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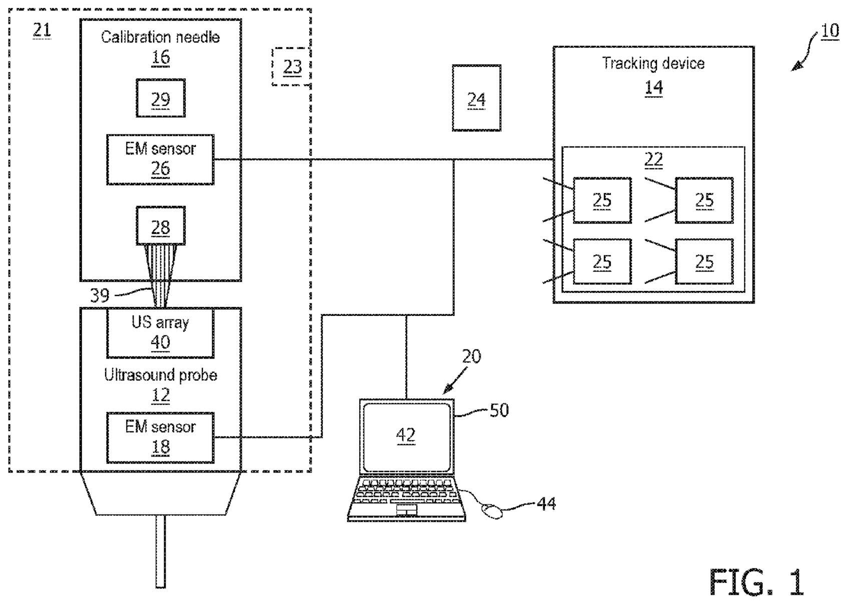

FIG. 1

(57) Abstract: An apparatus (10) for calibrating electromagnetic (EM) tracking of an associated ultrasound probe (12) includes a calibration needle (16), an EM tracking device including a field generator (14) and a reference EM sensor (24), an EM sensor (18, 26) on the ultrasound probe and on the calibration needle; at least one processor (50); and a non-transitory storage medium storing instructions to perform a EM tracking calibration method including: determining a location of the calibration needle in an ultrasound imaging space at a measurement time using the ultrasound probe; determining an EM-tracked location of the calibration needle at the measurement time; and generating a registration relating the location of the calibration needle in the ultrasound imaging space and the EM-tracked location of the calibration needle at the measurement time.

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SYSTEM AND METHOD FOR FAST AND AUTOMATED ULTRASOUND PROBE CALIBRATION

FIELD

The following relates generally to the ultrasound arts, calibration arts, probe tracking arts, electromagnetic tracking arts, image guided medical procedure arts, and related arts.

BACKGROUND

In medical procedures involving a tracked ultrasound (US) probe (such as an electromagnetically (EM)-tracked US probe), the EM tracker on the probe has to be registered to the US imaging array, a process called “calibration”. This calibration has to be highly accurate, to ensure the correct interpretation of US images during the procedure.

In a typical US probe calibration method, the user manually identifies (on an US image) the tip of an EM-tracked needle inserted in a tissue-mimicking or water phantom (e.g. using a mouse click), while the EM tracking system records the corresponding location of the EM sensor. The position and orientation of a static reference EM sensor are also recorded. Then, using the below equation, the registration between the US imaging array and the EM sensor on the US probe ($T_{US \rightarrow ProbeEM}$) is obtained.

$$T_{ProbeEM \rightarrow RefEM} \times T_{US \rightarrow ProbeEM} \times p_{US}(x,y,0) = T_{NeedleEM \rightarrow RefEM} \times p_{EM}(x,y,z) \qquad (1)$$

Where pUS(x,y,0) is the needle tip clicked by the user on the 2D US image, p_{EM} (x,y,z) is the 3D location of the needle EM sensor (calibrated to the needle tip) saved by the EM tracking system at the time of the user click, $T_{NeedleEM \rightarrow RefEM}$ is the known transformation from the needle EM sensor to the static reference sensor and $T_{ProbeEM \rightarrow RefEM}$ is the known transformation from the EM sensor on the US probe to the static reference sensor. The EM field generator (FG) can also serve as the reference coordinate system (instead of a specific reference sensor) to which all other tracked quantities are transformed.

