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(54) Title: ZONE VISUALIZATION FOR ULTRASOUND-GUIDED PROCEDURES

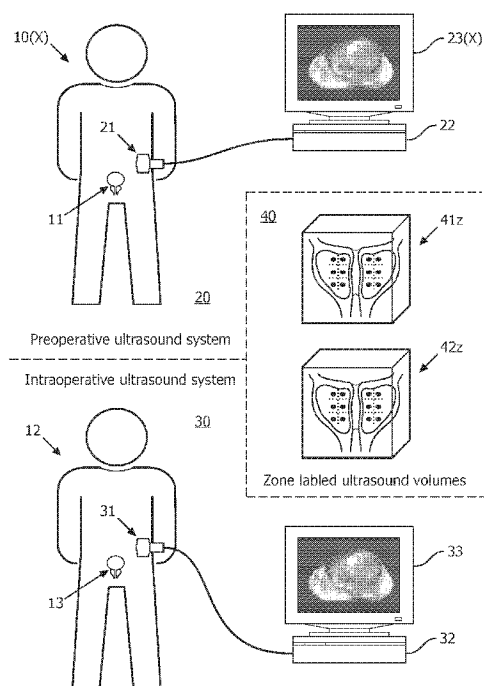


FIG. 1

(57) Abstract: A system for automatic zone visualization employing an ul-
trasound probe (31) and an ultrasound imaging workstation (32). In opera-
tion, ultrasound probe (31) scans an anatomical region, and the ultrasound
imaging workstation (32) tracks a generation of an ultrasound volume (42) of
an anatomical structure within a patient space responsive to the scan of the
anatomical region by the ultrasound probe (31). The ultrasound imaging
workstation (32) further tracks a labeling of procedurally-defined zones of
the anatomical structure within the ultrasound volume (42) derived from an
ultrasound volume model (41) of the anatomical structure labeled with the
procedurally-defined zones to thereby facilitate an ultrasound-guided visual-
ization of the anatomical structure.

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- *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))*

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ZONE VISUALIZATION FOR ULTRASOUND-GUIDED PROCEDURES

The present invention generally relates to automatic location of specific zones of an anatomical structure for visual guidance during an ultrasound-guided procedure (e.g., a prostate biopsy). The present invention specifically relates to zone labeling of a three-dimensional (“3D”) model of the anatomical structure as a basis for visualizing guidance through the zones during an ultrasound-guided procedure.

A medical image registration of a preoperative anatomical image with an intraoperative anatomical image has been utilized to facilitate image-guided interventional/surgical/diagnostic procedures. The main goal for the medical image registration is to calculate a geometrical transformation that aligns the same or different view of the same anatomical structure within the same or different imaging modality.

More particularly, prostate cancer affects one in six men in the western world, and it is the second leading cause of cancer death in American men. Transrectal ultrasound (“TRUS”)-guided systematic biopsy with different schemes (e.g., sextant, extended 12 core, etc.) are considered to be the standard of care in clinical practice. However, as two-dimensional (“2D”) ultrasound imaging is usually used, the field of view is limited. Furthermore, due to the lack of landmarks inside the prostate under ultrasound imaging, ultrasound based prostate imaging requires a significant amount of training and experience to precisely navigate to the desired location for biopsy.

Of importance, according to the urological literature on prostate biopsy, the cancer locations are not uniformly distributed inside the prostate gland. The research shows that there are some high risk areas inside the gland with higher possibilities to detect cancer. Known systematic biopsy schemes are designed in special ways to cover those high risk areas to achieve maximal cancer detection rate with certain number of biopsies. However, due to the limitations of the current ultrasound imaging guidance, there are trends that some zones (e.g., horns of the prostate gland) tend to be missed in many cases. It may result in higher false negative biopsy rates and some cancer cases may be missed.

