(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 April 2014 (17.04.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/057427 A1

(51) International Patent Classification:
A61B 8/00 (2006.01) *A61B 8/08* (2006.01)
A61B 8/02 (2006.01)

(21) International Application Number:
PCT/IB2013/059217

(22) International Filing Date:
8 October 2013 (08.10.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/710,795 8 October 2012 (08.10.2012) US

(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL]; High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(72) Inventors: **ZUO, Fei**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL). **KOLEN, Alexander Franciscus**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL). **BELT, Harm Jan Willem**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL). **FOKKENROOD, Steven Antonie Willem**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL). **HARKS, Godefridus Antonius**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(74) Agents: **STEFFEN, Thomas** et al.; High Tech Campus Building 5, NL-5656 AE Eindhoven (NL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) **Title**: ULTRASOUND DATA VISUALIZATION APPARATUS

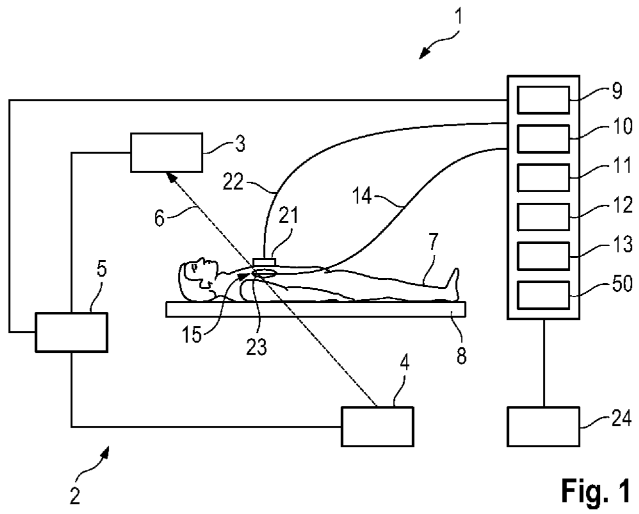

Fig. 1

(57) **Abstract**: The invention relates to an ultrasound data visualization apparatus for visualizing ultrasound data, in particular, during a cardiac ablation procedure. An M-mode ultrasound image of an object (23) being preferentially a heart of a person or a feature image of the object comprising features derived from the M-mode ultrasound image and a repetitive signal like an electrocardiography signal being indicative of a repetitive cycle in the image are provided. An image frames determination unit (13) determines image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal, wherein a display (24) displays the image frames temporally consecutively. Since the display shows these image frames temporally consecutively, a movie-like displaying of the ultrasound data is provided, which allows for a better observation of details and changes of the object, especially of changes in cardiac tissue during an ablation procedure.

WO 2014/057427 A1

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Ultrasound data visualization apparatus

FIELD OF THE INVENTION

The invention relates to an ultrasound data visualization apparatus, an ultrasound data visualization method and a computer program for visualizing ultrasound data. The invention relates further to an energy application apparatus comprising the ultrasound data visualization apparatus.

BACKGROUND OF THE INVENTION

US 2010/0185088 A1 discloses an ultrasound system comprising a memory configured to store ultrasound data including a movement cycle of an object of interest, wherein the ultrasound data are associated with ultrasound beams. The ultrasound system further comprises a processor configured to determine a partial M-mode image based on a line defined within the ultrasound data that is distinct from the ultrasound beams, wherein the processor is further configured to replicate the partial M-mode image at least once to form an M-mode image. The formed M-mode image is finally shown on a display. However, based on the formed M-mode image it is still very difficult to observe and trace details and changes within the movement cycle.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an ultrasound data visualization apparatus, ultrasound data visualization method and computer program for visualizing ultrasound data, which allow for a better observation of details and changes of a moving object. It is a further object of the present invention to provide an energy application apparatus for applying energy to the object, wherein the application of energy can be better controlled based on the visualized ultrasound data.

In a first aspect of the present invention an ultrasound data visualization apparatus for visualizing ultrasound data is presented, wherein the ultrasound data visualization apparatus comprises:

- an image providing unit for providing an image of an object being an M-mode ultrasound image of the object or a feature image of the object comprising features derived from the M-mode ultrasound image,
- a repetitive signal providing unit for providing a repetitive signal being indicative of a repetitive cycle in the image,
- an image frames determination unit for determining image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal,
- a display for displaying the image frames temporally consecutively.

Since the image frames are determined by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal and since the display shows these image frames temporally consecutively, a movie-like displaying of the ultrasound data is provided, which allows for a better observation of details and changes of the object.

The M-mode ultrasound image is preferentially a two-dimensional image consisting of adjacent A lines, wherein to two coordinates of the M-mode ultrasound image an ultrasound image value is assigned and wherein the two coordinates are indicative of the time and the depth within the object, respectively.

It is preferred that the object is a heart of a living being and the repetitive signal is indicative of a cardiac cycle of the living being. It is further preferred that the repetitive signal is an electrocardiography signal. This allows for an easy observation of details and changes within, for instance, a wall of a heart, especially during an ablation procedure. The repetitive signal providing unit can also be adapted to determine the repetitive signal from the provided image.

In a preferred embodiment, the image frames determination unit is adapted to determine the image frames such that an image frame corresponds to a complete repetitive cycle. Preferentially, each image frame corresponds to a complete cardiac cycle. This allows observing details and changes, which may occur at any temporal position within the repetitive cycle, in particular, within the cardiac cycle.

The image frames determination unit can also be adapted to determine the image frames such that an image frame corresponds to a part of the repetitive cycle, i.e. to a predefined interval of the repetitive cycle, which may be determined by the image frames determination unit based on the provided repetitive signal. In an embodiment, the image frames can correspond to a specific interval of a cardiac cycle like the Q-R or the Q-T interval. This allows highlighting only a specific part of the repetitive cycle that may be of interest for a certain application. The interval within the repetitive cycle like the Q-R or the Q-T interval can be predefined by, for instance, a user by using an input unit like a keyboard, a mouse, a touch screen, et cetera.

It is further preferred that the image frames determination unit is adapted to determine the image frames such that the image frames correspond to temporally adjacent repetitive cycles. This leads to the maximally achievable frequency of showing the images, thereby providing a high quality movie-like appearance.

Since the temporal length of the repetitive cycle may vary, the image frames determination unit can be adapted to amend the image frames such that the image frames have the same temporal length. For instance, the image frames determination unit can be adapted to perform at least one of a scaling procedure and a cropping procedure, i.e. a scaling procedure and/or a cropping procedure, for amending the image frames such that they have the same temporal length. The scaling can be, for instance, a linear or non-linear scaling of each repetitive cycle to ensure that all image frames have the same temporal size. The cropping procedure can be performed by taking for each image frame a fixed temporal interval starting from a trigger signal defined by the repetitive signal. For instance, if the repetitive signal is a cardiac signal, it can be triggered on the QRS complex, wherein starting from the QRS complex a fixed interval of, for instance, 200 ms can be used for the respective image frames, wherein the rest of the respective cardiac cycle may be discarded. This allows providing a high quality movie showing the object for observing details and changes, even if the repetitive cycle varies.

The image providing unit may be adapted to provide a motion map derived from the M-mode ultrasound image as the image to be segmented, i.e. a feature image being the motion map can be provided as the image to be segmented. For deriving the motion map known techniques like techniques, which are based on cross correlation that are widely used for strain imaging or techniques which are based on optical flow or block matching can be used.

