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(54) **Title:** WORKFLOW, SYSTEM AND METHOD FOR MOTION COMPENSATION IN ULTRASOUND PROCEDURES

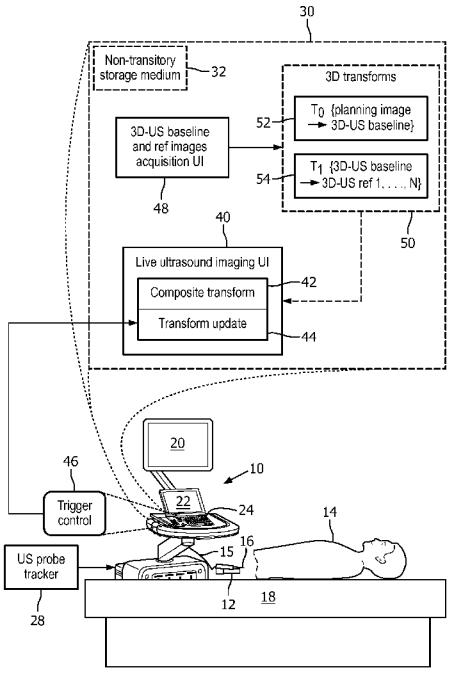

FIG. 1

(57) **Abstract:** An ultrasound imaging device (10) with an ultrasound probe (12) acquires a live ultrasound image which is displayed with a contour (62) or reference image (60) registered with the live ultrasound image using a composite transform (42). To update the composite transform, the ultrasound imaging device acquires a baseline three-dimensional ultrasound (3D-US) image (66) tagged with a corresponding baseline orientation of the ultrasound probe measured by a probe tracker, and one or more reference 3D-US images (70) each tagged with a corresponding reference orientation. Transforms (54) are computed to spatially register each reference 3D-US image with the baseline 3D-US image. A closest reference 3D-US image is determined whose corresponding orientation is closest to a current orientation of the ultrasound probe as measured by the probe tracker. The composite transform is updated to include the transform to spatially register the closest reference 3D-US image to the baseline 3D-US image.

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WORKFLOW, SYSTEM AND METHOD FOR MOTION COMPENSATION IN ULTRASOUND PROCEDURES

FIELD

The following relates generally to the imaging-guided surgical arts such as biopsy arts, brachytherapy arts, and the like, to ultrasound imaging performed to provide imaging guidance in such surgical procedures, and the like.

BACKGROUND

Imaging-guided surgical procedures are used for diverse purposes such as tissue sample extraction (i.e. biopsy) procedures, targeted laser ablation procedures, and brachytherapy procedures (in which radioactive seeds are delivered to targeted locations). Ultrasound (US) imaging is a common modality for image guidance of surgical procedures such as rectal prostrate biopsy or brachytherapy procedures. In these procedures, a rectal US probe is employed, and a grid may be used to align the biopsy needle or other interventional instrument. To obtain (near) real-time imaging, two-dimensional (2D) US imaging (commonly referred to as "live" 2D-US imaging) is commonly employed. 3D-US live imaging may also be employed if imaging speed is sufficient. To register the live US images in space, tracking of the US probe is performed, for example by electromagnetic (EM) tracking, optical tracking (if the probe is external to the patient), or so forth. Further, a pre-operative three-dimensional (3D) US baseline image is acquired to provide contouring of the prostate or other anatomical feature(s) of interest in 3D space. In some procedures, a three-dimensional (3D) planning image is acquired by another modality such as magnetic resonance imaging (MRI) or computed tomography (CT), the contouring is done in the planning image and the 3D US baseline image is used as an intermediary to register the planning image (or the contour defined in the planning image) to the live 2D-US image. In the latter case, the planning image is usually acquired prior to the image-guided surgical procedure to provide information for identifying tumors or other biopsy targets, contouring the prostate organ.

Some illustrative approaches are disclosed in Xu et al., U.S. Pat. No. 8,885,897. In one such illustrative approach, a pre-operative baseline 3D-US image is compared with a 3D diagnostic image (e.g. 3D-MRI) to determine a baseline transform which registers the baseline 3D-US and 3D-MRI volume images. During the surgical procedure, live 2D (or 3D) US images are acquired. One or a group of the live US images are

compared with the baseline 3D-US image to determine a motion correction transform. An image adjustment operates on the 3D-MRI image with the baseline transform and the motion correction transform to generate a motion corrected 3D-MRI image that is displayed together with (e.g. fused with) the display of the live US image. In this way, tissue motion (i.e. distortion or change) that may have occurred between acquisition of the 3D-MRI image and the subsequent live US imaging is compensated.

The following discloses new and improved systems and methods.

SUMMARY

In one disclosed aspect, an interventional imaging device includes an ultrasound probe, an ultrasound imaging device operatively connected with the ultrasound probe to perform ultrasound imaging using the ultrasound probe, a display, and a probe tracker (28) operative to track orientation of the ultrasound probe. The device further includes an electronic processor operatively connected with the ultrasound imaging device, the probe tracker, and the display. A non-transitory storage medium stores instructions readable and executable by the electronic data processor to operate the ultrasound imaging device to acquire a live ultrasound image and to operate the display to display the live ultrasound image together with a contour or reference image that is registered with the live ultrasound image using a composite transform, and to perform further operations including: operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image tagged with a corresponding baseline orientation of the ultrasound probe measured by the probe tracker for the baseline 3D-US image; operating the ultrasound imaging device to acquire one or more reference 3D-US images each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image; computing a transform to spatially register each reference 3D-US image with the baseline 3D-US image; determining a closest reference 3D-US image whose corresponding orientation is closest to a current orientation of the ultrasound probe measured by the probe tracker; and updating the composite transform to include the transform to spatially register the closest reference 3D-US image to the baseline 3D-US image.

In another disclosed aspect, a non-transitory storage medium stores instructions readable and executable by an electronic processor that is in operative communication with an ultrasound imaging device with an ultrasound probe and with a display and with a probe tracker operative to track orientation of the ultrasound probe. The instructions are readable and executable by the electronic processor to perform a live imaging

method including: operating the ultrasound imaging device to acquire a live ultrasound image; spatially registering a contour or reference image with the live ultrasound image using a composite transform; displaying the live ultrasound image together with the spatially registered contour or reference image on the display; and adjusting the composite transform. The adjustment is by operations including: operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image tagged with a corresponding baseline orientation of the ultrasound probe measured by the probe tracker for the baseline 3D-US image; operating the ultrasound imaging device to acquire one or more reference 3D-US images each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image; computing a set of transforms $\{T_{1,i}\}_{i=1,...,N}$ to spatially register the reference 3D-US images with the baseline 3D-US image where N is the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US image; determining a closest reference orientation which is closest to a current orientation of the ultrasound probe measured by the probe tracker; and updating the composite transform to a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$ where k indexes the determined closest reference 3D-US image whereby the transform $T_{1,k}$ spatially registers the determined closest reference 3D-US image indexed by k with the baseline 3D-US image and the transform $T_{2,k}$ spatially registers the determined closest reference 3D-US image with the live ultrasound image.

In another disclosed aspect, a live ultrasound imaging method is disclosed. An ultrasound imaging device is operated to acquire a time series of live ultrasound images using an ultrasound probe. A contour or reference image is spatially registered with the time series of live ultrasound images using a composite transform. The time series of live ultrasound images is displayed together with the spatially registered contour or reference image. The composite transform is adjusted by operations including: operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image tagged with a corresponding baseline orientation of the ultrasound probe measured by a probe tracker for the baseline 3D-US image; operating the ultrasound imaging device to acquire one or more reference 3D-US images each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image; computing a set of transforms $\{T_{1,i}\}_{i=1,...,N}$ to spatially register the reference 3D-US images with the baseline 3D-US image where N is the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US

image; determining a closest reference orientation which is closest to a current orientation of the ultrasound probe measured by the probe tracker; and updating the composite transform to a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$ where k indexes the determined closest reference 3D-US image whereby the transform $T_{1,k}$ spatially registers the determined closest reference 3D-US image indexed by k with the baseline 3D-US image and the transform $T_{2,k}$ spatially registers the determined closest reference 3D-US image with the live ultrasound image. The updated composite transform is used in the spatially registering of the contour or reference image with live ultrasound images of the time series of live ultrasound images acquired after the current live ultrasound image

One advantage resides in providing live ultrasound (US) imaging in the context of a baseline 3D-US image and/or an earlier-acquired 3D-MRI or other planning image, with improved correction of the baseline 3D-US or 3D-MRI image for tissue motion that may have occurred before or during the image-guided surgical procedure.