In summary, it is known that some high risk areas of the prostate can be significantly undersampled during biopsy due to the limitation of the imaging guidance technique. While such limitations may be compensated by the experience of

physicians, the present invention provides a systematic technical approach to improve the outcome of biopsy consistently by assisting physicians with automatic zone identification. More particularly, an ultrasound model of an anatomical structure is labeled to two (2) or more procedurally-defined zones derived from a scheme designed for optimizing an ultrasound-guided procedure on the anatomical structure. For example, an ultrasound model of prostate may be labeled by procedurally-defined zones that are associated with a known scheme for an ultrasound-guided biopsy sampling of the gland, particularly a scheme considered to be the standard of care in clinical practice (e.g., sextant, extended 12 core, saturation sampling, anterior sampling etc.).

One form of the present invention is a system for automatic zone visualization employing an ultrasound probe and an ultrasound imaging workstation. In operation, ultrasound probe scans an anatomical region, and the ultrasound imaging workstation tracks a generation of an ultrasound volume of an anatomical structure within a patient space responsive to the scan of the anatomical region by the ultrasound probe. The ultrasound imaging workstation further tracks a labeling of procedurally-defined zones of the anatomical structure within the ultrasound volume derived from an ultrasound volume model of the anatomical structure labeled with the procedurally-defined zones to thereby facilitate an ultrasound-guided visualization of the anatomical structure.

The foregoing form and other forms of the present invention as well as various features and advantages of the present invention will become further apparent from the following detailed description of various embodiments of the present invention read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

FIG. 1 illustrates zone labeled ultrasound volumes in accordance with the present invention.

FIG. 2 illustrates a flowchart representative of an exemplary embodiment of an automatic visualization method in accordance with the present invention.

FIG. 3 illustrates an exemplary implementation of the flowchart illustrated in FIG. 2.

For purposes of the present invention, the term a “procedurally-defined zone” is broadly defined as zones of an anatomical structure derived from a scheme designed for optimizing an ultrasound-guided procedure on the anatomical structure. For example, an ultrasound model of prostate may be labeled by procedurally-defined zones that are associated with a known or proposed scheme for an ultrasound-guided biopsy sampling of the gland, particularly a scheme considered to be the standard of care in clinical practice (e.g., sextant, extended 12 core, saturation sampling, anterior sampling etc.).

Also, for purposes of the present invention, the terms “tracking”, “reconstruction”, “segmentation” and “registration” as well as related terms are to be broadly interpreted as known in the art of the present invention.

In practice, the present invention applies to any anatomical regions (e.g., head, thorax, pelvis, etc.) and anatomical structures (e.g., bones, organs, circulatory system, digestive system, etc.).

To facilitate an understanding of the present invention, exemplary embodiments of the present invention will be provided herein directed to automatic zone visualization of ultrasound imaging of a prostate. Nonetheless, those having ordinary skill in the art will appreciate how to execute automatic zone visualization of ultrasound imaging for all anatomical regions and structures therein.

Referring to FIG. 1, a preoperative ultrasound system 20 employs a 2D ultrasound probe 21 and an ultrasound imaging workstation 22 to generate a stream of ultrasound images 23 of an anatomical tissue of a prostate 11 of a subject 10 as subject 10 is being scanned by 2D ultrasound probe 21. As will be further described in connection with FIGS. 2 and 3, preoperative ultrasound system 20 is utilized to scan an X number of subjects 10 to acquire an X number of ultrasound volumes of prostate 11 reconstructed from the ultrasound images to thereby build a volume model 41z of prostate 11 labeled with procedurally-defined zones as symbolically shown by the matrix of dots therein. Alternatively, system 20 may employ a 3D ultrasound probe (not shown).

An intraoperative ultrasound system 30 employs a 2D ultrasound probe 31 and an ultrasound imaging workstation 32 to generate a stream of ultrasound images 33 of an anatomical tissue of a prostate 13 of a patient 12 as patient 12 is being scanned by 2D ultrasound probe 31. As will be further described in connection with FIGS. 2 and 3,

intraoperative ultrasound system 20 is utilized to scan patient 12 to acquire an ultrasound volume 42z of prostate 13 and to track a registration of zone labeled volume model 41z to ultrasound volume 42z to thereby label ultrasound volume 42z with the procedurally-defined zones as symbolically shown by the matrix of dots therein.