The display can be adapted to display the image frames temporally consecutively overlaid over a reference image frame. For instance, if the ultrasound data visualization apparatus is used for monitoring a cardiac ablation procedure, the reference image frame can be an image frame, which has been taken before the ablation procedure has been started. The new image frames, which are overlaid with the reference image frame, can then be image frames taken during the ablation procedure, in order to visualize pre-ablation image data and realtime image data at the same time. The overlay can be provided with, for instance, 50 percent transparency.

The image frames determination unit can also be adapted to subtract the image frames from a reference image frame for generating subtraction image frames and to provide the subtraction image frames to the display as the image frames to be consecutively displayed. This allows emphasizing changes between the object at a time, at which the reference image frame has been taken, and the object at a time, at which a current image frame is taken. For instance, the reference image frame can be an image frame, which has been taken before an ablation procedure has been started, wherein this reference image frame can be subtracted from an actual image frame taken during an ablation procedure, in order to emphasize changes caused by the ablation procedure. Also in this embodiment the display can be adapted to display the image frames, which in this embodiment are subtraction image frames, temporally consecutively overlaid over the reference image frame.

In a further aspect of the present invention an energy application apparatus for applying energy to an object is presented, wherein the energy application apparatus comprises:

- an energy application device for applying energy to the object,
- an ultrasound imaging device for generating an M-mode ultrasound image of the object ,
- an ultrasound data visualization apparatus as defined in claim 1.

In a further aspect of the present invention an ultrasound data visualization method for visualizing ultrasound data is presented, wherein the ultrasound data visualization method comprises:

- providing an image of an object being an M-mode ultrasound image of the object or a feature image of the object comprising features derived from the M-mode ultrasound image by an image providing unit,
- providing a repetitive signal being indicative of a repetitive cycle in the image by a repetitive signal providing unit,
- determining image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal by an image frames determination unit,
- displaying the image frames temporally consecutively by a display.

In a further aspect of the present invention a computer program for visualizing ultrasound data is presented, wherein the computer program comprises program code means for causing an ultrasound data visualization apparatus as defined in claim 1 to carry out the steps of the visualization method as defined in claim 12, when the computer program is run on a computer controlling the visualization apparatus.

It shall be understood that the ultrasound data visualization apparatus of claim 1, the energy application apparatus of claim 12, the ultrasound data visualization method of claim 13 and the computer program of claim 14 have similar and/or identical preferred embodiments, in particular, as defined in the dependent claims.

It shall be understood that a preferred embodiment of the invention can also be any combination of the dependent claims with the respective independent claim.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 shows schematically and exemplarily an embodiment of an energy application apparatus for applying energy to an object,

Fig. 2 shows schematically and exemplarily a tip of a catheter of the energy application apparatus,

Fig. 3 shows exemplarily an M-mode ultrasound image,

Fig. 4 illustrates a sequence of image frames derived from an M-mode ultrasound image,

Figs. 5 to 8 exemplarily show image frames derived from an M-mode ultrasound image,

Fig. 9 shows image frames derived from a motion map,

Fig. 10 shows schematically and exemplarily an embodiment of an ultrasound data visualization apparatus for visualizing ultrasound data, and

Fig. 11 shows a flowchart exemplarily illustrating an embodiment of an ultrasound data visualization method for visualizing ultrasound data.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows schematically and exemplarily an embodiment of an energy application apparatus 1 for applying energy to an object. In this embodiment the energy application apparatus 1 is an ablation apparatus for ablating cardiac tissue of a heart wall. The ablation apparatus 1 comprises an ablation catheter 14 for being introduced into a heart 23 of a person 7 located on a support unit 8 like a patient table. The tip 15 of the ablation catheter 14 is schematically and exemplarily shown in more detail in Fig. 2.

The catheter tip 15 comprises an ablation electrode 16 being, in this embodiment, a cap electrode. The ablation electrode 16 is electrically connected with an ablation energy source 9 like a radio frequency energy source via an electrical connection 19 which is preferentially an electrical wire. The ablation electrode 16, the ablation energy source 9 and the electrical connection 19 can be regarded as being an energy application device for applying energy to the heart 23.

In the ablation electrode 16 irrigation openings 18 are provided for allowing irrigation fluid flowing within the ablation catheter 14 to leave the catheter tip 15. The irrigation fluid, which is preferentially a cooling fluid, is provided by an irrigation fluid source 10.

The catheter tip 15 further comprises an ultrasound transducer 17 located at a further opening within the ablation electrode 16 for sending ultrasound signals into cardiac tissue of the wall of the heart 23 and for receiving ultrasound signals from the cardiac tissue. The ultrasound transducer 17 is connected to an ultrasound control unit 11 via an electrical connection 20. The ultrasound control unit 11 is adapted such that M-mode ultrasound images of the cardiac tissue are generated. The ultrasound control unit 11, the ultrasound transducer 17 and the electrical connection 20 can therefore be regarded as being an ultrasound imaging device for generating an M-mode ultrasound image of the cardiac tissue.

The ablation apparatus further comprises an 11 for providing an image of the cardiac tissue being the M-mode ultrasound image generated by the ultrasound imaging device 11, 17, 20. In this embodiment the image providing unit 11 is just a receiving unit for receiving the generated M-mode ultrasound image from the ultrasound imaging device 11, 17, 20 and for providing the received M-mode ultrasound image to an image frames determination unit 13. However, in another embodiment the image providing unit 11 can also be adapted to generate a feature image of the cardiac tissue based on the received M-mode ultrasound image, wherein the feature image can be provided to the image frames determination unit 13. For instance, the image providing unit 11 can be adapted to generate a feature image that represents a certain image transformation of the M-mode ultrasound image. The feature image may be a motion map that is generated from the M-mode ultrasound image and that shows the amount of axial motion. The motion map can define a motion field that has the same size than the M-mode ultrasound image, wherein each point in the two-dimensional motion map indicates the cardiac tissue motion at a time t and at a depth

d. For generating such a motion map the image providing unit 11 can be adapted to apply known motion determination techniques to the M-mode ultrasound image like cross-correlation-based techniques that are widely used for strain imaging or optical-flow-based techniques or block-matching based techniques.

The ablation apparatus further comprises a repetitive signal providing unit for providing a repetitive signal being indicative of a repetitive cycle in the image. In this embodiment, the repetitive signal providing unit is formed by electrocardiography electrodes 21 arranged on the person 7, an electrocardiography control unit 12 and corresponding electrical connections 22. The repetitive signal providing unit provides therefore, in this embodiment, an electrocardiography signal as the repetitive signal. In another embodiment the repetitive signal providing unit can also be adapted to provide the repetitive signal in another way. For instance, the repetitive signal providing unit 12 can be adapted to determine the repetitive signal from the M-mode ultrasound image.

Due to cardiac contraction and optionally a possible movement of the ablation catheter the M-mode ultrasound image exhibits a repetitive pattern. The M-mode ultrasound image can therefore be used to generate the repetitive signal. For extracting the repetitive signal from the M-mode ultrasound image the repetitive signal providing unit 12 can be adapted to perform one or several of the following procedures.