Another advantage resides in providing live US imaging in the context of one or more organ contours or other image features delineated in a baseline 3D-US image and/or an earlier-acquired 3D-MRI or other planning image, with improved correction of the image feature(s) for tissue motion that may have occurred before or during the image-guided surgical procedure.

Another advantage resides in providing live US imaging guidance for an image-guided surgical procedure with improved robustness against tissue deformation produced by repositioning of the ultrasound probe.

Another advantage resides in providing live US imaging guidance for an image-guided surgical procedure with improved accuracy when the US probe is moved to different orientations to provide optimal viewing perspective for visualization of the surgical procedure.

Another advantage resides in providing one or more of the foregoing benefits with concomitant rapid live US imaging and consequently improved live image guidance for an image-guided surgical procedure.

A given embodiment may provide none, one, two, more, or all of the foregoing advantages, and/or may provide other advantages as will become apparent to one of ordinary skill in the art upon reading and understanding the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 diagrammatically shows an illustrative ultrasound (US)-guided prostate biopsy system.

FIGURE 2 shows representative images with tissue motion correction suitably produced by the US-guidance portion of the US-guided prostate biopsy system of FIGURE 1.

FIGURE 3 diagrammatically shows acquisition and processing of 3D baseline and reference US images performed by the US-guided prostate biopsy system of FIGURE 1.

FIGURE 4 diagrammatically shows live US imaging performed in support of a prostate biopsy surgical procedure by the US-guidance portion of the US-guided prostate biopsy system of FIGURE 1.

DETAILED DESCRIPTION

The accuracy and robustness of image registration-based motion compensation depends on the similarity of the images being registered. In some US-guided surgical procedures, the orientation of the US probe may be adjusted by the surgeon during the procedure to provide a preferred vantage point for viewing the surgery. This can create substantially different tissue deformation when compared with the baseline US image, and thus make registration between the dissimilar live US and baseline 3D-US images obtained with different probe orientation challenging. Such registration is especially difficult in the case of live 2D-US images due to the reduced image information in the 2D-US image upon which to base the registration.

Approaches disclosed herein in recognition of this problem provide a plurality of reference 3D-US images acquired with different ultrasound probe orientations. One of these is designated as the baseline 3D-US image. Each reference 3D-US image and the baseline 3D-US image is tagged with its probe orientation, that is, with the orientation of the ultrasound probe at the time the 3D-US reference or baseline image was acquired. Each reference 3D-US image is spatially registered with the baseline 3D-US image. If a different-modality planning image is also provided (for example, a 3D-MRI image or a 3D-CT image), it is spatially registered with the designated baseline image using cross-modality spatial image registration. As the interventional (i.e. surgical) procedure progresses, it is monitored

using the ultrasound imaging device, which acquires live US images at a rate sufficient to provide (near) real-time imaging of the prostate or other surgical area. Typically, the live US images are two-dimensional (2D) images, although 3D live US images are contemplated if 3D-US acquisition speed is sufficient (e.g., if a 3D-US probe is employed).

Initially, the baseline 3D-US image is used for superimposing the surgically relevant contour(s) (e.g. prostate contour) and/or fusing the live US image with the planning image or a contextual 3D-US image. Alternatively, as the tracking system tracks the US probe orientation during the live US imaging, this orientation can be used to initially select the closest reference or baseline 3D-US image for this purpose. If a reference 3D-US image is selected, then the superimposition of the relevant contour(s) and/or fused 3D image entails spatially transforming using both a transform between the live US image and the closest reference 3D-US image and the initially generated transform between closest reference 3D-US image and the baseline 3D-US image.

This live tracking with contour superimposition and/or 3D image fusion continues as the interventional procedure proceeds. However, if the surgeon adjusts positioning of the US probe by a sufficiently large amount, the employed transform will become increasingly inaccurate since the presumed similarity between US probe orientation used for acquiring the live US image and the closest reference or baseline 3D-US image will become more dissimilar. As this continues, the surgeon may be expected to notice increasingly poor alignment between the live US image and the superimposed contour(s) and/or fused 3D image. At this point, the surgeon may press a trigger button or other user input to trigger an update of the spatial registration. In this update procedure, the tracking system determines the current US probe orientation for live US imaging, and this orientation is compared with the tagged US probe orientations of the baseline and reference 3D-US images to select the closest 3D-US image. The transforms are updated accordingly (e.g. a new closest reference 3D-US image is selected, the transform between new closest reference 3D-US image and the baseline 3D-US image is chosen for subsequent use, and thereafter the live US image is registered with the new closest reference 3D-US image.

In this way, motion (e.g. differential tissue deformation) caused by the surgeon repositioning the US probe is accounted for more accurately. This is done in a computationally efficient manner, because the computationally costly cross-modality registration between the planning image (e.g. 3D-MRI or 3D-CT image) and the baseline 3D-US image is not re-computed, and likewise the less computationally costly (but still

somewhat costly) transforms between the reference 3D-US images and the baseline 3D-US image are not re-computed.

In some variant embodiments, contrary to this last advantage there may be an option (e.g. selectable by the surgeon or automatically triggered by an unacceptable value of a spatial registration quality metric) to acquire one or more additional reference 3D-US image(s) and/or to re-acquire a previously acquired reference 3D-US image and to compute (or re-compute) the transform(s) between the newly acquired reference 3D-US image(s) and the baseline 3D-US image. This variant approach, if employed, provides a mechanism to correct for larger motion (e.g. greater tissue deformation) or for repositioning of the US probe to a position far from any of the orientations of the reference 3D-US images by updating the reference 3D-US image(s).

With reference to FIGURE 1, an illustrative interventional imaging device suitable for implementing the foregoing is shown. An ultrasound (US) imaging device **10** may, for example, be an EPIQ™ ultrasound imaging system available from Koninklijke Philips N.V., Amsterdam, the Netherlands, or may be another commercial or custom-built ultrasound imaging system. The ultrasound imaging device **10** is operatively connected with an US probe **12** to perform ultrasound imaging using the ultrasound probe **12**. The illustrative US probe is a rectal ultrasound probe **12** which is inserted into the rectum of a patient **14**. (The lower half of the patient is cut away in diagrammatic FIGURE 1 to reveal the inserted probe **12** which would otherwise be occluded from view. Typically, the patient is lying on the side or facing up with the legs lifted up and fixed on a table extension.) The illustrative choice of a rectal US probe **12** is a conventional choice for US monitoring of a prostate procedure; more generally, the disclosed interventional imaging approaches may be used with other types of US probes and/or for monitoring other types of interventional surgical procedures, e.g. the US probe may be a transcutaneous US probe used in monitoring a liver or breast procedure. The illustrative ultrasound probe **12** is connected with the ultrasound imaging system **10** via cabling **15**. The illustrative rectal ultrasound probe **12** for use in a prostate procedure includes an integrated biopsy needle assembly **16** for collecting biopsy samples. More generally, any type of image-guided biopsy technique may be employed, e.g. a transrectal ultrasound-guided biopsy using the integral probe **12**, **16** as illustrated in which the ultrasound probe is inserted into the rectum and accesses the prostate via the rectal wall; or a transperineal biopsy in which the ultrasound probe is passed into the rectum but the biopsy needle passes through the perineum to access the prostate (optionally using a stereotactic grid plate or the like); or so forth. In some interventional procedures, the biopsy

needle or other interventional instrument(s) may not be connected with the US probe. For the illustrative transrectal prostate biopsy procedure, the patient **14** lies on his side (as diagrammatically indicated in FIGURE 1) on a diagrammatically indicated patient bed or support **18** with suitable pillows or other supports (not shown). The illustrative ultrasound imaging system **10** includes a display **20** for displaying ultrasound images, and one or more user interfacing components such as a user interface display **22** and user control panel **24** including user input devices such as a keyboard, dedicated buttons, a trackball or mouse or other pointing device, or so forth. Instead of or in addition to a pointing device, one or both display components **20**, **22** may be a touchscreen display enabling user input by pressing a location on the display **20**.