Current US tracking technology estimates the position of a passive ultrasound sensor (e.g., PZT, PVDF, copolymer or other piezoelectric material) mounted on the tracked surgical tool in the field of view (FOV) of a conventional diagnostic US B-mode image by analyzing the signal received by the ultrasound sensor as the beams of the imaging probe sweep the FOV. Time-of-flight measurements provide the axial/radial distance of the passive ultrasound sensor from the imaging array, while amplitude measurements and knowledge of the beam firing sequence provide the lateral / angular position of the sensor. When used with 3D transducers (i.e., 2D matrix arrays), the elevational position of the sensor can also be obtained in a similar manner. Therefore, the 3D position of the sensor can be estimated in real-time, provided it is present within the FOV of the imaging transducer.

Current methods to perform the US probe calibration are usually manual, subjective and therefore, error-prone, apart from being time-consuming and tedious to perform. With respect to equation (1) above, any errors in the user identification of the needle tip (i.e., in $p_{US}(x,y,0)$) will propagate to errors in the estimation of the probe calibration $T_{US \rightarrow ProbeEM}$.

The following proposes a fast and automated method to calibrate a tracked US probe, thus, removing the subjectivity associated with current methods, while ensuring high accuracy.

Interventional procedures often involve multi-modality imaging protocols for diagnosis and/or navigational guidance. For example, magnetic resonance imaging (MRI) can be used as a pre-procedural imaging modality primarily for diagnosis, segmentation etc. and ultrasound (US) for intra-procedural guidance. In such cases, the intra-procedural US (which is most often two dimensional (2D)) has to be registered to the pre-procedural MRI. To spatially interpret ultrasound images correctly in such interventional procedures, a tracking system, typically an electromagnetic (EM) tracking system, is employed. In EM tracking, a field generator produces a low intensity electromagnetic field that varies spatially so as to produce EM-encoded space. A stationary reference EM sensor is placed in this field, and a probe EM sensor is attached to the ultrasound probe. A small electrical current is induced in each sensor by the spatially encoded EM field, and is used to determine position in the EM field, referenced to the position of the EM reference sensor or to the EM field generator (FG). Such EM tracking systems are commercially available, for example the Aurora EM tracking system from Northern Digital Inc. (NDI), Ontario, Canada.

For correct spatial interpretation of the ultrasound images, it is further necessary to spatially register the ultrasound image to the position of the EM sensor on the ultrasound probe. This is defined as a transformation $T_{US \rightarrow ProbeEM}$ where ProbeEM denotes the position of the EM sensor on the US probe. Currently, this is done as a manual procedure. A calibration needle including an EM sensor at or close to the needle tip (and calibrated to the needle tip, so that the reported EM position is that of the needle tip) is imaged by ultrasound while being tracked by the EM tracking. In the ultrasound image, the user manually marks the location of the needle tip. The EM position of the needle EM sensor is recorded at the time of the manual user click, and the relation:

$$T_{ProbeEM \rightarrow RefEM} \times T_{US \rightarrow ProbeEM} \times p_{US}(x,y,0) = T_{NeedleEM \rightarrow RefEM} \times p_{EM}(x,y,z) \qquad (1)$$

is solved for US image position → probe EM sensor position transformation $T_{US \rightarrow ProbeEM}$. Then the transformation $T_{US \rightarrow RefEM} = T_{ProbeEM \rightarrow RefEM} \times T_{US \rightarrow ProbeEM}$ locates the ultrasound image with reference to the reference EM sensor (where $T_{ProbeEM \rightarrow RefEM}$ is the known transformation from the EM sensor on the US probe to the static reference EM sensor).

This approach has some disadvantages. It is labor-intensive, particularly because the just-described process is preferably repeated for a dozen or more different locations to map out the space. Additionally, errors can be introduced if the needle tip is not located precisely by the operator/user in the two-dimensional (2D) plane of the ultrasound image sweep.

Improvements disclosed herein address the foregoing and other disadvantages of existing tracking systems, methods, and the like.