The M-mode ultrasound image can be projected to the time axis such that the resulting repetitive signal is a one-dimensional signal in time, wherein the value of the repetitive signal at a certain time is a summation of the signal amplitude of an A line of the M-mode ultrasound image at the certain time. The resulting one-dimensional repetitive signal can be processed by, for instance, a peak detection algorithm for deriving a trigger signal. The summation of the signal amplitude of the respective A line can be performed with respect to the complete respective A line or only with respect to a segment of the respective A line.

It is also possible to derive the repetitive signal from the M-mode ultrasound image by calculating motion cycles using autocorrelation. Temporally consecutive regions of the M-mode ultrasound image can be defined, wherein these temporally consecutive regions can be, for instance, rectangular blocks. Each region of the M-mode ultrasound image can then be compared with a temporally adjacent block by using a matching function, which may be based on, for instance, the sum of absolute differences in the signal amplitude in temporally adjacent regions. Due to the repetitive nature of the M-mode ultrasound image the matching result will also be periodic such that the matching result may be regarded as being a repetitive signal. This repetitive signal can be further processed by, for instance, peak detection for deriving a trigger signal.

The repetitive signal providing unit 12 can also be adapted to apply a motion analysis procedure like a strain imaging procedure or a tissue Doppler procedure to the M-mode ultrasound image for deriving a tissue velocity map. Due to the repetitive nature of the M-mode ultrasound image the derived tissue velocity map will also show a repetitive pattern. This tissue velocity map can be further processed for generating a one-dimensional repetitive signal that can be used to determine a trigger signal. The one-dimensional repetitive signal can be generated by, for instance, taking the maximum or the average velocity at each time.

The image frames determination unit 13 is adapted to determine image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal. In this embodiment, the provided M-mode ultrasound image is temporally segmented into image frames corresponding to different cardiac cycles based on the electrocardiography signal. In the following the temporal segmentation of the M-mode ultrasound image will be exemplarily described with reference to Fig. 3.

Fig. 3 shows exemplarily an M-mode ultrasound image 31. In Fig. 3 the horizontal axis represents the time t and the vertical axis represents the distance D to the ultrasound transducer 17, which is related to the depth within the cardiac tissue. The lines 30 indicate different cardiac cycles, i.e. the region between two consecutive lines 30 in Fig. 3 corresponds to a cardiac cycle and is determined by the image frames determination unit 13 as being an image frame.

In this example, the image frames determination unit 13 is adapted to determine a trigger signal from the repetitive signal and to use the trigger signal for segmenting the M-mode ultrasound image into the image frames. For instance, the image frames determination unit 13 can be adapted to identify the QRS complex in the electrocardiography signal and to provide a trigger signal, which indicates the time instances of the QRS complex as the beginnings of the respective cardiac cycles.

The lines 30 indicate the time instances corresponding to the trigger signal, i.e. the lines 30 indicate the beginning of the respective cardiac cycle. Based on this trigger signal the image frames determination unit 13 can subdivide the M-mode ultrasound image into segments, wherein each segment corresponds to one complete cardiac cycle. Each segment, i.e. the respective image region between two adjacent lines 30, forms an image frame. The determined image frames correspond to temporally adjacent cardiac cycles.

A cardiac cycle is completed, if a next actual trigger signal occurs. Thus, after a new actual trigger signal has been occurred, the A lines, which are on the left hand side of the new actual trigger signal, can form an actual image frame.

The heartbeat will very likely not be constant, especially in the case of atrial fibrillation. For instance, the intervals between the QRS complexes may be varying. The image frames determination unit 13 is therefore preferentially adapted to amend the image frames such that the image frames have the same temporal length. For instance, the electrocardiography signal can be used to trigger on the QRS complex, wherein the image frames determination unit 13 can be adapted to take a fixed interval of the M-mode ultrasound image after the QRS complex as the respective image frame and to discard the rest of the respective cardiac cycle. Thus, the image frames determination unit 13 can be adapted to perform a cropping procedure for amending the image frames such that they have the same temporal length. Alternatively, the image frames determination unit 13 can be adapted to linearly or non-linearly scale each image frame, which corresponds to a cardiac cycle, such that they all have the same temporal length, i.e. in order to ensure that all of the output frames have the same size.

The ablation apparatus 1 further comprises a display 24 for displaying the image frames temporally consecutively. By showing the image frames consecutively over time, i.e. in a movie-like fashion, even small changes in cardiac motion behavior can be seen, because the human visual interpretation is very sensitive to local changes in a static background, i.e. since by using this mode of visualization the image frames from consecutive cardiac cycles are exactly shown in the same temporal manner and are replaced at each new heartbeat, details in changes within one heart cycle can be more easily observed and traced. Thus, a dynamic visualization of cardiac motion cycles based on an M-mode ultrasound image or a feature image derived from the M-mode ultrasound image can be provided for ultrasound-based cardiac ablation monitoring.

Fig. 4 shows schematically and exemplarily a sequence of image frames, which may be generated by the image frames determination unit 13 and which may be shown temporally consecutively at the same location on the display 24. In this example a first image frame 32, a 21st image frame 33, a 17th image frame 34 and a 130th image frame 35 are shown. These image frames are retrieved from an M-mode ultrasound image, which has been generated during an ablation procedure. As can be seen in this sequence of image frames, the amount of cardiac motion due to myocardium contraction changes over time during ablation, wherein this change in myocardium contraction would be difficult to see from an original M-mode ultrasound image. Thus, showing the image frames temporally consecutively on the display 24, wherein image segments of the same phase of each cardiac cycle are overlaid, makes tissue changes more visible. Due to the myocardium contraction and/or catheter motion only a specific phase from each cardiac cycle may be very informative concerning a specific aspect, which should be observed, for example, a lesion progression. By displaying the image frames temporally consecutively, wherein each image frame corresponds to a cardiac cycle, the changes of the cardiac tissue at this specific phase can be easily observed.

In the following aspects will be illustrated, which can be of interest to an electrophysiology physician, who may carry out the ablation procedure, and which can be easily revealed by the described visualization mode.

For instance, the described visualization can be used to monitor a cardiac motion change as exemplarily illustrated in above Fig. 4 and as exemplarily illustrated in Fig. 5. Fig. 5 shows exemplarily two image frames 36, 37, wherein the image frame 36 corresponds to a cardiac cycle before the ablation procedure has been started and the image frame 37 corresponds to a cardiac cycle after the ablation procedure has been completed. The entire sequence of image frames, of which only two image frames are shown in Fig. 5, can be temporally consecutively shown on the display 24, wherein in the resulting movie a change in cardiac motion can be clearly observed.

A further aspect, which may be observed by watching the movie on the display 24, is the differentiation between adjacent structures. This is illustrated in Fig. 6, which shows two image frames 38, 39 of a sequence of image frames determined from an M-mode ultrasound image. If the image frames of the complete sequence are temporally consecutively shown on the display 24, it can be seen that the atrial tissue 44 and the adjacent lung structure 45 move with different motion frequencies. This can clearly be observed in the movie-like visualization and can be used for distinguishing between the atrial tissue 44 and the adjacent lung structure 45. The motion frequencies are different, because the motion of the atrial tissue reflects more the cardiac motion and the motion of the lung structure reflects more the breathing motion.