With continuing reference to FIGURE 1, the interventional imaging device further includes a probe tracker **28** that is operative to track orientation of the US probe. The probe tracker **28** may, for example, comprise an electromagnetic (EM) tracker such as the Aurora® EM tracking system available from Northern Digital Inc. (NDI, Ontario, Canada). An EM tracker employs EM sensors on tracked components, e.g. one or more EM sensors (not shown) are suitably mounted on or in the US probe **12** to enable tracking its position and orientation. In other embodiments, the probe tracker may comprise a gyroscope sensor, a coordinate measurement machine (CMM) having an end attached to the US probe and a base secured to a reference point, or so forth. In other contemplated embodiments in which the US probe is visible, e.g. a transcutaneous US probe disposed external of the patient, the probe tracker **28** may utilize optical tracking using optical reflectors or the like mounted on the US probe **12**, or a range camera. Fiber optic shape sensing and localization in which fiber Bragg gratings, Raleigh scattering or the like is used determine a shape, position or orientation of an optical fiber and from that data, a position or orientation of the ultrasound probe, may also be used. These are merely illustrative examples. In the illustrative examples described herein, the probe tracker **28** is assumed to be an EM tracker.

With continuing reference to FIGURE 1, the interventional imaging device further includes an electronic processor **30** that is operatively connected with the US imaging device **10** and the display **20**, **22**, and with a non-transitory storage medium **32** that stores instructions readable and executable by the electronic data processor **30** to operate the ultrasound imaging device **10** to perform operations as disclosed herein. The electronic processor **30** may be embodied as a microprocessor or microcontroller of the US imaging device **10** (as diagrammatically indicated in FIGURE 1), and/or as the microprocessor or microcontroller of a computer or other separate electronic data processing device, and/or so

forth. The non-transitory storage medium **32** may, by way of non-limiting illustration, include a hard disk drive or other magnetic storage medium, a flash memory, read-only memory (ROM) or other electronic storage medium, an optical disk or other optical storage medium, various combinations thereof, or so forth.

FIGURE 1 further diagrammatically depicts operations of a live ultrasound imaging process performed by the electronic processor **30** executing instructions read from the non-transitory storage medium **32**. This process includes providing a live ultrasound imaging user interface (UI) **40**, in which a live ultrasound image is acquired using the ultrasound imaging device **10** and the US probe **12**. The live ultrasound image is displayed on the display **20**. To provide context, the live ultrasound image is displayed together with a contour or reference image that is registered with the live ultrasound image using a composite transform **42**. For example, for providing interventional imaging in support of a prostate biopsy procedure, the context may be a planning 3D-MRI of the prostate (or a 3D-CT image, or so forth), or may be a contour of the prostate drawn in such a 3D-MRI. The composite transform **42** may be updated occasionally by a transform update process **44**, described in more detail elsewhere herein. In some embodiments, the transform update process **44** is triggered by a trigger control **46** operable by the surgeon or other user. For example, the user control panel **24** or some other user input control may operate as the trigger control **46** for triggering updates of the spatial registration **42** used to spatially register anatomical contour(s) and/or a fused 3D reference image to the live ultrasound image. It will be appreciated that the trigger control **46** may take various forms, such as a handheld remote control in wireless radio or infrared contact with the ultrasound imaging system **10**, a soft key shown in the user interface display **22** (which in this case would be touch-sensitive), a dedicated trigger key on the control panel **24**, or so forth.

Typically, the UI **40** implemented by the electronic processor **30** operates the ultrasound imaging device **10** to acquire and display a time series of live ultrasound images with the superimposed contour or fused reference image registered with each live ultrasound image using the composite transform. The live ultrasound images of the time series are preferably acquired at a sufficiently fast rate (i.e. “frame rate” in analogy to a video display) so that the live imaging UI **40** provides the surgeon with a near-real time view of the biopsy needle or other interventional instrument penetrating the prostate or other surgical target. In some ultrasound imaging devices, the live ultrasound images are two-dimensional (2D) live ultrasound images acquired using the US probe **12** having a one-dimensional ultrasound transducer array. In other embodiments employing an US probe with a 2D ultrasound

transducer array capable of rapidly acquiring a 3D-US image, it is contemplated for the live ultrasound images to be 3D live ultrasound images.

To provide context, the live imaging UI **40** implemented by the electronic processor **30** further displays a contour or reference image together with the live ultrasound image. For example, a contour of the prostate may be superimposed on the displayed live ultrasound image depicting the prostate, and/or a 3D-MRI planning image may be fused with the live ultrasound image, e.g. using alpha blending or the like. However, cross-modality spatial registration of the 3D MRI, 3D-CT or other non-ultrasound planning image with the live ultrasound image is a computationally intensive process. Furthermore, in the case of a 2D live ultrasound image the accuracy of such spatial registration may be limited by the spatial information captured by the 2D live ultrasound image (the spatial information of a 2D live ultrasound image is limited to a plane in space). To alleviate these difficulties, a baseline three-dimensional ultrasound (3D-US) image is acquired using a 3D-US image acquisition user interface (UI) **48**. Operation of the 3D-US image acquisition UI **48** depends on the particular type of the US probe **12** being employed. If the US probe **12** includes a 2D ultrasound transducer array then it can acquire a 3D-US image directly. If the US probe **12** includes only a linear ultrasound transducer array then the 3D-US image acquisition UI **48** may instruct the user to sweep the US probe **12** through a spatial distance to provide three-dimensional ultrasound echo data for generating the 3D-US image. As described elsewhere herein, the 3D-US image acquisition UI **48** is used to acquire a baseline 3D-US image and one or more reference 3D-US images with different orientations of the US probe **12** used for acquisition of the various baseline and reference 3D-US images.

It is to be appreciated that the US probe tracker **28** is provided, e.g. as an EM probe tracker that tracks the position and orientation of the US probe **12** by way of measuring spatial positions of one or more EM sensors disposed on or in the US probe **12**. Each live ultrasound image is tagged with a corresponding orientation of the US probe **12** measured by the probe tracker **28** for that live ultrasound image. Likewise, each baseline 3D-US image or reference 3D-US image is tagged with a corresponding baseline or reference orientation, respectively, of the US probe **12** measured by the probe tracker **28** for that baseline or reference 3D-US image. The orientation of the US probe **12** corresponding to an US image is the orientation of the US probe **12** measured by the probe tracker **28** for the US image. This corresponding orientation is measured by the probe tracker **28** for the US image, e.g. measured during the acquisition of the US image or shortly before or after acquisition of the US image while the orientation of the US probe **12** remains that used in acquiring the US

image. Each US image is tagged with the corresponding orientation of the US probe **12** measured by the probe tracker **28** for the US image. The term "tag" connotes that the corresponding orientation measured by the probe tracker **28** for the US image is associated with the US image in data storage so that the electronic processor **30** executing the instructions of the non-transitory storage medium **32** can retrieve the corresponding orientation and recognize it to be the orientation of the US probe **12** used when acquiring the corresponding US image. The tagging may, for example, be direct image tagging, e.g. the orientation may be stored as metadata contained in a header of the US image data file, or may be indirect, e.g. stored in a table, spreadsheet, or the like which indexes the US images and includes a column, field, or the like storing the corresponding orientation measured by the probe tracker **28** for each US image.