5 Please note the images of the zone labeled prostate within model 41 and volume 42 are not intended to be anatomically correct, but serves only as a simplified example of a zone labeled prostate for purposes of facilitating a description of an automatic zone visualization of the present invention based on zone labeled model 41z and volume 42z, which will now be provided herein.

10 Referring to FIGS. 2 and 3, the workflow of a flowchart 50 (FIG. 2) encompasses three (3) major aspects (FIG. 3) including various resource inputs 60, a tracked image registration 61, and a tracked output visualization 62.

 Generally, a preoperative resource 60p includes a stream of scanned ultrasound images 23 of prostate 11 for each subject 10 (FIG. 1) (or alternatively a 3D ultrasound
15 image of prostate 11 of one or more subjects 10). Intraoperative resources 60i include a stream of scanned ultrasound images 33 of prostate 13 of patient 12 (FIG. 1) (or alternatively a 3D ultrasound image of prostate 13 of patient 12) and tracking data TD of 2D ultrasound probe 31 (FIG. 1) as patient 12 is scanned. Output visualization 62 symbolically shows the zones on a real-time stream of ultrasound image 33 in real time
20 in accordance with a visualization strategy for differentiating the zones (e.g., color coding, text labels and/or audio feedback).

 Between inputs 60 and output 62, image registration 61 includes various processes for building prostate volume model 41z, tracking a reconstruction of a volume image 42 from ultrasound image stream 33, mapping a segmented prostate
25 from volume image 42 to volume model 41z. By doing these aspects, the zones can be mapped to the real time ultrasound streaming 33z by using the device tracking data TD.

 More particularly, ultrasound system 30 (FIG. 1) may stream ultrasound images 33 by either capturing the screen display of ultrasound imaging workstation 32, or directly from an output port of ultrasound imaging workstation 32 in an internal
30 transfer mode. Alternatively to 2D ultrasound probe 31, a 3D ultrasound probe can be used to obtain a 3D image of the prostate without the need for reconstructing the volume from 2D images.

Ultrasound system 30 also employs or cooperates with a tracking system to obtain a pose and position of 2D ultrasound probe 31 in real time for mapping ultrasound image stream 33 (or 3D image) to the 3D patient space. The pose and position of ultrasound probe 31 may be obtained by using any known device tracking technique (e.g., electromagnetic tracking or optical sensor tracking)

Flowchart 50 has four main stages S51-S54. A stage S51 of flowchart 50 encompasses workstation 20 (FIG. 1) building prostate volume model 41 with procedurally-defined zones. Specifically, a statistical shape model of the prostate is built by workstation 20 using a training data set having shapes obtained retrospectively from subjects 10 (FIG. 1). For each shape, corresponding zones of interest are labeled. The zones are procedurally-defined zones associated with a known or proposed scheme for an ultrasound-guided biopsy sampling of the gland, particularly a scheme considered to be the standard of care in clinical practice (e.g., sextant, extended 12 core, etc.). By applying statistical shape analysis (e.g., principal component analysis), prostate volume model 41 with labeled procedurally-defined zones is built by workstation 20.

In one embodiment, a preferred biopsy sampling scheme is added to the prostate volume model 41 by identifying a number N of locations in the prostate (typically $N \geq 10$). Each location can be identified as a geometrical object (e.g., a point, a small sphere or other simple shape (e.g. ellipsoid) in prostate volume model 41. These locations can later serve to guide the systematic sampling of the prostate according to the desired scheme.

A stage S52 of flowchart 50 encompasses workstation 30 (FIG. 1) reconstructing an ultrasound volume 42. Specifically, as ultrasound probe 31 is being tracked while scanning prostate 13 of patient 12, the pose and position of ultrasound probe 31 are known. By using this tracking data TD, ultrasound frames of stream 33 are transformed to the 3D patient space. By performing a sweep through the whole gland to obtain ultrasound image stream 33 covering the entire prostate 13, ultrasound volume 42 containing the prostate is reconstructed. Alternatively, if a 3D probe is used for acquisition, reconstruction of stage S52 may be omitted since the ultrasound workstation 32 provides the 3D volume image directly. Nonetheless, the 3D probe will be tracked to transform ultrasound volume 42 to 3D patient space.