The aspect, which may be readily observed by using the described visualization mode, can also be a contrast change. Fig. 7 shows exemplarily two image frames 40, 41 of a sequence of image frames, which are temporally consecutively shown at the same place on the display 24. The image frame 40 on the left side corresponds to a cardiac cycle before the ablation procedure has been started and the image frame 41 on the right side corresponds to a cardiac cycle after the ablation procedure has been completed. The visualization allows for a clear observation of the contrast change due to ablation.

The aspect, which can be observed by watching the movie generated by showing the image frames temporally consecutively at the same place on the display, can also be, for instance, a scatter change or a speckle change. Fig. 8 shows exemplarily two image frames 42, 43 of a sequence of image frames, wherein the image frame 42 on the left side corresponds to a cardiac cycle before the ablation procedure has been started and the image frame 43 on the right side corresponds to a cardiac cycle after the ablation procedure has been completed.

As already mentioned above, the image providing unit 11 can also be adapted to determine a feature image of the cardiac tissue comprising features derived from the M-mode ultrasound image. In particular, the image providing unit 11 can be adapted to generate a motion map from the M-mode ultrasound image. If then the motion map is segmented by the image frames determination unit 13 in accordance with the cardiac cycles, in order to determine the image frames, wherein the image frames, which are based on the motion map, are then temporally consecutively displayed by the display 24, a motion movie can be generated, wherein each image frame shows the motion field of one complete cardiac cycle. Fig. 9 shows exemplarily two image frames 46, 47 of such a sequence of image frames, which have been determined by segmenting a motion map in accordance with the cardiac cycle. The image frame 46 on the left side was taken before the ablation procedure has been started and the image frame 47 on the right side was taken after the ablation procedure has been completed. The image frames 46, 47 show obvious differences in the tissue motion between the pre-ablated healthy tissue and the ablated tissue. The healthy tissue shows more prominent contraction motion, while the necrosis shows more reduced motion due to increased stiffness.

The display 24 can also be adapted to display the image frames temporally consecutively overlaid over a reference image frame. Thus, it can be possible to include one kind of reference in the visualization, which may be important for the specific application of cardiac ablation monitoring. For instance, a snapshot of an image frame, i.e. one of the image frames determined by the image frames determination unit 13, which has been taken before the ablation procedure has been started, can be used as the reference image frame. The display can then be adapted to generate an overlay with 50 percent transparency, wherein new actual image frames, which correspond to actual cardiac cycles, are overlaid with transparency over the reference image frame. This allows showing reference data and realtime data at the same time. The image frames determination unit 13 can also be adapted to subtract the image frames obtained from the M-mode image or from the feature image from the reference image frame for generating subtraction image frames, wherein the image frames determination unit 13 can further be adapted to provide the subtraction image frames to the display 24 as the image frames to be consecutively displayed. For instance, a reference image frame, which corresponds to a cardiac cycle that was present before ablation has been started, can be subtracted from an image frame, which corresponds to a new actual cardiac cycle, in order to emphasize changes before and during ablation in the movie presented by the display 24. The subtraction images can also be overlaid with the reference image frame, which preferentially corresponds to a cardiac cycle, which was present before the ablation procedure had been started.

Referring again to Fig. 1, the ablation apparatus 1 further comprises a position detection system 2 for detecting the position of the tip 15 of the catheter 14 within the person 7. In this embodiment the position detection system 2 is an x-ray fluoroscopy system, in particular, an x-ray C-arm system. The x-ray fluoroscopy system comprises an x-ray source 4 for generating x-rays 6 which traverse the person 7 on the table 8, wherein the x-rays 6, which have traversed the person 7, are detected by an x-ray detector 3. The x-ray fluoroscopy system 2 further comprises a fluoroscopy control unit 5 for controlling the x-ray source 4 and the x-ray detector 3. The x-ray detector 3 generates x-ray images of the person 7, which can be shown on the display 24. On the generated x-ray images the tip 15 of the catheter 14 is visible within the person 7 such that the x-ray images show the position of the tip 15 of the catheter 14 within the person 7. In other embodiments other position detection systems for detecting the position of the catheter tip within the person can be used like position detection systems which are based on electromagnetic sensors, ultrasound sensors, et cetera.

The ablation apparatus further comprises a navigation unit 50 for allowing the catheter 14, in particular, the catheter tip 15, to be navigated to a desired location within the person 7. The navigation unit 50 can be adapted to allow a user to navigate the catheter 14 completely by hand or semi-automatically. The catheter 14 comprises built-in guiding means (not shown in Fig. 1), which can be controlled by the navigation unit 50. The catheter 14 can, for example, be steered and navigated by the use of steering wires, in order to guide the catheter tip 15 to a desired location within the person 7.

The image providing unit 11, the repetitive signal providing unit 12, the image frames determination unit 13 and the display 24 can be regarded as being an ultrasound data visualization apparatus for visualizing ultrasound data. In the embodiment shown in Fig. 1

the ultrasound data visualization apparatus is integrated with the ablation apparatus 1. However, in another embodiment the ultrasound data visualization apparatus can also be a separate apparatus as will be described in the following with reference to Fig. 10.

Fig. 10 shows schematically and exemplarily an ultrasound data visualization apparatus 125, which forms a separate system, i.e. a system not being integrated with the ablation apparatus 1. Also in this embodiment the ultrasound visualization apparatus comprises an image providing unit 111 for providing an image of an object 23 being an M-mode ultrasound image of the object 23 or a feature image of the object 23 comprising features derived from the M-mode ultrasound image. The image providing unit 111 can be adapted to receive an M-mode ultrasound image from an ultrasound imaging device and to provide the received M-mode ultrasound image to an image frames determination unit 113 of the ultrasound data visualization apparatus 125. The image providing unit 111 can also be adapted to determine a feature image of the object 23 comprising features derived from the received M-mode ultrasound image. For instance, the image providing unit 111 can be adapted to derive a motion map from the received M-mode ultrasound image as described above with reference to the image providing unit 11 shown in Fig. 1.

The ultrasound data visualization apparatus 125 further comprises a repetitive signal providing unit 112 for providing a repetitive signal being indicative of a repetitive cycle in the image. For instance, the repetitive signal providing unit 112 can just be a receiving unit for receiving an electrocardiography signal from an electrocardiography device and to provide the received electrocardiography signal as the repetitive signal. However, the repetitive signal providing unit 112 can also be adapted to determine the repetitive signal from, for instance, the M-mode ultrasound image.

The ultrasound data visualization apparatus 125 further comprises an image frames determination unit 113 for determining image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal and a display 124 for displaying the image frames temporally consecutively. The image frames determination unit 113 and the display 124 can be similar to the image frames determination unit 13 and the display 24, respectively, described above with reference to Fig. 1.

In the following an embodiment of an ultrasound data visualization method for visualizing ultrasound data will exemplarily be described with reference to a flowchart shown in Fig. 11.

In step 201 an image of an object being an M-mode ultrasound image of the object or a feature image of the object comprising features derived from the M-mode ultrasound image is provided by an image providing unit. In step 202 a repetitive signal being indicative of a repetitive cycle in the image is provided by a repetitive signal providing unit. For instance, an electrocardiography signal is provided as the repetitive signal or a repetitive signal is determined from the M-mode ultrasound image. Steps 201 and 202 are performed in parallel such that the A-lines of the M-mode ultrasound image can be assigned to the repetitive cycles. In step 203 image frames are determined by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal by an image frames determination unit, wherein in step 204 the image frames are displayed temporally consecutively by a display.