The 3D-US image acquisition UI **48** is used to acquire 3D-US images with different orientations of the US probe **12**, which are used to generate a set of 3D transforms **50** used (in part) to construct the composite transform **42**. More particularly, the 3D-US image acquisition UI **48** is used to acquire a baseline 3D-US image tagged with a corresponding baseline orientation measured by the probe tracker **28** for the baseline 3D-US image. A cross-modality spatial image registration process is then applied to generate a 3D transform **52**, designated without loss of generality as T_0 herein, which registers a 3D planning image (e.g. 3D-MRI, 3D-CT image, 3D-positron emission tomography image, or so forth) with the baseline 3D-US image. This cross-modality image registration is computationally costly, and/or optionally may entail receipt of user input such as designation of corresponding landmarks in the planning image and baseline 3D-US image, respectively, or contouring of corresponding features in the planning image and baseline 3D-US image, respectively. However, the cross-modality image registration is typically performed only once for a given surgical procedure.

If the US probe **12** were to be kept in a fixed position throughout the surgical procedure, then it would be sufficient to acquire a single baseline 3D-US image and to generate the transform T_0 **52** registering the 3D planning image with the baseline 3D-US image. The composite transform **42** would then be a product of the transform T_0 and a second transform registering the baseline 3D-US image with the live ultrasound image. (Note that the term "product" as used herein in this context denotes a functional combination of T_0 and the second transform. This may be variously achieved, e.g. by applying T_0 to an image and then applying the second transform to the image).

However, during the surgical procedure, the surgeon may elect to re-position the US probe **12** to obtain a different vantage for live ultrasound imaging of the interventional instrument and target organ (e.g. biopsy needle penetrating the prostate in the case of a prostate biopsy procedure). In so doing, the re-positioned US probe may produce motion, e.g. a change in the tissue deformation produced by the US probe **12**. Such motion (i.e. different tissue deformation compared with the baseline orientation of the US probe **12**) is not, in general, accurately accounted for by the baseline 3D-US image.

To address this problem, in disclosed approaches the 3D-US image acquisition UI **48** is additionally used to acquire one or more reference 3D-US images each tagged with a corresponding reference orientation measured by the probe tracker **28** for that reference 3D-US image. Without loss of generality, the number of reference 3D-US images that are acquired is denoted herein as N, where N is an integer greater than or equal to one. A spatial image registration process is then applied to generate a set of 3D transforms **54**, designated without loss of generality as $\{T_{1,i}\}_{i=1,...,N}$ herein, where N is again the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US image. (Note, where the appropriate index is apparent the employed transform may be designated by the shorthand T_1). As this is a same-modality (ultrasound-ultrasound) spatial registration, it is relatively low in computational cost and can in some embodiments be performed using automated feature detection processes (e.g. corner detectors or other image gradient segmentation approaches) for identifying corresponding features in the reference and baseline 3D-US images, respectively, so that the image registration can be implemented in a fully automated fashion. Alternatively, user inputs may be employed, e.g. delineating corresponding features and/or corresponding contours.

The composite transform **42** then comprises a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$. (Again, the term "product" as used herein in this context denotes a functional combination of $T_{1,k}$ and $T_{2,k}$, e.g. by applying $T_{1,k}$ to the baseline 3D-US image and then applying $T_{2,k}$ to the baseline 3D-US image after its transformation by $T_{1,k}$). This may be variously achieved, e.g. by applying T_0 to an image and then applying the second transform to the image). The index k here indexes a reference 3D-US image whose corresponding reference orientation should be close to the current orientation of the US probe **12** used in acquiring the current live ultrasound image. Thus, $T_{1,k}$ spatially registers the baseline 3D-US image to the reference 3D-US image indexed by k. The transform $T_{2,k}$ spatially registers the reference 3D-US image indexed by k with the live ultrasound image. Thus, the product of the transforms $T_{1,k}$ and $T_{2,k}$ operates to spatially register the baseline

3D-US image to the current live ultrasound image. If the contour or reference image to be displayed together with the live ultrasound image is the 3D planning image or a contour drawn in the 3D planning image, then the composite transform **42** further includes the transform T_0, i.e. the composite transform **42** comprises the product of the transform T_0, the transform $T_{1,k}$, and the transform $T_{2,k}$. (Yet again, the term "product" as used herein in this context denotes a functional combination of T_0, $T_{1,k}$, and $T_{2,k}$, e.g. by applying T_0 to the planning image or to a contour drawn in the planning image to transform to the spatial frame of the baseline 3D-US image, and then applying $T_{1,k}$ to transform to the spatial frame of the reference 3D-US image indexed by k, and then applying $T_{2,k}$ to transform to the spatial frame of the live ultrasound image).

(In some embodiments, it is contemplated that the reference contour or reference image to be displayed together with the live ultrasound image may be the baseline 3D-US image or a contour drawn in the baseline 3D-US image. In this case, the composite transform **42** would not include T_0, and indeed in such embodiments there may be no 3D planning image acquired by a modality other than ultrasound.)

With the framework described above with reference to FIGURE 1, updating the composite transform **42** to account for a re-positioning of the US probe **12** entails determining the closest reference orientation of the US probe **12** to a current orientation of the US probe **12** measured by the probe tracker **28**. In the composite transform **42**, $T_{1,k}$ is updated by setting k equal to the index of the reference 3D-US image with that closest reference orientation. For displaying live images subsequent to this updating, $T_{2,k}$ is constructed to spatially register the reference 3D-US image indexed by updated k with the live ultrasound image. The transform T_0 (if employed) is not modified by this update, thus advantageously avoiding the computational cost of re-computing the transform T_0.

With reference to FIGURE 2, the effect of such an update is shown. FIGURE 2, lefthand image, depicts a baseline 3D-US image of a prostate with a contour superimposed. In this illustrative example, the contour is drawn in the baseline 3D-US image, but alternatively it may be a contour drawn in a 3D planning image such as a 3D-MRI and transformed to the spatial frame of the baseline 3D-US image using the transform T_0. FIGURE 2, middle image, depicts a 2D live ultrasound image with the contour of FIGURE 1, transformed by the transform $T_{1,k}$ and $T_{2,k}$ to the spatial frame of the 2D live ultrasound image. However, as seen in FIGURE 2, there is a large mismatch between the contour and the boundary of the prostate in the 2D live ultrasound image (indicated by arrows in FIGURE 2, middle image). FIGURE 2, right image, shows the same 2D live ultrasound image with an

updated contour which is updated by updating the composite transform to employ the transform $T_{1,k}$ with k updated to the closest reference 3D-US image. FIGURE 2 also indicates the successive application of the transforms T_0, T_1, and T_2 suitable for implementing the composite transform comprising the product of the transforms T_0, T_1, and T_2.

It may be noted that in a limiting case, it may be that the closest reference orientation to the current orientation of the US probe **12** is actually the baseline orientation corresponding to the baseline 3D-US image, rather than to any of the reference 3D-US images. In such a case, the transform T_1 may be omitted or, from an alternative viewpoint, the transform T_1 may be set to a unity transform such that applying unity transform T_1 to the baseline 3D-US image outputs the same baseline 3D-US image without modification.

The baseline orientation is preferably chosen to be the orientation most commonly used in performing the surgical procedure. For example, in the case of a prostate biopsy, the baseline orientation may preferably be an axial orientation. The additional reference volumes (reference 3D-US images) are obtained in the same region of interest as the baseline 3D-US image, but with different probe orientations that may induce different tissue deformation and thereby different image appearance. The reference volumes are registered to the baseline volume to map image voxels in the reference volume to image voxels in the baseline volume. Since these are volumetric registrations, a significant amount of image information can advantageously be used for registration, which enables determining the transforms $\{T_{1,i}\}_{i=1,\ldots,N}$ **54** accurately and robustly, despite the deformation-induced differences between the volumes.