A stage S53 of flowchart 50 encompasses workstation 30 segmenting the prostate from ultrasound volume 42 and registering prostate volume model 41 with the segmented prostate. Specifically, a main purpose of performing segmentation is to assist registering the prostate volume model 41 to ultrasound volume 42, as it is very
5 challenging to directly map prostate volume model 41 to ultrasound image stream 33. The segmentation may be performed in two (2) ways. The first option is to segment the ultrasound sweep data frame by frame. The obtained 2D segmentation sequences are then mapped to 3D space using the same transformations as in the reconstruction stage S52 to get the 3D segmentation. Alternatively, the reconstructed ultrasound volume 42
10 is segmented directly in 3D space by using a model based approach. If the prostate boundary in ultrasound volume 42 is not as clear as in the 2D ultrasound image stream 33, the two (2) options may be combined to achieve better segmentation performance.

Once the reconstructed ultrasound volume 42 is segmented, a surface based registration method (e.g., iterative closest points based registration) is applied to
15 register prostate volume model 41 with the segmented prostate of reconstructed ultrasound volume 42 to yield a zone labeled ultrasound volume 42z. With this registration, procedurally zones labeled in prostate volume model 42z are mapped to the patient space. With the real time tracking information available, the zones may be transformed to ultrasound image stream 33.

20 A stage S54 of flowchart 50 encompasses workstation 30 displaying a zone visualization in real time. Specifically, once the zones are mapped to ultrasound image stream 33, procedurally-defined zone(s) can be visualized over an ultrasound image 33z when being intersected. The intersected zone(s) are highlighted with a zone label displayed. In addition, different visualized zones may be differentiated with color
25 coding, text labels, or audio feedback. For example, while a set of zones are being intersected by a ultrasound image 33z, the intersection areas are shown in each corresponding color or label with or without audio feedback. As an addition or alternative approach, the locations of the biopsy sampling scheme are visualized jointly with ultrasound image 33z. This helps the user to adjust ultrasound probe 31 look
30 direction until the biopsy path is aligned with the locations of the sampling scheme.

Flowchart 50 is terminated upon completion of the procedure.

In an alternative embodiment of flowchart 50, stage S51 and the registration of stage S53 may be omitted whereby prostate volume model 41 may be defined using reconstructed ultrasound volume 42 in lieu of compounding a model using X number of prior subjects. Specifically, the procedurally-defined zones are created based on
5 geometric sub-division of an intra-procedural segmentation of reconstructed ultrasound volume 42. Examples of such sub-division include, but are not limited to, (1) dividing the intra-procedural segmentation of reconstructed ultrasound volume 42 in two (2) halves along the mid-sagittal plane and thus creating a “left” and “right” zone, and (2) dividing in the intra-procedural segmentation of reconstructed ultrasound volume 42
10 thirds using axial cut-planes, thus creating base/mid-gland/axial zones.

Referring to FIGS. 1-3, those having ordinary skill in the art will appreciate numerous benefits of the present invention including, but not limited to, automatic zone visualization of ultrasound-imaged guidance of anatomical structures.

While various embodiments of the present invention have been illustrated and
15 described, it will be understood by those skilled in the art that the embodiments of the present invention as described herein are illustrative, and various changes and modifications may be made and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt the teachings of the present invention without
20 departing from its central scope. Therefore, it is intended that the present invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out the present invention, but that the present invention includes all embodiments falling within the scope of the appended claims.