BRIEF SUMMARY

In accordance with one illustrative example, an apparatus for calibrating electromagnetic (EM) tracking of an associated ultrasound probe includes an EM tracking device including a field generator configured to generate an EM field in an EM-encoded space and a reference EM sensor, an EM sensor disposed on the ultrasound probe, a calibration needle; an EM sensor disposed on the calibration needle; at least one processor; and a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a EM tracking calibration method including: determining a location of the calibration needle in an ultrasound imaging space at a measurement time using the ultrasound probe; determining an EM-tracked location of the calibration needle at the measurement time from EM tracking by the EM tracking device of the EM sensor disposed on the calibration needle; and generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the EM-tracked location of the calibration needle at the measurement time.

In accordance with another illustrative example, an apparatus for calibrating tracking of an associated ultrasound probe includes: a tracking device configured to locate tracking sensors in a tracking space; an ultrasound probe tracking sensor disposed on the ultrasound probe; a calibration needle; a calibration needle tracking sensor disposed on a calibration needle; at least one processor; and a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a tracking calibration method including: determining a location of the calibration needle in an ultrasound imaging space at a measurement time using the ultrasound probe; determining a tracked location of the calibration needle at the measurement time from tracking by the tracking device of the calibration needle tracking sensor disposed on the calibration needle; and generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the tracked location of the calibration needle at the measurement time.

In accordance with another illustrative example, an apparatus for calibrating tracking of an associated ultrasound probe includes: a tracking device configured to locate tracking sensors in a tracking space; an ultrasound probe tracking sensor disposed on the ultrasound probe; a calibration needle; a calibration needle tracking sensor disposed on a calibration needle; an ultrasound transducer disposed on the calibration needle; at least one processor; and a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a EM tracking calibration method including: performing an ultrasound sweep comprising a plurality of ultrasound beams emitted in different directions by the ultrasound probe; detecting a transducer signal generated by the ultrasound transducer in response to sonication of the ultrasound transducer during the ultrasound sweep; determining a measurement time as a time stamp of the detected transducer signal; determining a location of the calibration needle in an ultrasound imaging space at the measurement time from a direction of the ultrasound beam that sonicated the ultrasound transducer and comparison of the measurement time with a trigger time of the ultrasound beam that sonicated the ultrasound transducer and the time-of-flight along the ultrasound beam; determining a tracked location of the calibration needle at the measurement time from tracking by the tracking device of the calibration needle tracking sensor disposed on the calibration needle; and generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the tracked location of the calibration needle at the measurement time.

One advantage resides in providing faster and automated ultrasound probe calibration.

Another advantage resides in in reducing errors in ultrasound probe calibration.

Further advantages of the present disclosure will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description. It will be appreciated that a given embodiment may provide none, one, two, or more of these advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure 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 illustrates an apparatus for calibrating a tracking process of an ultrasound probe according to one aspect.

FIGURE 2 diagrammatically illustrates the calibration needle of the apparatus of FIGURE 1.

FIGURE 3 is an exemplary flow chart of the calibration process of the apparatus of FIGURE 1.

FIGURES 4-7 are exemplary flow charts of alternative operations of the calibration process of FIGURE 3.

FIGURE 8 diagrammatically illustrates a calibration process of the apparatus of FIGURE 1 in which the needle is moved relative to the probe.

FIGURE 9 diagrammatically illustrates a calibration process of the apparatus of FIGURE 1 in which the probe is moved relative to the needle.

FIGURES 10 and 11 show interpolation approaches for performing a synchronization operation of FIGURE 3.

FIGURE 12 illustrates a graph of the image frame of the position of a probe or needle of the apparatus of FIGURE 1 vs. a magnitude of a sensor signal of the needle.

DETAILED DESCRIPTION

Some embodiments disclosed herein replace the manual labeling of the needle tip in an ultrasound image with an automated process. In one embodiment, the calibration needle tip is modified by adding an additional ultrasound transducer, which emits a signal in response to being sonicated during the ultrasound sweep. This transducer signal is time stamped, recorded, and synchronized with the timestamped EM data. The ultrasound sweep includes outputting a trigger signal marking the start of each ultrasound beam emission, and so location of the transducer in the 2D ultrasound sweep plane is determined based on which beam sonicated the transducer along with the “time of flight” of the beam to the transducer (effectively one-half of the echo time of US imaging since the return echo is not used). This automatically determined location in US image space is substituted for the manually labeled position in the ultrasound image.