With continuing reference to FIGURE 1 and with further reference to FIGURE 3, a process suitably performed by the electronic processor **30** executing instructions read from the non-transitory storage medium **32** to generate the 3D transforms **50** is described. The process receives a 3D planning image **60**, and optionally also receives one or more feature contours **62** drawn in the planning image **60** (if such contours are to be superimposed onto the live ultrasound image). An operation **64** performed by the 3D-US image acquisition UI **48** acquires a baseline 3D-US image **66** tagged with a corresponding baseline orientation of the US probe **12** measured by the probe tracker **28** for the baseline 3D-US image **66**. An operation **68** performed by the 3D-US image acquisition UI **48** acquires one or more reference 3D-US images **70** (i.e. N such images) each tagged with a corresponding reference orientation of the US probe **12** measured by the probe tracker **28** for that reference 3D-US image. (It will be appreciated that the operations **64**, **68** may be performed with various ordering). An operation **72** applies a cross-modality image

registration to register the planning image **60** (and hence the contour **62**, if drawn in the planning image **62**) with the baseline 3D-US image **66**. This generates the transform T_0 **52**. An operation **74** applies a same-modality (ultrasound-ultrasound) image registration to register the baseline 3D-US image **66** with each reference 3D-US image of the one or more reference 3D-US images **70**. This generates the set of transforms $\{T_{1,i}\}_{i=1,...,N}$ **54**.

With continuing reference to FIGURE 1 and with further reference to FIGURE 4, a process suitably performed by the electronic processor **30** executing instructions read from the non-transitory storage medium **32** to perform the live ultrasound imaging including the update **44** of the composite transform **42** in response to activation of the trigger control **46** is described. In the example of FIGURE 4, the live ultrasound images are assumed to be 2D live ultrasound images. In an operation **80**, an initial 2D live ultrasound image is acquired and tagged with its corresponding orientation of the US probe **12**. In an operation **82**, the 2D live ultrasound image is spatially registered with the closest reference (or baseline) 3D-US image to generate the transform T_2 **84**, and the 2D live ultrasound image is displayed in an operation **86** together with the contour or reference image. Thereafter, a time series of 2D live images is generated by iterating the steps **82**, **84**, **86**, **88**. As this time series live imaging is performed, the user may elect to re-position the US probe **12** causing the initially chosen closest 3D-US image to no longer be sufficiently accurate (e.g. as shown in FIGURE 2, middle image). When the user recognizes this degrading accuracy, the user may activate the update trigger **46** which is detected in an operation **90**. In an operation **92** the current orientation of the US probe **12** as measured by the probe tracker **28** is compared with the reference orientations and the baseline orientation, and the closest reference orientation (indexed k herein, without loss of generality) is selected. Flow then passes back to operation **82** to continue the live ultrasound imaging using the updated closest 3D-US reference image indexed k (i.e. the transform T_1 is updated to the index k and the transform T_2 is updated to $T_{2,k}$ by registering the 2D live ultrasound image and the updated closest reference 3D-US image indexed k).

Although not shown in FIGURE 4, optionally, if additional reference orientations are needed that were not acquired in the setup process (FIGURE 3), the live ultrasound imaging time series production (i.e. iteration of operations **82**, **84**, **86**, **88**) may be interrupted and one or more additional reference 3D-US images with the additional reference orientations may be acquired and registered with the baseline 3D-US image as per operations **68**, **74** of FIGURE 3. If the initial set of transforms is $\{T_{1,i}\}_{i=1,...,N}$ **54**, then the new transform for the additional reference orientation may be suitably denoted as $T_{1,N+1}$. Such a new

reference 3D-US image acquisition may be triggered, for example, if in the operation **92** the closest reference orientation of the US probe **12** is different from the current orientation of the US probe **12** by more than a threshold amount. As previously noted, if the US probe **12** has only a linear array of ultrasound transducers, operating the ultrasound imaging device to acquire the new reference 3D-US image may include prompting the user to manually manipulate the US probe **12** to perform a designated sweep of the US probe **12** during the acquisition of the new reference 3D-US image.

In the illustrative embodiments (e.g. FIGURE 1), the transform update **44** is triggered manually by user operation of the trigger control **46**. In alternative embodiments, it is contemplated to automatically trigger the transform update **44** upon detection of a trigger condition. For example, an update may be triggered if, in the operation **82**, a fit quality metric for the spatially registered images indicates a low accuracy of the spatial registration.

In the illustrative implementations of the transform update **44**, a single live ultrasound image is taken as the current live ultrasound image. In alternative embodiments, the current live ultrasound image may comprises a plurality of live ultrasound images of the time series of live ultrasound images acquired with the same current orientation. Thus, for example, the registration operation **82** may optimally register the plurality of live ultrasound images with best accuracy averaged over the plurality of live ultrasound images. Such an approach can improve accuracy and reduce the likelihood of spurious results due to an outlier 2D live ultrasound image having substantial noise or other image artifact(s).

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. An interventional imaging device comprising:

an ultrasound probe (12);

an ultrasound imaging device (10) operatively connected with the ultrasound probe to perform ultrasound imaging using the ultrasound probe;

a display (20, 22);

a probe tracker (28) operative to track orientation of the ultrasound probe;

an electronic processor (30) operatively connected with the ultrasound imaging device, the probe tracker, and the display; and

a non-transitory storage medium (32) storing instructions readable and executable by the electronic data processor to operate the ultrasound imaging device to acquire a live ultrasound image and to operate the display to display the live ultrasound image together with a contour (62) or reference image (60) that is registered with the live ultrasound image using a composite transform (42) and to perform further operations including:

operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image (66) tagged with a corresponding baseline orientation of the ultrasound probe measured by the probe tracker for the baseline 3D-US image;

operating the ultrasound imaging device to acquire one or more reference 3D-US images (70) each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image;

computing a transform (54) to spatially register each reference 3D-US image with the baseline 3D-US image;

determining a closest reference 3D-US image whose corresponding orientation is closest to a current orientation of the ultrasound probe measured by the probe tracker; and

updating the composite transform to include the transform to spatially register the closest reference 3D-US image to the baseline 3D-US image.

2. The interventional imaging device of claim 1 wherein:

the operation of computing a transform (54) to spatially register each reference 3D-US image with the baseline 3D-US image computes a set of transforms $\{T_{1,i}\}_{i=1,...,N}$ where N is the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US image; and

the updating of the composite transform (42) comprises updating the composite transform to a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$ where k indexes the determined closest reference 3D-US image and the transform $T_{2,k}$ spatially registers the determined closest reference 3D-US image with the live ultrasound image.

3. The interventional imaging device of claim 2 wherein:

the updated composite transform (42) comprises a product of a transform T_0 and the transform $T_{1,k}$ and the transform $T_{2,k}$ where the transform T_0 spatially registers a three-dimensional planning image (60) acquired by an imaging modality other than ultrasound with the baseline 3D-US image; and

the updating of the composite transform does not update the transform T_0.

4. The interventional imaging device of claim 3 wherein the three-dimensional planning image (60) acquired by an imaging modality other than ultrasound comprises a three-dimensional magnetic resonance image (3D-MRI) or a three-dimensional computed tomography (3D-CT) image.

5. The interventional imaging device of any one of claims 3-4 wherein the contour (62) or reference image (60) that is displayed together with the live ultrasound image comprises a contour (62) defined in the planning image and registered with the baseline 3D-US image using the transform T_0.

6. The interventional imaging device of any one of claims 2-5 wherein the electronic data processor (30) operates the ultrasound imaging device (10) to acquire and display a time series of live ultrasound images together with the contour (62) or reference image (60) registered with the live ultrasound images using the composite transform (42), and wherein:

the transform $T_{2,k}$ of the updated composite transform is generated for the live ultrasound images acquired subsequent to the updating of the composite transform by spatially registering the determined closest reference 3D-US image indexed by k with the live ultrasound image.

7. The interventional imaging device of any one of claims 1-6 wherein the updating of the composite transform (42) is triggered by detection of user activation of a trigger control (46).

8. The interventional imaging device of any one of claims 1-7 wherein the ultrasound probe (12) comprises a rectal ultrasound probe and the contour (62) or reference image (60) comprises a prostate contour or reference image depicting a prostate.

9. The interventional imaging device of any one of claims 1-8 wherein the live ultrasound image is a two-dimensional ultrasound image.