Claims

1. A system for automatic zone visualization, the system comprising:
an ultrasound probe (31) operable to scan an anatomical region; and
an ultrasound imaging workstation (32) operably connected to the ultrasound probe (31) to track a generation of an ultrasound volume (42) of an anatomical structure within a patient space responsive to a scan of the anatomical region by the ultrasound probe (31),
wherein the ultrasound imaging workstation (32) is operable to track a labeling of procedurally-defined zones of the anatomical structure within the ultrasound volume (42) derived from an ultrasound volume model (41) of the anatomical structure labeled with the procedurally-defined zones, and
wherein the procedurally-defined zones within the ultrasound volume (42) facilitate an ultrasound-guided visualization of the anatomical structure.
2. The system of claim 1, wherein the ultrasound imaging workstation (32) maps ultrasound volume model (41) to a tracked generation of the ultrasound volume (42).
3. The system of claim 1, wherein the ultrasound imaging workstation (32) maps ultrasound volume model (41) to a segmentation of the anatomical structure from a tracked generation of the ultrasound volume (42).
4. The system of claim 1, wherein the ultrasound imaging workstation (32) generates the ultrasound volume model (41) as a geometric sub-division model of a segmentation of the anatomical structure within the ultrasound volume (42).
5. The system of claim 1,
wherein the ultrasound probe (31) is further operable to guide a visualization of at least one of the procedurally-defined zones of the anatomical structure;
wherein the ultrasound imaging workstation (32) is operably connected to the ultrasound probe (31) to generate a ultrasound image (33) responsive to the ultrasound

probe (31) guiding a visualization of the at least one of the procedurally-defined zones of the anatomical structure; and

wherein the ultrasound image (33) visualizes the at least one of the procedurally-defined zones derived from the zone labeled ultrasound volume (42).

6. The system of claim 5, wherein the ultrasound imaging workstation (32) tracks a generation of the ultrasound image (33) within the patient space and zone labels the at least one of the procedurally-defined zones on the ultrasound image (33) as a function of a tracking intersection of the ultrasound image (33) and the ultrasound volume (42).

7. The system of claim 5, wherein the ultrasound imaging workstation (32) differentiates at least two procedurally-defined zones visualized within the ultrasound image (33).

8. The system of claim 7, wherein a differentiation of the at least two procedurally-defined zones visualized within the ultrasound image (33) includes at least one of color coding, text labeling and audio feedback.

9. A method for automatic zone visualization, the method comprising:
generating an ultrasound volume (42) of an anatomical structure derived from an ultrasound scan of an anatomical region; and

tracking a labeling of procedurally-defined zones of the anatomical structure within the ultrasound volume (42) derived from an ultrasound volume model (41) of the anatomical structure labeled with the procedurally-defined zones,

wherein the procedurally-defined zones within the ultrasound volume (42) facilitate an ultrasound-guided visualization of the anatomical structure.

10. The method of claim 9, wherein the tracking of the labeling of procedurally-defined zones of the anatomical structure within the ultrasound volume (42) includes:

mapping the ultrasound volume model (41) to a tracked generation of the ultrasound volume (42).

11. The method of claim 9, wherein the tracking of the labeling of procedurally-defined zones of the anatomical structure within the ultrasound volume (42) includes:
mapping the ultrasound volume model (41) to a segmentation of the anatomical structure from a tracked generation of the ultrasound volume (42).
12. The method of claim 9, wherein the ultrasound volume model (41) is a geometric sub-division model of a segmentation of the anatomical structure within the ultrasound volume (42).
13. The method of claim 9, further comprising:
generating a ultrasound image (33) responsive to an ultrasound probe (31)
guiding a visualization of at least one of the procedurally-defined zones of the anatomical structure,
wherein the ultrasound image (33) visualizes the at least one of the procedurally-defined zones derived from the zone labeled ultrasound volume (42).
14. The method of claim 13,
wherein the generation of the ultrasound image (33) is tracked within the patient space and
wherein the at least one of the procedurally-defined zones is zone labeled on the ultrasound image (33) as a function of a tracking intersection of the ultrasound image (33) and the ultrasound volume (42).
15. The method of claim 14, wherein at least two procedurally-defined zones are differentiated within the ultrasound image (33).