In alternative embodiments, other options can be used instead of the needle-placed ultrasound transducer. In one approach, the transducer is replaced by a passive ultrasound reflector and the echo is detected using the ultrasound probe in receive mode. For example, the ultrasound sensor disposed on a calibration needle “listens” to the emitted ultrasound beams from the ultrasound probe and re-emits an acoustic pulse that can be detected by the ultrasound probe. In another approach, the needle tip is designed to be visible in an ultrasound image, and image processing is used to detect the needle location in the ultrasound image.

To address the problem that the needle tip may not be precisely in the 2D ultrasound sweep plane, either the needle tip can be moved linearly approximately transverse to the 2D plane, or the ultrasound probe can be rocked or moved linearly to sweep the 2D plane across a stationary needle tip. The ultrasound sweep for which the signal from the needle tip (transducer signal in the main embodiment, or ultrasound echo strength or image contrast in the alternative embodiments) is largest is then used for the calibration. The requisite motion of the needle tip or ultrasound probe can be provided by a robotic apparatus, or can be done manually since the timestamped data are stored and the sweep providing the strongest signal can then be identified retrospectively.

With reference now to FIGURE 1, a schematic illustration of an apparatus **10** for calibrating electromagnetic (EM) tracking of an associated ultrasound probe **12** is shown. The apparatus **10** includes an EM tracking device **14**, a calibration needle **16**, an EM sensor **18** that is disposed on the ultrasound probe **12**; and at least one computer **20** (and optionally, a robotic apparatus **21** configured to move the calibration needle **16** relative to the ultrasound probe **12**), each of these components being described in more detail below.

The EM tracking device **14** is configured to locate one or more tracking sensors in a tracking space. In one example, the EM tracking device **14** includes a field generator **22** configured to generate an EM field in an EM-encoded tracking space containing both the ultrasound probe **12** and the calibration needle **16**. The EM tracking device **14** also optionally includes a reference EM sensor **24** located in the EM-encoded space. The EM tracking device **14** is configured to locate tracking EM sensors (e.g., a calibration needle EM sensor **26** located on the calibration needle **16** and/or the probe EM sensor **18** located on the ultrasound probe **12**) in the EM-encoded tracking space relative to the reference EM sensor **24** or relative to the field generator **22**. The EM tracking device **14** can be any commercially-available EM tracking device, such as the Aurora Electromagnetic Tracking System (available from Northern Digital, Inc., Waterloo, Ontario, Canada), or can be a custom-built device.

The calibration needle EM sensor **26** is configured to detect the generated EM field by the EM tracking device **14**. At least one ultrasound transducer **28** is also disposed on the calibration needle **16** and is configured to detect sonication of the needle tip by the ultrasound probe **12**. While EM tracking is described herein, any other tracking system can be employed that is capable of tracking position of the calibration needle. For example, the calibration needle **16** may alternatively include reflective echogenic tracking sensors **29** which are tracked by an optical tracking device (not shown).

Referring now to one embodiment shown in FIGURE 2, the calibration needle **16** may include a needle body **30** with a needle tip **32** disposed at a first end of the needle body and a wiring hub **34** disposed at a second opposing end of the needle body. The EM sensor 18 (not shown in FIGURE 2) may be disposed at the needle tip **32** or at a known distance from the needle tip **32** within an interior of the needle body **30** or integrated into the walls of the needle body. The EM sensor **18** is configured to detect the generated EM field by the EM tracking device **14**. The ultrasound transducer **28** is also located at or at a known distance from the needle tip **32**. The relative positions of EM sensor **18** and the ultrasound transducer **28** are assumed to be known *a priori*, e.g. spatially registered using orthogonal x-ray or fluoroscopy or CT imaging of the needle (alternately, both the EM and US sensor positions are registered to the needle tip). Wiring **38**, preferably in the interior of the probe body **30**, connects to the EM sensor **18** and the ultrasound sensor **28**, e.g. using the hub **34** as a wiring feedthrough.