Steps 201 to 204 may be performed in a loop-like fashion, wherein, if the generated M-mode ultrasound image and the repetitive signal allow a determination of a next image frame, this next image frame is shown on the display, wherein then, if the M-mode ultrasound image and the repetitive cycle allow the determination of a following image frame, this following image frame is shown on the display, in order to update the display very fast, in particular, substantially in realtime. The segmentation of the M-mode ultrasound image can therefore be performed concurrently with providing the M-mode ultrasound image and the repetitive signal.

In an embodiment, the repetitive signal providing unit may be adapted to determine the repetitive signal not from an electrocardiography measurement, but in another way, in particular, from the provided M-mode ultrasound image, especially in case of atrial fibrillation or if ablated tissue is to be observed.

Although in an above described embodiment the repetitive signal providing unit is adapted to determine the repetitive signal from the M-mode ultrasound image by using certain procedures for deriving the repetitive signal, in other embodiments the repetitive signal providing unit can also be adapted to determine the repetitive signal from the M-mode ultrasound image in another way. For instance, instead of transforming the M-mode ultrasound image into a velocity domain, the M-mode ultrasound image can also be transformed into another domain, wherein from the transformed image in the other domain a repetitive signal can be determined, for example, by taking the maximum or the average of the transformed M-mode ultrasound image at the respective time.

Although in an above described embodiment the image frames determination unit is adapted to determine the image frames such that an image frame corresponds to a complete cardiac cycle, in another embodiment the image frames determination unit can also be adapted to determine the image frames such that an image frame corresponds to a certain interval of the cardiac cycle like the Q-R or the Q-T interval. Also these image frames may be modified such that they have the same temporal length.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

A single unit or device may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Procedures like the determination of the feature image, the determination of the image frames, the scaling or cropping of the image frames, the determination of subtraction image frames, et cetera performed by one or several units or devices can be performed by any other number of units or devices. The procedures and/or the control of the ultrasound data visualization apparatus in accordance with the ultrasound data visualization method can be implemented as program code means of a computer program and/or as dedicated hardware.

A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium, supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

Any reference signs in the claims should not be construed as limiting the scope.

The invention relates to an ultrasound data visualization apparatus for visualizing ultrasound data, in particular, during a cardiac ablation procedure. An M-mode ultrasound image of an object being preferentially a heart of a person or a feature image of the object comprising features derived from the M-mode ultrasound image and a repetitive signal like an electrocardiography signal being indicative of a repetitive cycle in the image are provided. An image frames determination unit determines image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal, wherein a display displays the image frames temporally consecutively. Since the display shows these image frames temporally consecutively, a movie-like displaying of the ultrasound data is provided, which allows for a better observation of details and changes of the object, especially of changes in cardiac tissue during an ablation procedure.

CLAIMS:

1. An ultrasound data visualization apparatus for visualizing ultrasound data, the ultrasound data visualization apparatus comprising:

- an image providing unit (11; 111) for providing an image of an object (23) being an M-mode ultrasound image of the object (23) or a feature image of the object (23) comprising features derived from the M-mode ultrasound image,
- a repetitive signal providing unit (12, 21, 22; 112) for providing a repetitive signal being indicative of a repetitive cycle in the image,
- an image frames determination unit (13; 113) for determining image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal,
- a display (24; 124) for displaying the image frames temporally consecutively.

2. The ultrasound data visualization apparatus as defined in claim 1, wherein the object (23) is a heart of a living being and the repetitive signal is indicative of a cardiac cycle of the living being.

3. The ultrasound data visualization apparatus as defined in claim 1, wherein the repetitive signal providing unit (112) is adapted to determine the repetitive signal from the provided image.

4. The ultrasound data visualization apparatus as defined in claim 1, wherein the image frames determination unit (13; 113) is adapted to determine the image frames such that an image frame corresponds to a complete repetitive cycle.

5. The ultrasound data visualization apparatus as defined in claim 1, wherein the image frames determination unit (13; 113) is adapted to determine the image frames such that an image frame corresponds to a predefined interval of the repetitive cycle.

6. The ultrasound data visualization apparatus as defined in claim 1, wherein the image frames determination unit (13; 113) is adapted to determine the image frames such that the image frames correspond to temporally adjacent repetitive cycles.

7. The ultrasound data visualization apparatus as defined in claim 1, wherein the temporal length of the repetitive cycle varies, wherein the image frames determination unit (13; 113) is adapted to amend the image frames such that the image frames have the same temporal length.

8. The ultrasound data visualization apparatus as defined in claim 7, wherein the image frames determination unit (13; 113) is adapted to perform at least one of a scaling procedure and a cropping procedure for amending the image frames such that they have the same temporal length.

9. The ultrasound data visualization apparatus as defined in claim 1, wherein the image providing unit (111) is adapted to provide a motion map derived from the M-mode ultrasound image as the image to be segmented.

10. The ultrasound data visualization apparatus as defined in claim 1, wherein the display (24; 124) is adapted to display the image frames temporally consecutively overlaid over a reference image frame.

11. The ultrasound data visualization apparatus as defined in claim 1, wherein the image frames determination unit (13; 113) is adapted to subtract the image frames from a reference image frame for generating subtraction image frames and to provide the subtraction image frames to the display as the image frames to be consecutively displayed.

12. An energy application apparatus for applying energy to an object, the energy application apparatus (1) comprising:

- an energy application device (9, 16, 19) for applying energy to the object,
- an ultrasound imaging device (11, 17, 20) for generating an M-mode ultrasound image of the object (23),
- an ultrasound data visualization apparatus as defined in claim 1.

13. An ultrasound data visualization method for visualizing ultrasound data, the ultrasound data visualization method comprising:

- providing an image of an object being an M-mode ultrasound image of the object (23) or a feature image of the object (23) comprising features derived from the M-mode ultrasound image by an image providing unit (11; 111),
- providing a repetitive signal being indicative of a repetitive cycle in the image by a repetitive signal providing unit (12, 21, 22; 112),
- determining image frames by temporally segmenting the provided image into image frames corresponding to different repetitive cycles based on the repetitive signal by an image frames determination unit (13; 113),
- displaying the image frames temporally consecutively by a display (24; 124).

14. A computer program for visualizing ultrasound data, the computer program comprising program code means for causing an ultrasound data visualization apparatus as defined in claim 1 to carry out the steps of the ultrasound data visualization method as defined in claim 13, when the computer program is run on a computer controlling the ultrasound data visualization apparatus.