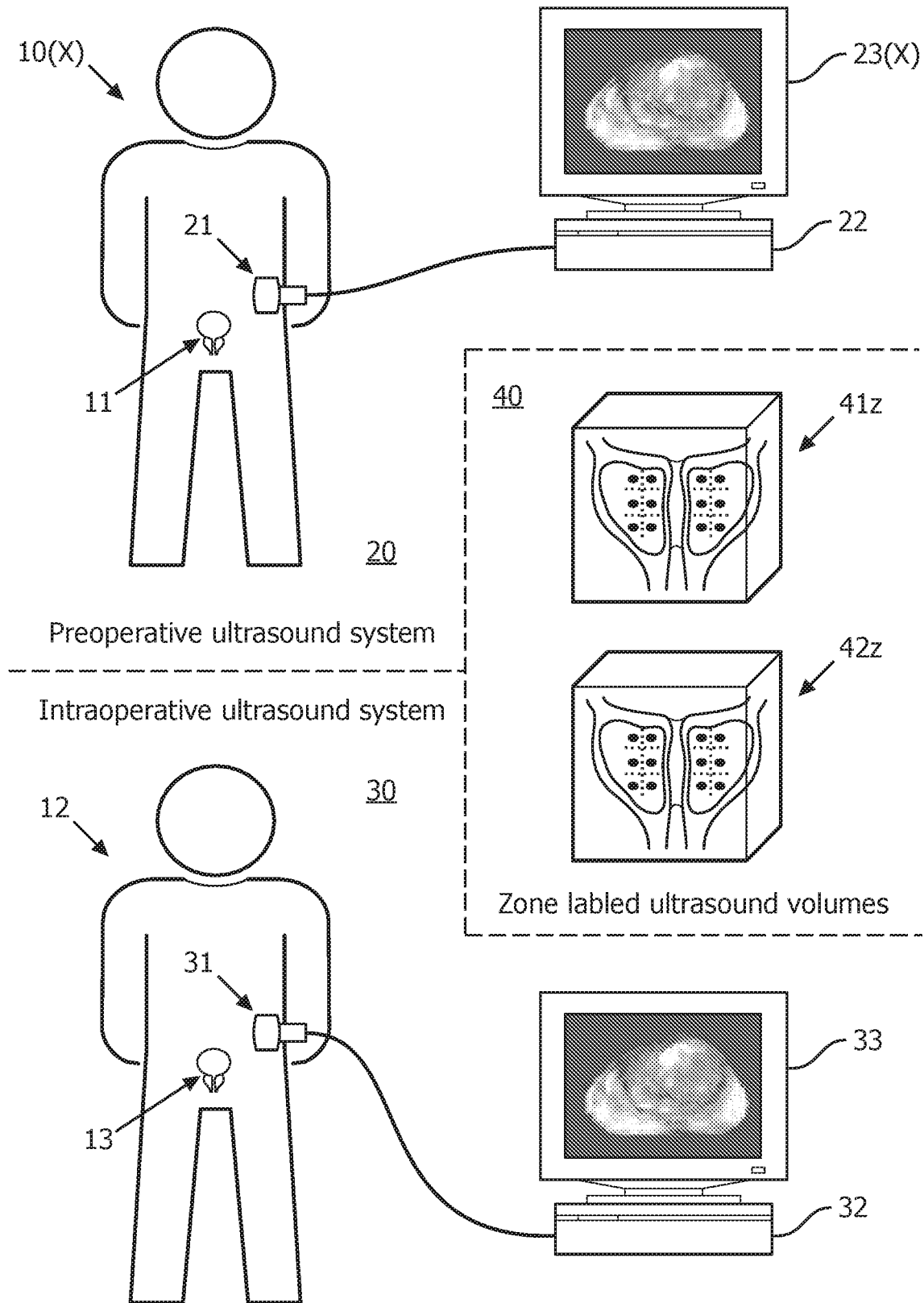


FIG. 1

Flowchart 50

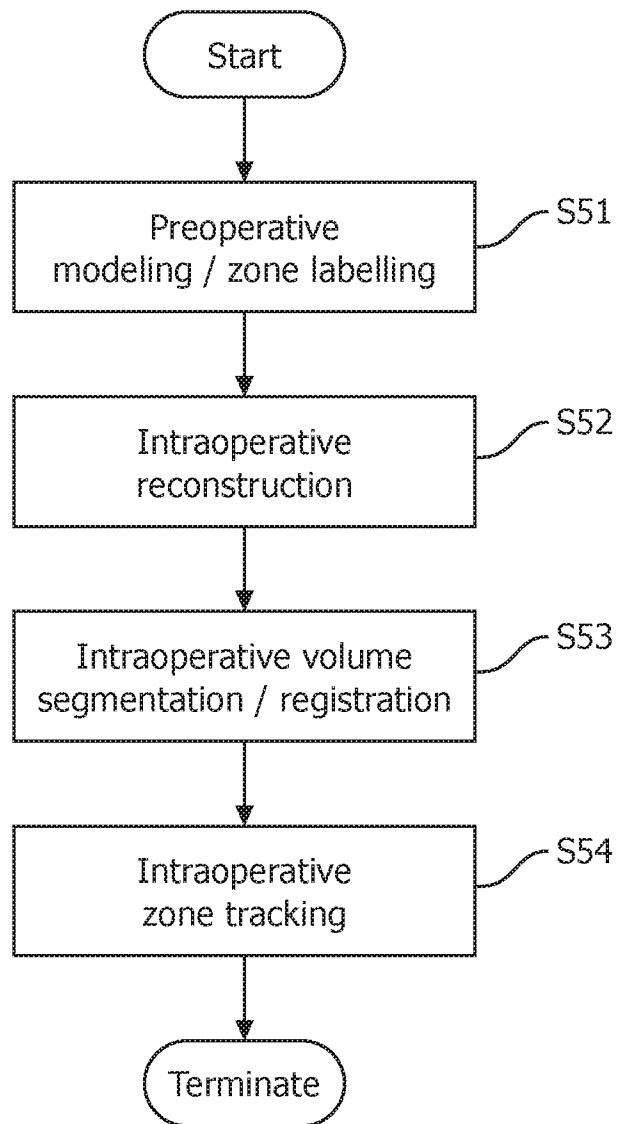


FIG. 2

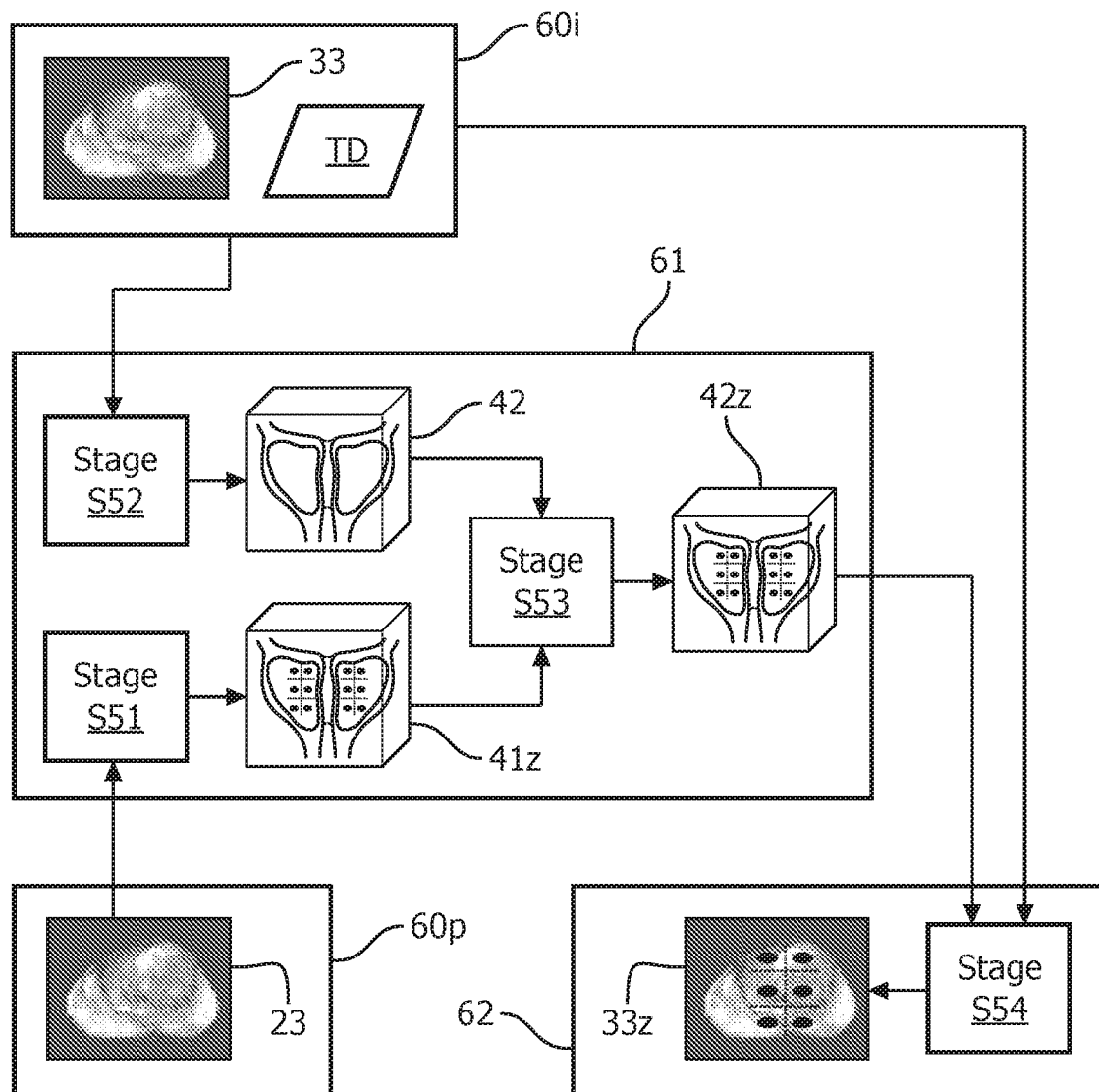


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No

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A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B8/08 A61B8/00 G06T7/00
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 G06T

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)

EP0-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	US 2012/172724 A1 (HILL ANTHONY D [US] ET AL) 5 July 2012 (2012-07-05) abstract figures 1-8 paragraph [0020] - paragraph [0044] -----	1-15