Referring back to FIGURE 1, the at least one computer **20** includes typical components, such as at least one display component **42**, at least one user input component **44**, at least one electronic processor **50** (e.g. a microprocessor, multi-core microprocessor, or so forth) programmed to perform calibration functions as disclosed herein. In some examples, the display **42** can be a touch-sensitive display. The user input component **44** can be a mouse, a keyboard, a stylus, an aforementioned touch-sensitive display, a microphone, and/or the like.

With reference now to FIGURE 3, the at least one processor **50** is programmed to perform an EM tracking calibration method **100** of the ultrasound probe **12** in the EM encoded space. At step **102**, a location of the calibration needle **16** in an ultrasound imaging space is determined at a measurement time using the ultrasound probe **12** and the ultrasound transducer **28**. This is the value $p_{US}(x,y,0)$ in Equation (1). At step **104**, a tracked location (e.g., an EM-tracked location) of the calibration needle **16** is determined at the measurement time from tracking (e.g., EM tracking) by the tracking device **14** of the EM sensor **26** disposed on the calibration needle **16**. This is the position $p_{EM}(x,y,z)$ in Equation (1). At the same time, the EM tracking system is monitoring the position of the reference EM sensor **24**. From this, the transform $T_{NeedleEM \rightarrow RefEM}$ is determined. At a step **106**, a tracked location (e.g., an EM-tracked location) of the ultrasound probe **12** is determined at the measurement time from tracking (e.g., EM tracking) by the tracking device **14** of the EM sensor **18** disposed on the ultrasound probe

12. From this along with the tracked position of the reference EM probe **24** the transform $T_{ProbeEM \rightarrow RefEM}$ is determined. Thus, at step **108**, a registration ($T_{US \rightarrow ProbeEM}$) relating the location $p_{US}(x,y,0)$ of the calibration needle **16** in the ultrasound imaging space at the measurement time and the tracked location $p_{EM}(x,y,z)$ of the calibration needle at the measurement time is generated by solving Equation (1) for $T_{US \rightarrow ProbeEM}$.

As shown in FIGURES 4-9, the step **102** of determining the location $p_{US}(x,y,0)$ of the calibration needle **16** in the ultrasound imaging space at the measurement time using the ultrasound probe **12** can be performed in a variety of methods. In one embodiment, as shown in FIGURE 4, step **102** includes: detecting a signal emitted by the ultrasound transducer **28** in response to being sonicated by an ultrasound beam **39** emitted by an ultrasound transducer array **40** of the ultrasound probe **12** (see FIGURE 1), in which the measurement time is a time stamp of the detected signal (**112**); and determining the location of the calibration needle **16** in the ultrasound imaging space from a direction of the ultrasound beam **39** and comparison of the measurement time with a trigger time of the ultrasound beam (**114**). This comparison yields the "time of flight" of the ultrasound beam from the array **40** to the transducer **28**.

In another embodiment, as shown in FIGURE 5, step **102** includes: performing an ultrasonic sweep using the ultrasound probe **12** (**116**); detecting, with the ultrasound probe **12**, an ultrasonic transmission from the calibration needle **16** in response to the ultrasonic sweep in which the measurement time is a time stamp of the detected ultrasonic reflection (**118**); and determining the location of the calibration needle **16** in the ultrasound imaging space from a direction of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission from the sensor and comparison of the measurement time with a trigger time of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission from the sensor (**120**). This comparison yields the "echo time" of the ultrasound beam from the array **40** to the calibration needle **16** and back to the ultrasound transducer array **40**, and hence is twice the "time-of-flight" of the previous embodiment.

In a further embodiment, as shown in FIGURE 6, step **102** includes: acquiring an ultrasound image in the ultrasound imaging space with an imaging device (e.g., with an ultrasound imaging device, which is not shown) (**122**); and determining the location of the calibration needle **16** in the ultrasound imaging space by detecting an image of the calibration needle in the ultrasound image, in which the measurement time is an acquisition time stamp of the image of the calibration needle in the ultrasound image (**124**). In one example, the acquisition time stamp of the image can be the time of image acquisition, under the assumption that the acquisition time for the entire image is small. In another example, the acquisition time stamp of the image can be the exact time of sonication of the calibration needle (similar to the time stamp determined at **112**), thus providing a more precise time value. Determination of the location of the calibration needle **16** in the ultrasound image can use any suitable image segmentation or feature recognition technique, such as matched filtering using a known filter kernel representing the calibration needle in the image. In this example, the reflective sensors **29** comprise an echogenic strip or beacon at the tip of the calibration needle **16**.