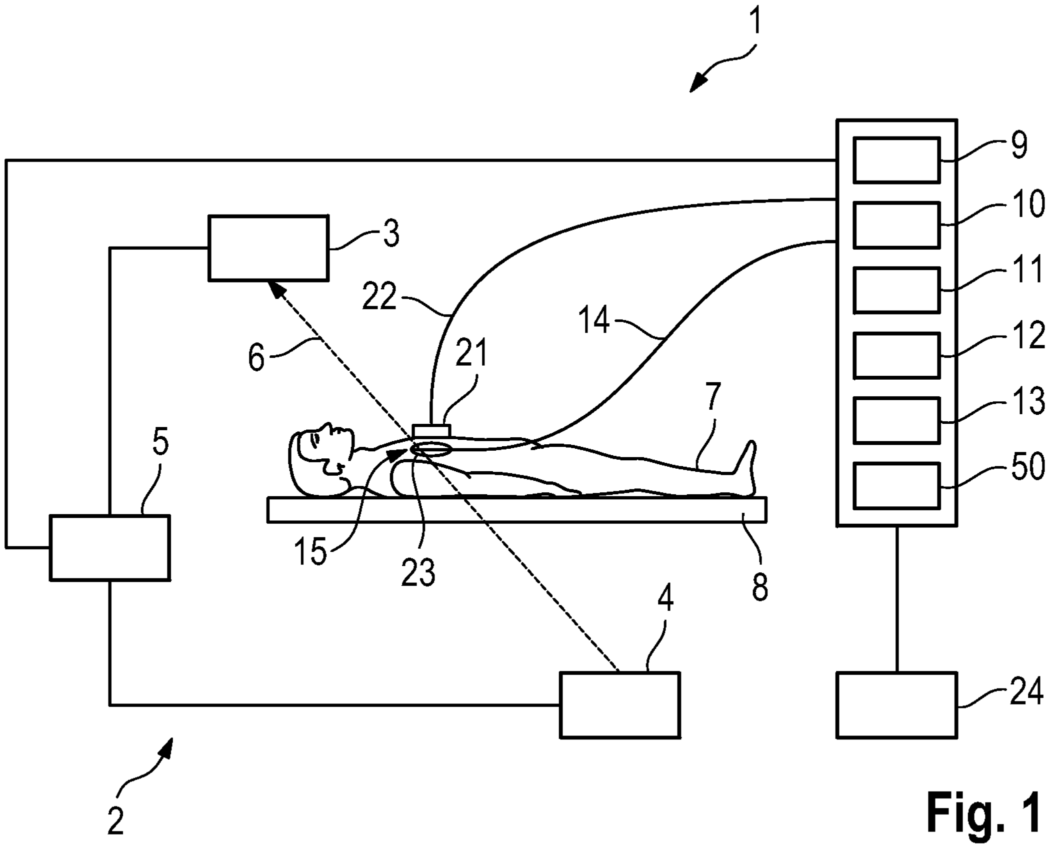

Fig. 1

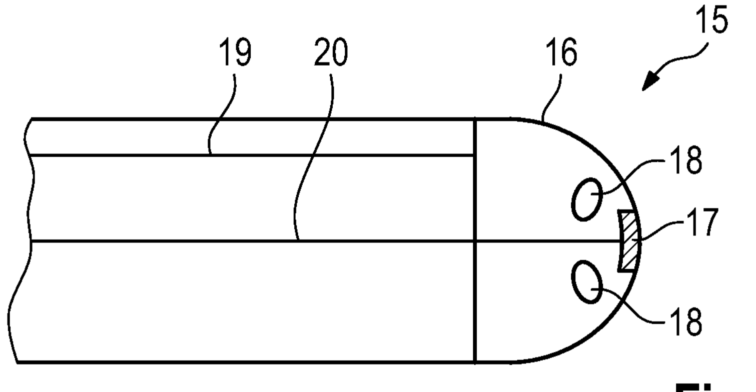

Fig. 2

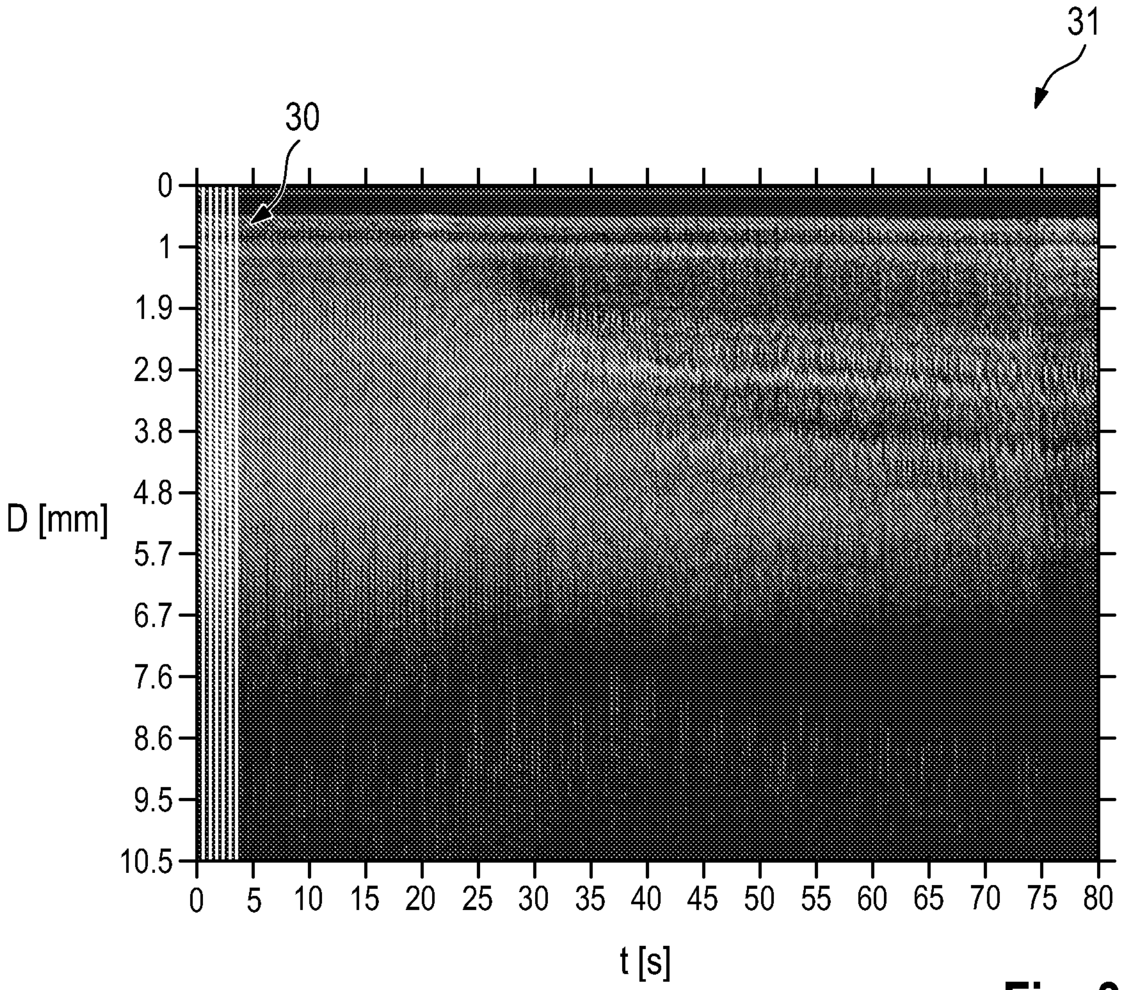
31
30
0
1
1.9
2.9
3.8
4.8
5.7
6.7
7.6
8.6
9.5
10.5
D [mm]
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
t [s]