A	US 2013/237811 A1 (MIHAILESCU LUCIAN [US] ET AL) 12 September 2013 (2013-09-12) abstract figures 1-16 paragraph [0077] - paragraph [0228] -----	1-15
A	US 2013/324841 A1 (KAMEN ALI [US] ET AL) 5 December 2013 (2013-12-05) abstract figures 1-9 paragraph [0020] - paragraph [0047] ----- -/-	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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"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

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Date of the actual completion of the international search

19 June 2015

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03/07/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Moehrs, Sascha

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/051135

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/153506 A1 (KONINKL PHILIPS NV [NL]; NAT INST OF HEALTH NIH [US]) 17 October 2013 (2013-10-17) abstract figures 1-8 page 12, line 18 - page 30, line 18 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	YAN PINGKUN KRUECKER JOCHEN		
发明人	YAN, PINGKUN KRUECKER, JOCHEN		
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外部链接	Espacenet		

摘要(译)

一种用于使用超声探头 (31) 和超声成像工作站 (32) 的自动区域可视化的系统。在操作中，超声探头 (31) 扫描解剖区域，并且超声成像工作站 (32) 响应于超声波对解剖区域的扫描，跟踪患者空间内的解剖结构的超声体积 (42) 的生成。探针 (31)。超声成像工作站 (32) 进一步跟踪超声体积 (42) 内的解剖结构的程序限定区域的标记，该区域是从用程序限定区域标记的解剖结构的超声体积模型 (41) 导出的，从而便于超声引导的解剖结构可视化。