10. The interventional imaging device of any one of claims 1-9 wherein the probe tracker (28) comprises an electromagnetic (EM) tracker and at least one EM sensor disposed on or in the ultrasound probe (12).

11. A non-transitory storage medium (32) storing instructions readable and executable by an electronic processor (30) that is in operative communication with an ultrasound imaging device (10) with an ultrasound probe (12) and with a display (20, 22) and with a probe tracker (28) operative to track orientation of the ultrasound probe, the instructions readable and executable by the electronic processor to perform a live imaging method including:

operating the ultrasound imaging device to acquire a live ultrasound image;

spatially registering a contour (62) or reference image (60) with the live ultrasound image using a composite transform (42);

displaying the live ultrasound image together with the spatially registered contour or reference image on the display; and

adjusting the composite transform by operations including:

operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image (66) tagged with a corresponding

baseline orientation of the ultrasound probe measured by the probe tracker for the baseline 3D-US image;

operating the ultrasound imaging device to acquire one or more reference 3D-US images (70) each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image;

computing a set of transforms $\{T_{1,i}\}_{i=1,...,N}$ (54) to spatially register the reference 3D-US images with the baseline 3D-US image where N is the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US image;

determining a closest reference orientation which is closest to a current orientation of the ultrasound probe measured by the probe tracker; and

updating the composite transform to a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$ where k indexes the determined closest reference 3D-US image whereby the transform $T_{1,k}$ spatially registers the determined closest reference 3D-US image indexed by k with the baseline 3D-US image and the transform $T_{2,k}$ spatially registers the determined closest reference 3D-US image with the live ultrasound image.

12. The non-transitory storage medium (32) of claim 11 wherein:

the updating updates the composite transform (42) to a product of a transform T_0 (52) and the transform $T_{1,k}$ and the transform $T_{2,k}$ where the transform T_0 spatially registers a three-dimensional planning image (60) acquired by an imaging modality other than ultrasound with the baseline 3D-US image (66); and

the contour (62) or reference image (60) that is displayed together with the live ultrasound image is the planning image or a contour defined in the planning image.

13. The non-transitory storage medium (32) of any one of claims 11-12 wherein the operations of operating the ultrasound imaging device (10) to acquire the live ultrasound image, spatially registering the contour (62) or reference image (60) with the live ultrasound image, and displaying the live ultrasound image together with the spatially registered contour or reference image are repeated iteratively to acquire and display a time series of live ultrasound images together with the contour or reference image registered with the live ultrasound images using the composite transform (42).

14. The non-transitory storage medium (32) of claim 13 wherein the operations of operating the ultrasound imaging device (10) to acquire the baseline 3D-US image (66), operating the ultrasound imaging device to acquire the one or more reference 3D-US images, and computing the set of transforms $\{T_{1,i}\}_{i=1,\ldots,N}$ (54) are performed prior to the acquiring and displaying of the time series of live ultrasound images.

15. The non-transitory storage medium (32) of claim 14 wherein the updating of the composite transform (42) is by operations further including:

interrupting the acquiring and displaying of the time series of live ultrasound images to operate the ultrasound imaging device (10) to acquire a new reference 3D-US image tagged with the corresponding reference orientation and computing a new transform $T_{1,N+1}$ that spatially registers the new reference 3D-US image with the baseline 3D-US image (66);

wherein if the determined closest reference orientation corresponds to the new reference 3D-US image then the composite transform is updated to a product of at least the transform $T_{1,N+1}$ and a transform $T_{2,N+1}$ the transform $T_{2,N+1}$ spatially registers the new reference 3D-US image with the live ultrasound image.

16. The non-transitory storage medium (32) of claim 15 wherein the operating of the ultrasound imaging device (10) to acquire the new reference 3D-US image includes prompting a user to manually manipulate the ultrasound probe (12) to perform a designated sweep of the ultrasound probe (12) during the acquisition of the new reference 3D-US image.

17. The non-transitory storage medium (32) of any one of claims 11-16 wherein the adjusting of the composite transform (42) is triggered by detection of user activation of a trigger control (46).

18. The non-transitory storage medium (32) of any one of claims 11-17 wherein the operating of the ultrasound imaging device (10) to acquire the live ultrasound image comprises:

operating the ultrasound imaging device to acquire the live ultrasound image consisting of a two-dimensional ultrasound image.

19. A live ultrasound imaging method comprising:

operating an ultrasound imaging device (10) to acquire a time series of live ultrasound images using an ultrasound probe (12);

spatially registering a contour (62) or reference image (60) with the time series of live ultrasound images using a composite transform (42);

displaying the time series of live ultrasound images together with the spatially registered contour or reference image; and

adjusting the composite transform by operations including:

operating the ultrasound imaging device to acquire a baseline three-dimensional ultrasound (3D-US) image (66) tagged with a corresponding baseline orientation of the ultrasound probe measured by a probe tracker (28) for the baseline 3D-US image;

operating the ultrasound imaging device to acquire one or more reference 3D-US images (70) each tagged with a corresponding reference orientation of the ultrasound probe measured by the probe tracker for the reference 3D-US image;

computing a set of transforms $\{T_{1,i}\}_{i=1,...,N}$ (54) to spatially register the reference 3D-US images with the baseline 3D-US image where N is the number of reference 3D-US images and the transform $T_{1,i}$ spatially registers the reference 3D-US image indexed by i with the baseline 3D-US image;

determining a closest reference orientation which is closest to a current orientation of the ultrasound probe measured by the probe tracker; and

updating the composite transform to a product of at least a transform $T_{1,k}$ and a transform $T_{2,k}$ where k indexes the determined closest reference 3D-US image whereby the transform $T_{1,k}$ spatially registers the determined closest reference 3D-US image indexed by k with the baseline 3D-US image and the transform $T_{2,k}$ spatially registers the determined closest reference 3D-US image with the live ultrasound image;

wherein the updated composite transform is used in the spatially registering of the contour or reference image with live ultrasound images of the time series of live ultrasound images acquired after the current live ultrasound image.

20. The live ultrasound imaging method of claim 19 wherein the current live ultrasound image comprises a plurality of live ultrasound images of the time series of live ultrasound images acquired with the same current orientation.