Fig. 3

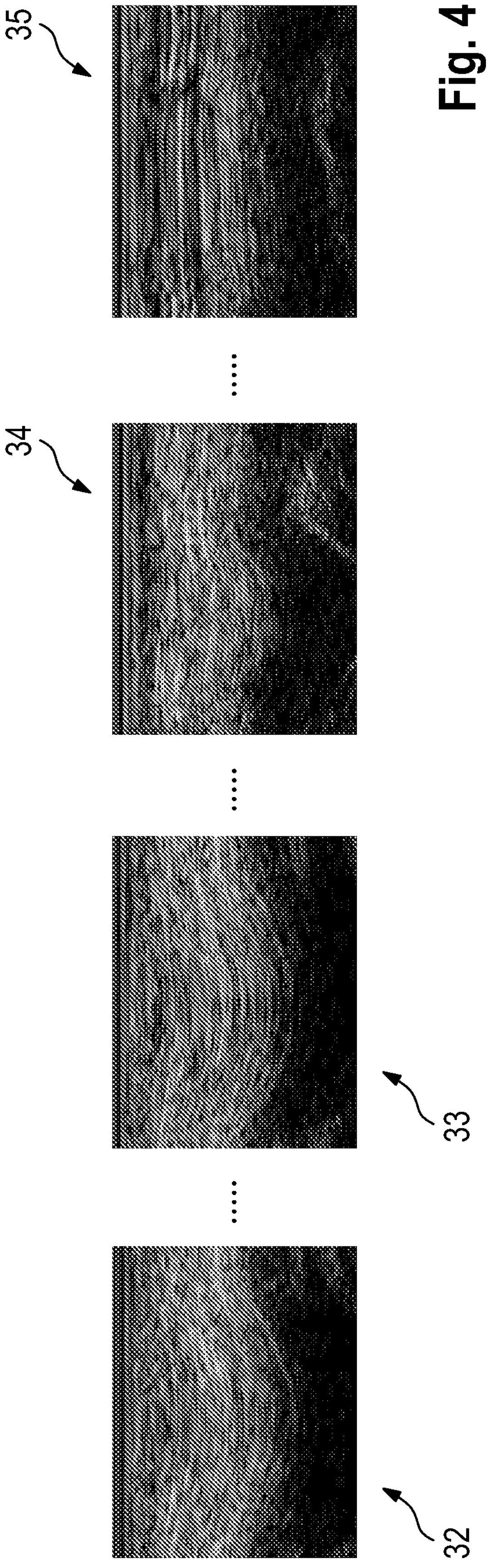

Fig. 4

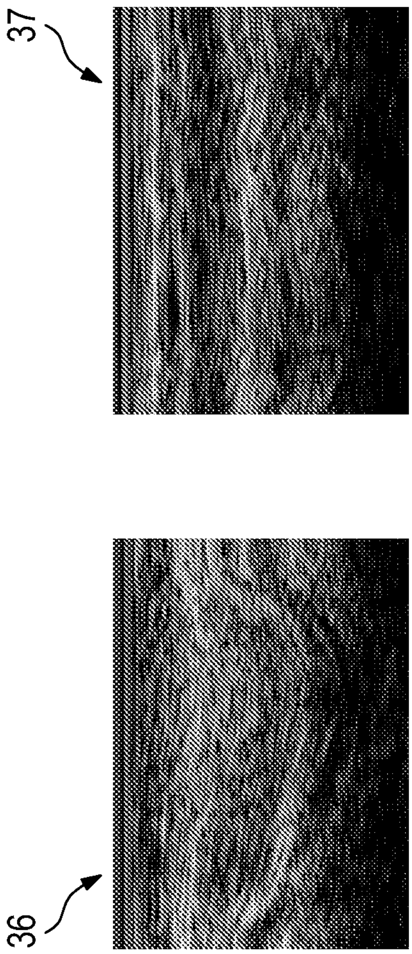

Fig. 5

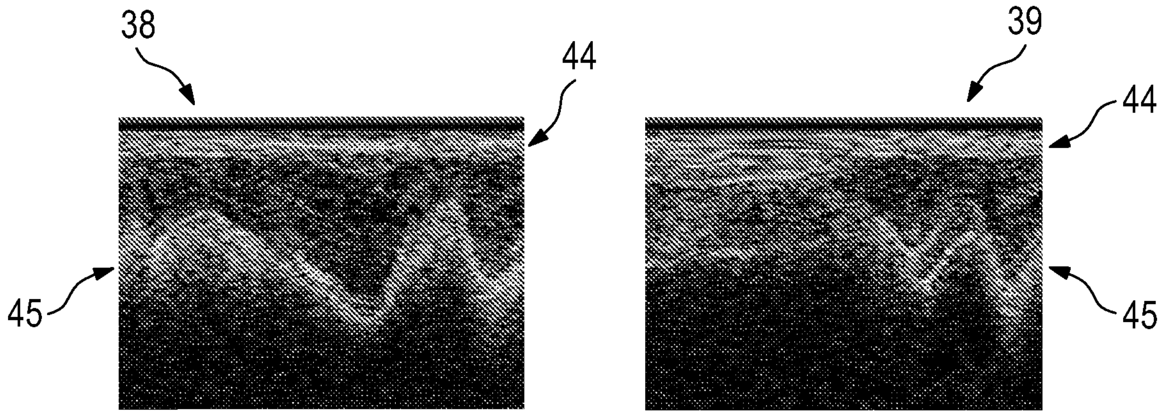

Fig. 6

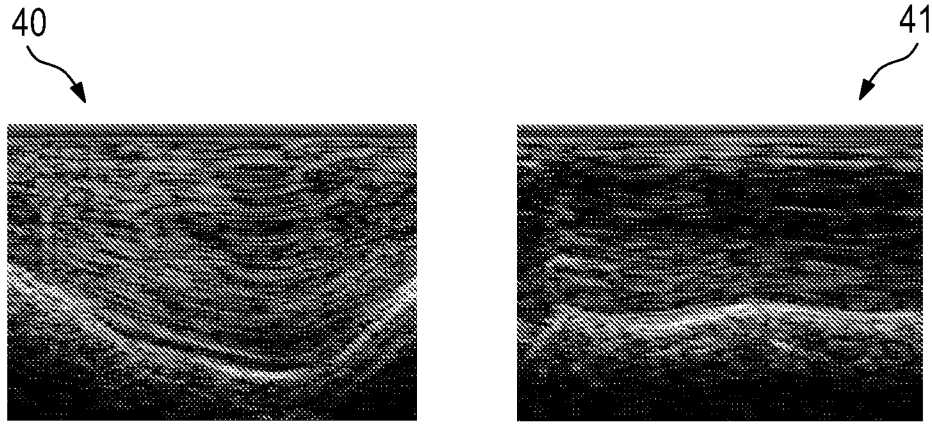

Fig. 7

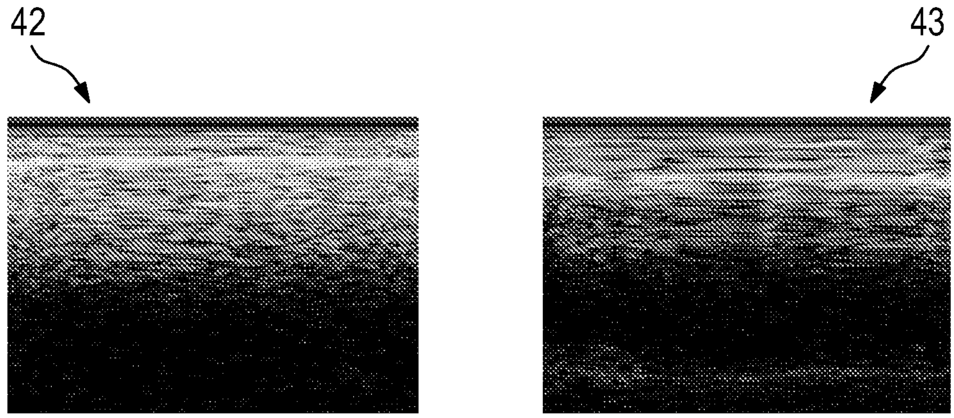

Fig. 8

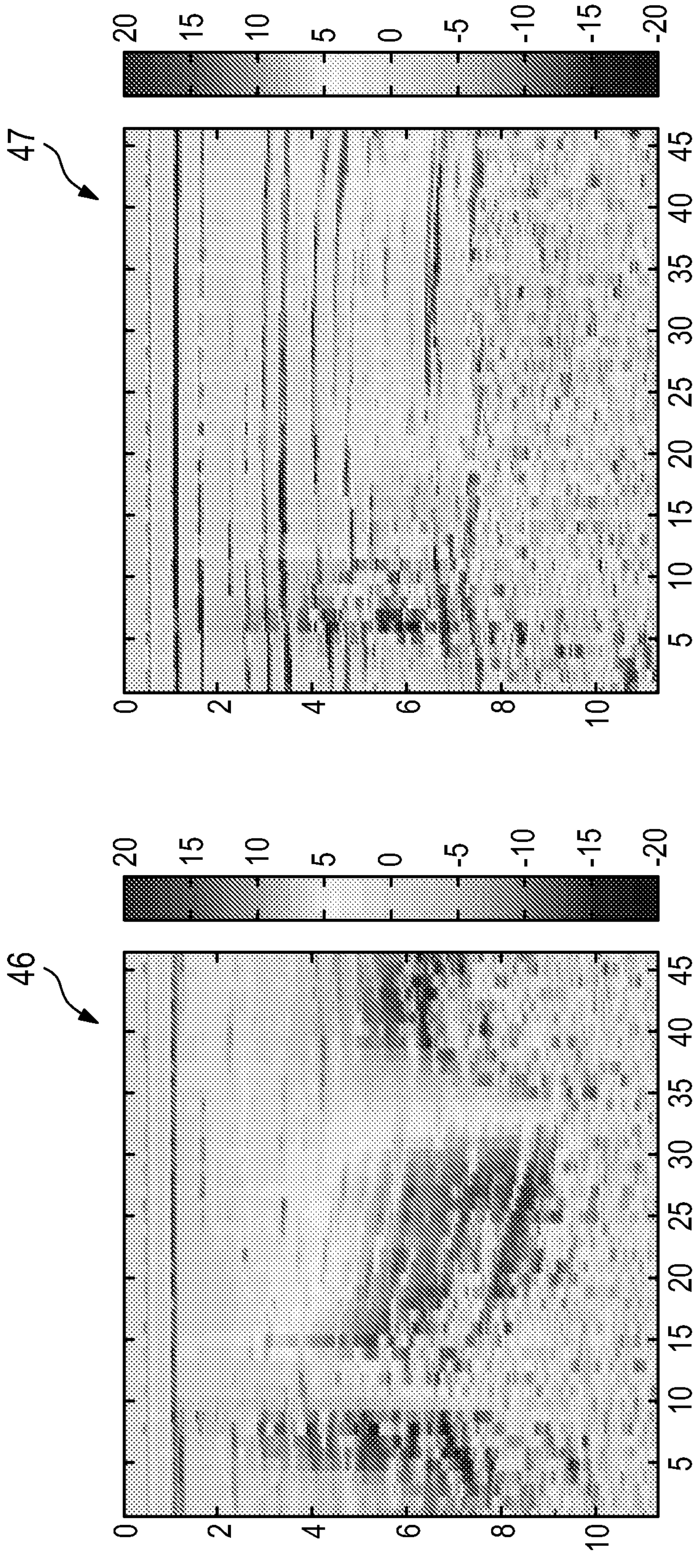
47
46
20 15 10 5 0 -5 -10 -15 -20
20 15 10 5 0 -5 -10 -15 -20
0 2 4 6 8 10
0 2 4 6 8 10
5 10 15 20 25 30 35 40 45
5 10 15 20 25 30 35 40 45

Fig. 9

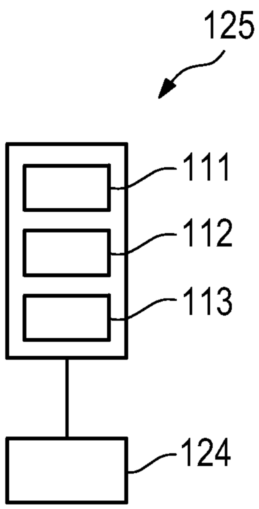

Fig. 10

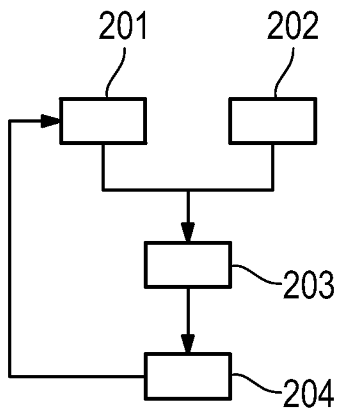

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/059217

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B8/00 A61B8/02 A61B8/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KETTERLING J A ET AL: "Prospective ECG-gated mouse cardiac imaging with a 34-MHz annular array transducer", IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS AND FREQUENCY CONTROL, IEEE, US, vol. 54, no. 7, 2 July 2009 (2009-07-02), pages 1394-1404, XP011281844, ISSN: 0885-3010 abstract figures 1,2,5,6,7 Section II. -----	1-14
X	EP 1 779 787 A2 (BIOSENSE WEBSTER INC [US]) 2 May 2007 (2007-05-02) abstract figures 1-9 paragraph [0046] - paragraph [0107] -----	1,12-14
