 to 12, wherein the instructions to perform further imaging comprise instructions indicating one or more orientations in which to position the ultrasound probe while performing the further imaging, the one or more orientations in which to position the ultrasound prove corresponding to orientations of the one or more gaps.

14. A system according to any of claims 10 to 13, wherein the ultrasound probe is further configured to capture an initial ultrasound image before capturing the series of ultrasound images, and wherein the processor is further configured to identify one or more features of the subject in the initial image, and use the one or more identified features to determine whether the probe is correctly positioned on the region of interest.

15. A system according to any of claims 10 to 14, wherein arranging the series of captured ultrasound images in the three-dimensional arrangement comprises selecting one of the images as a reference image and arranging the remaining images relative to the reference image in the arrangement, based on the differences in the orientations in which they were captured and the orientation in which the reference image was captured.

16. A system according to any of claims 10 to 15, wherein the system is further configured to:

identify a feature of the subject in a plurality of the captured ultrasound images;

compare the position of the identified feature in the plurality of the captured ultrasound images to determine a lateral offset between the plurality of captured ultrasound images, and translate one or more of the plurality of captured ultrasound images to compensate for the lateral offset.

17. A storage medium comprising computer instructions executable by one or more processors, the computer instructions when executed by the one or more processors causing the one or more processors to perform a method according to any of claims 1 to 9.

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Claims searched:	1-17	**Date of search:**	11 April 2023

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-17	US 2008/0146941 A1 (DALA-KRISHNA) See especially paragraphs [0010], [0011], [0032], [0034] - [0036], [0038], [0061], [0063]
X	1-17	EP 0487339 A1 (ADVANCED TECH LAB) See especially column 1, lines 34-37, column 2, lines 13-23, 39-50, column 6, lines 43-44, column 9, lines 15-22
X	1-17	WO 2017/200515 A1 (ANALOGIC CORP) See especially page 2, paragraph 1, page 5, paragraph 1, page 6, paragraph 3
X	1-17	WO 2016/201006 A1 (UNIV LELAND STANFORD JUNIOR) See especially paragraphs [0008], [0009], [0032], [0073], [0082]
X	1-17	WO 2006/127142 A2 (WORCESTER POLYTECH INST) See especially page 3, paragraph 4, page 7, paragraph 2, page 8, paragraph 2, page 9, paragraph 2
X	1-17	CN 114869332 A (BOZHOU LIANQI MEDICAL TECH CO LTD) See especially paragraphs [0012], [0032], [0034]

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

A61B

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
A61B	0008/13	01/01/2006
G01S	0015/89	01/01/2006