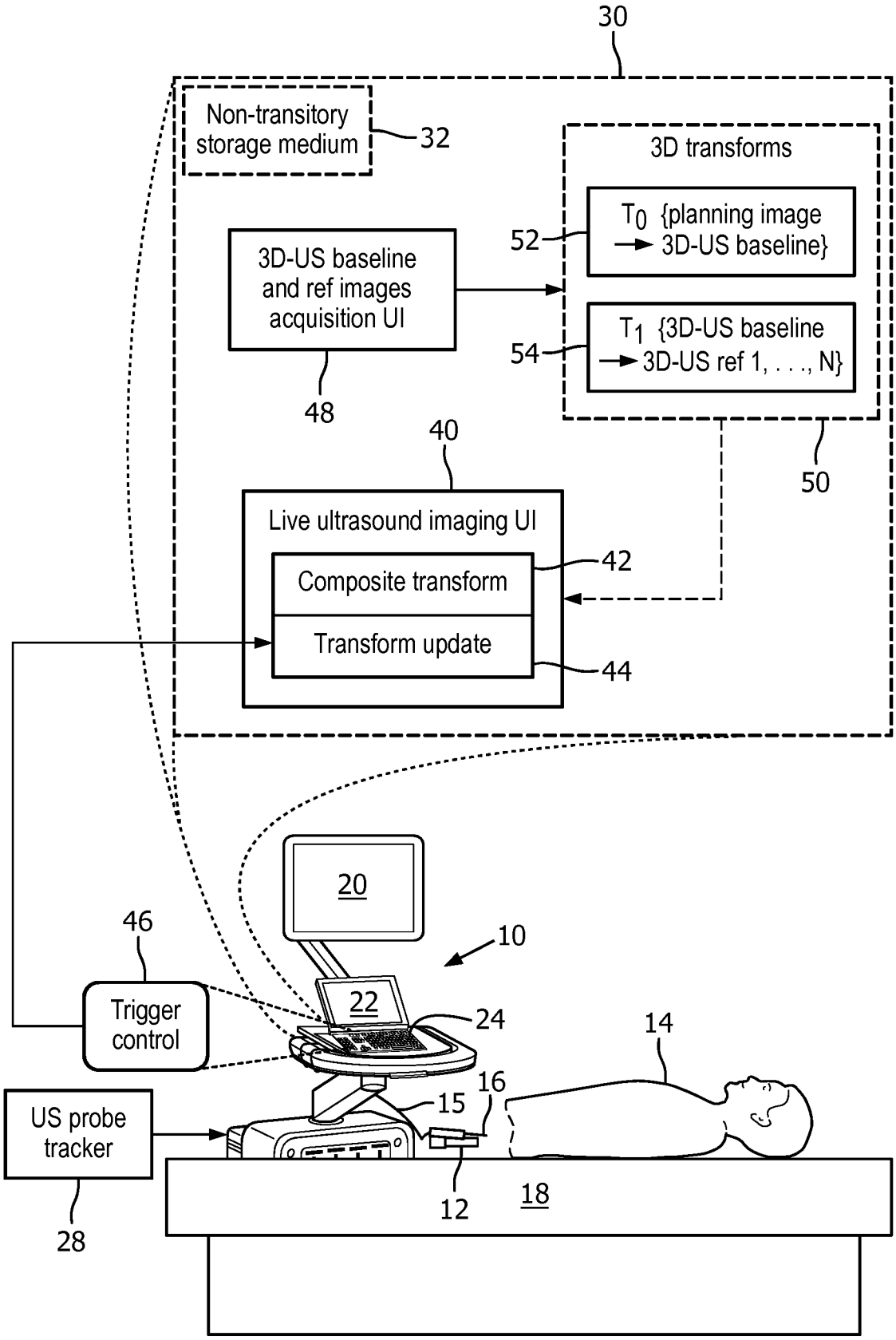
30
Non-transitory storage medium
32
3D transforms
T_0 {planning image → 3D-US baseline}
52
3D-US baseline and ref images acquisition UI
T_1 {3D-US baseline → 3D-US ref 1, . . ., N}
54
48
40
50
Live ultrasound imaging UI
Composite transform
42
Transform update
44
20
46
10
Trigger control
22
24
14
16
15
US probe tracker
12
18
28

FIG. 1

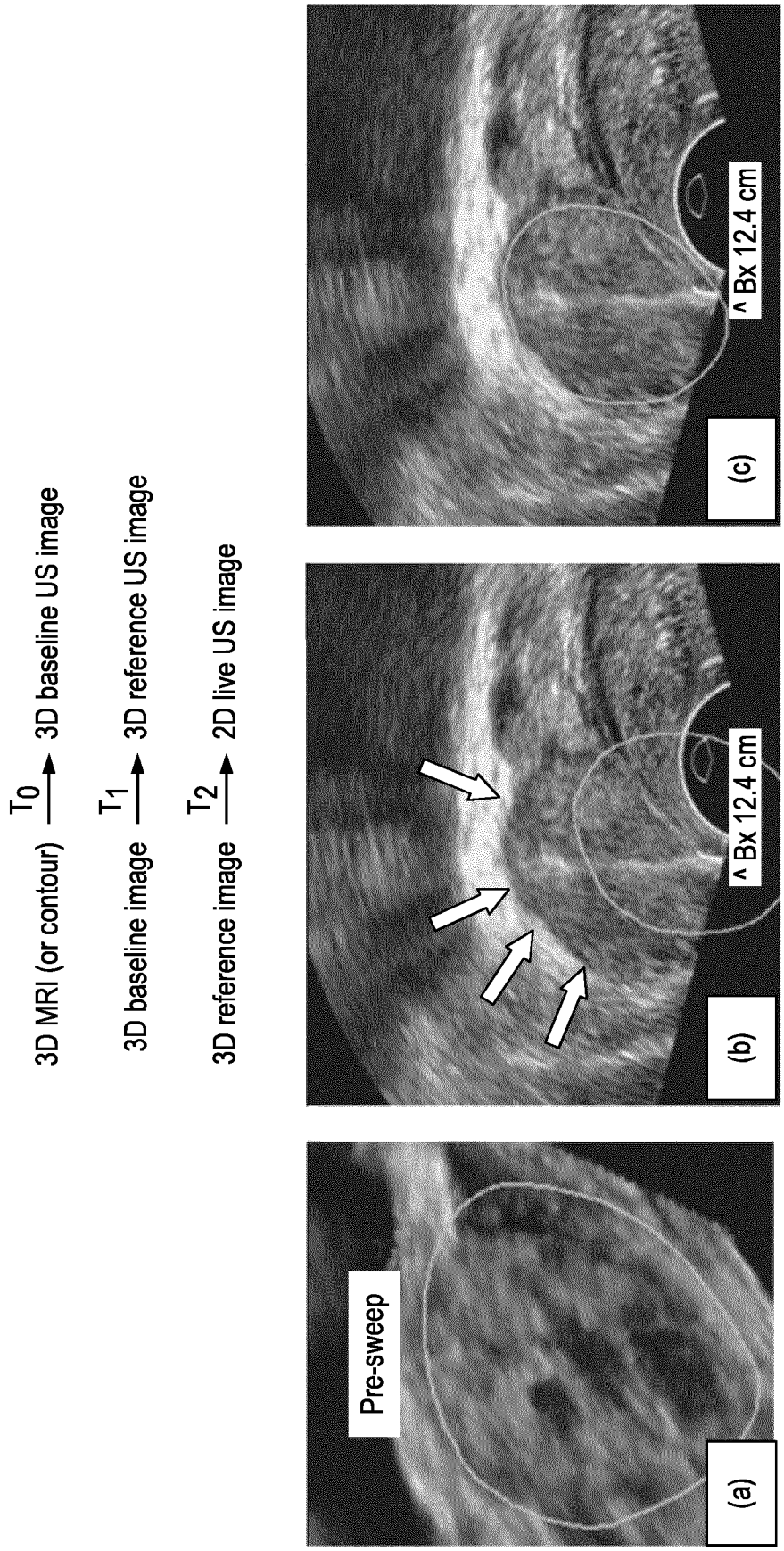
3D MRI (or contour)
T0
3D baseline US image
3D baseline image
T1
3D reference US image
3D reference image
T2
2D live US image
Pre-sweep
(a)
^ Bx 12.4 cm
(b)
^ Bx 12.4 cm
(c)