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 January 2014	10/02/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Moehrs, Sascha

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/059217

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JING DENG ET AL: "Fetal echocardiography in three and four dimensions", ULTRASOUND IN MEDICINE AND BIOLOGY, NEW YORK, NY, US, vol. 22, no. 8, 2 January 1996 (1996-01-02), pages 979-986, XP002405068, ISSN: 0301-5629, DOI: 10.1016/S0301-5629(96)00119-6 abstract Section "Discussion" -----	3
A	US 2010/145197 A1 (STAPF DANIEL [DE] ET AL) 10 June 2010 (2010-06-10) abstract figures 1-13 paragraph [0032] -----	10,11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/059217

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1779787 A2	02-05-2007	AT 534330 T	15-12-2011
		AU 2006233220 A1	17-05-2007
		BR PI0604497 A	28-08-2007
		CA 2565532 A1	28-04-2007
		CN 101002689 A	25-07-2007
		EP 1779787 A2	02-05-2007
		EP 2208466 A1	21-07-2010
		IL 178850 A	28-06-2012
		JP 5367215 B2	11-12-2013
		JP 2007117746 A	17-05-2007
		KR 20070046000 A	02-05-2007
		US 2007106146 A1	10-05-2007
US 2010145197 A1	10-06-2010	NONE	