FIG. 2

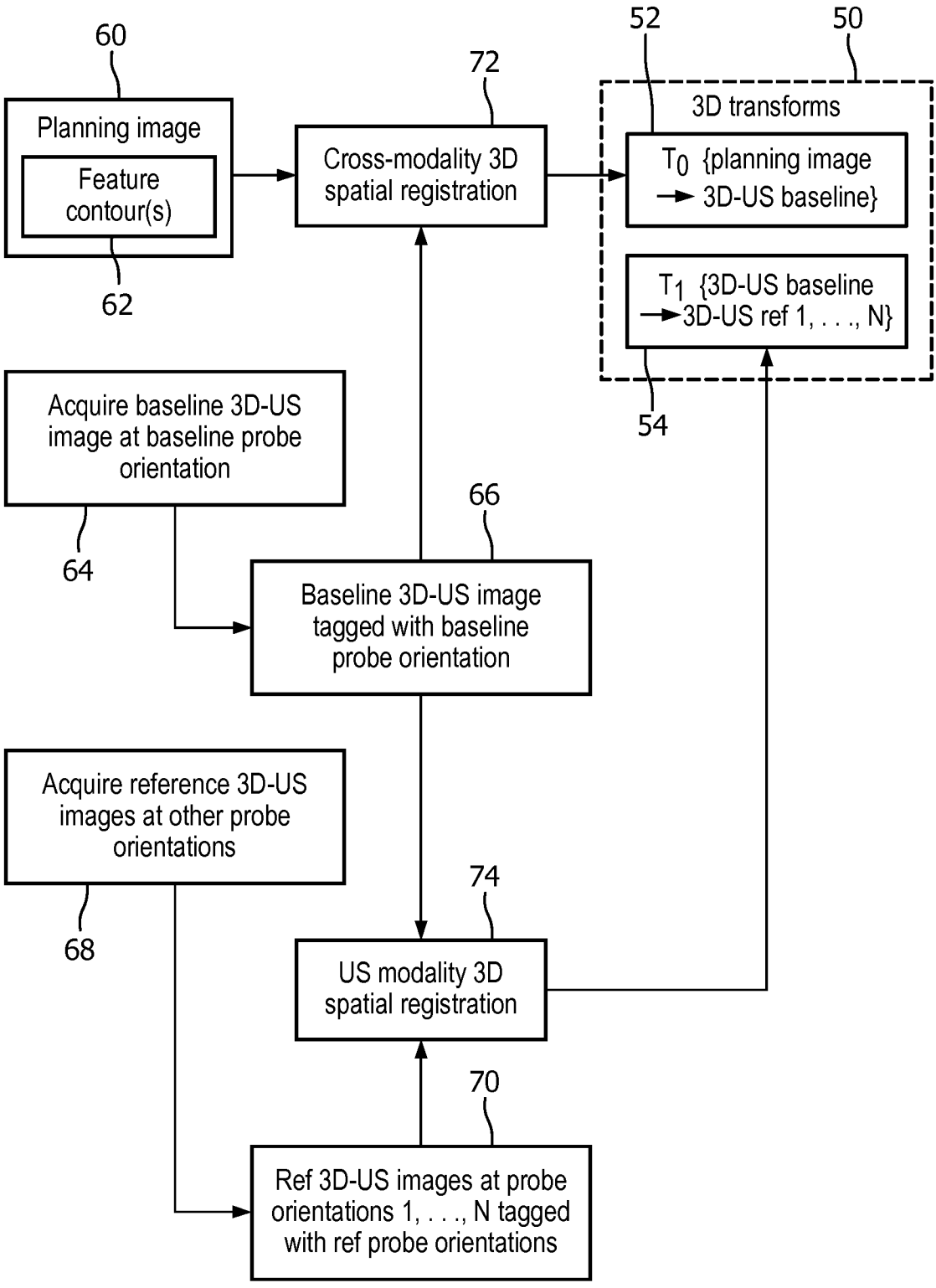
60
Planning image
Feature contour(s)
62
72
Cross-modality 3D spatial registration
52
50
3D transforms
T0 {planning image → 3D-US baseline}
T1 {3D-US baseline → 3D-US ref 1, . . ., N}
54
Acquire baseline 3D-US image at baseline probe orientation
64
66
Baseline 3D-US image tagged with baseline probe orientation
Acquire reference 3D-US images at other probe orientations
68
74
US modality 3D spatial registration
70
Ref 3D-US images at probe orientations 1, . . ., N tagged with ref probe orientations

FIG. 3

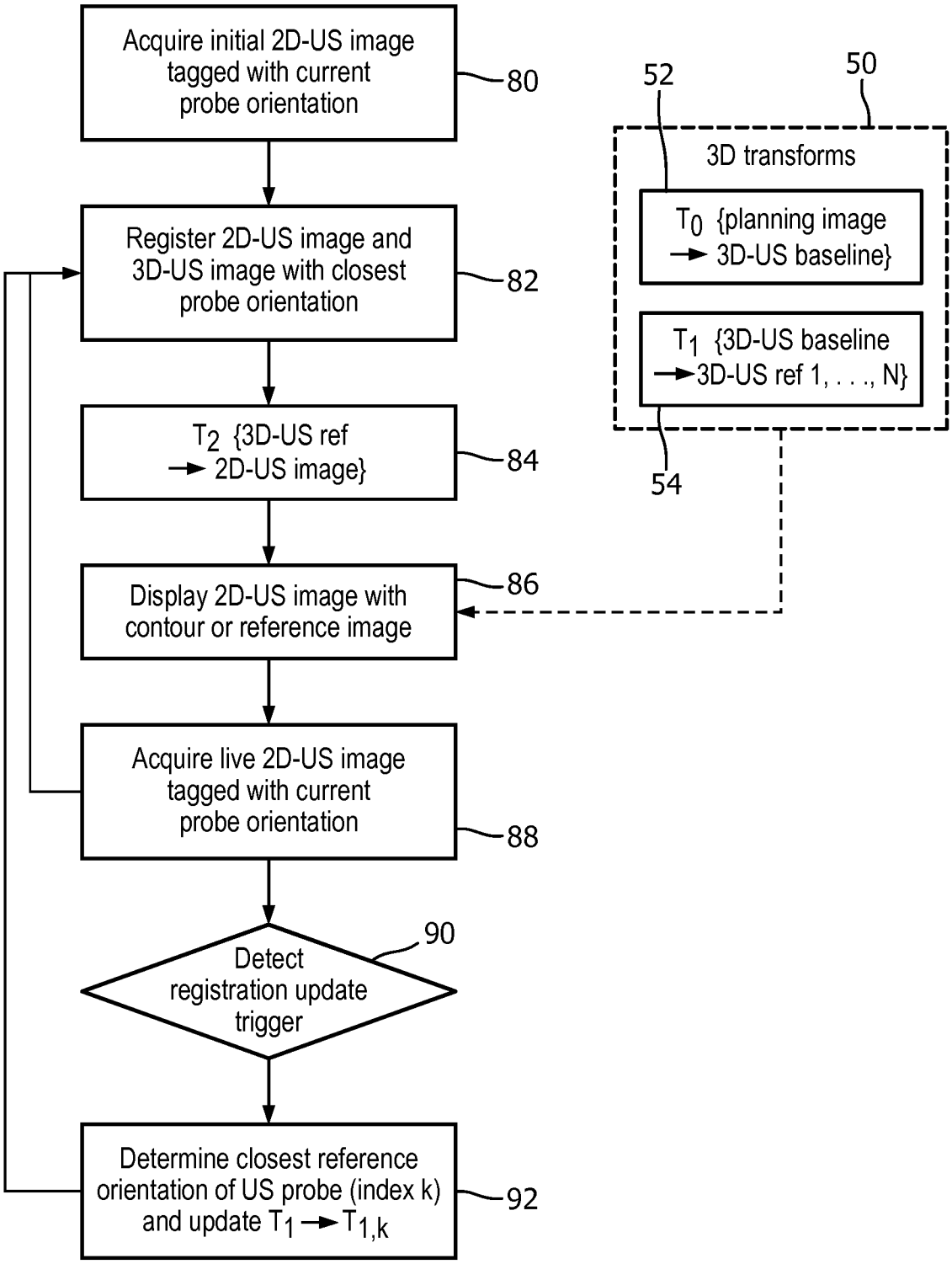
Acquire initial 2D-US image tagged with current probe orientation
80
Register 2D-US image and 3D-US image with closest probe orientation
82
T2 {3D-US ref → 2D-US image}
84
Display 2D-US image with contour or reference image
86
Acquire live 2D-US image tagged with current probe orientation
88
Detect registration update trigger
90
Determine closest reference orientation of US probe (index k) and update T1 → T1,k
92
50
52
3D transforms
T0 {planning image → 3D-US baseline}
T1 {3D-US baseline → 3D-US ref 1, . . ., N}
54

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/061636

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T7/30
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)
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)
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	WO 2016/178198 A1 (KONINKLIJKE PHILIPS NV [NL]) 10 November 2016 (2016-11-10)	1,2, 6-11, 13-20
A	page 1 - page 16	3-5,12

A	EP 2 131 326 A2 (MEDISON CO LTD [KR]; KOREA ADVANCED INST SCI & TECH [KR]) 9 December 2009 (2009-12-09) the whole document	1-20

☐ 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

"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
8 August 2018	21/08/2018

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	Celik, Hasan

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/061636

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