In the foregoing, it is assumed that the EM tracking measurements and the ultrasound data are both time stamped to enable synchronization between the two sets of measurements. This synchronization can be complicated if the sampling time intervals for EM and ultrasound are not synchronized. This can be addressed by suitable interpolation techniques.

The foregoing disclosed calibration techniques assume the calibration needle **16** is located in the ultrasound beam generated by the ultrasound transducer array **40** of the ultrasound probe **12**. This assumption is likely to be correct if the ultrasound transducer array **40** is a three-dimensional (3D) array, but less likely if it is a two-dimensional (2D) array. In the latter case, an automated approach for relatively moving the ultrasound probe **12** and calibration needle **16** can be used to determine when the calibration needle **16** is optimally positioned in the 2D ultrasound plane.

As shown in FIGURE 7, optimization of the position of the calibration needle **16** includes a step **102** of determining candidate locations of the calibration needle **16** using the ultrasound probe **12** with a plurality of different relative positions of the ultrasound probe and the calibration needle (**126**); for each candidate location, determining a corresponding ultrasound-induced signal strength associated with the determination of the candidate location (**128**); determining the location of the calibration needle **16** in the ultrasound imaging space as the candidate location having the highest corresponding signal strength (**130**); and determining the measurement time as a time stamp of the candidate location having the highest corresponding signal strength (**132**). In some examples, **126** includes operating the robotic apparatus **21** to move the calibration needle **16** relative to the ultrasound probe **12** (or vice versa) to traverse the plurality of different relative positions of the ultrasound probe and the calibration needle. In other examples, the robotic apparatus **21** can include a holder or clamp **23** configured to hold the calibration needle **16** (or alternatively the ultrasound probe **12**). In a suitable approach, the calibration needle **16** may be moved over a range of angles θ or linearly by 'x' mm orthogonal to the ultrasound probe **12** sufficient to sweep the tip **32** through the 2D ultrasound plane.

In this embodiment, the calibration workflow can be performed in a water tank or in a tissue-mimicking phantom. The calibration needle **16** and the ultrasound probe **12** should be positioned such that the ultrasound sensors **40** on the calibration needle **16** lie outside an US image plane in an elevational direction (e.g., outside the elevational spread of the US image plane). The calibration needle **16** and the ultrasound probe **12** can be held in place using the holder **23**, or alternatively can be held manually by the user.

Next, either the calibration needle **16** or the ultrasound probe **12** is moved (with the other being stationary), such that the ultrasound sensors **40** on the calibration needle **16** first enter the elevational coverage of the US image plane and then eventually exit the image plane. In one example, motion of the calibration needle **16** (shown in FIGURE 8) or the ultrasound probe **12** (shown in FIGURE 9) can be accomplished using a simple 1D motion stage that is positioned appropriately. In another example, this motion can be performed manually, with the user holding the device to be moved. Rather than a 1D motion the calibration needle **16** can be rotated over a range of angles [θ].

As shown in FIGURE 10, for example, the time synchronization described at **106** can be performed by a suitable synchronization operation, for example by interpolation. In one suitable synchronization approach, both data streams (ultrasound and EM) are acquired and stored in the computer **22**. Hence, a clock of the computer **22** can be used to regulate/interpret the data. Persistence or interpolation is used to "fill in" missing data from the data stream acquired at a lower acquisition rate and is then temporally matched to the data stream captured at a higher frame rate..

With brief reference to FIGURE 10, an illustrative interpolation approach for performing the synchronization operation is described. FIGURE 10 shows time stamps (column labeled "Time"), 2D sensor positions (column labeled "US tracking data"), and EM sesnor positions (column labeled “EM tracking data”). To illustrate the interpolation consider that at time instant T_4, there are missing entries in both the needle tracking and probe tracking data. The missing data may be interpolated using a weighted average of the data immediately preceding and succeeding the current time point T_4. For the needle tracking data, this amounts to interpolating (X_1,Y_1) and (X_2,Y_2), such as: $(a_4X_1+b_4X_2\ ,\ a_4Y_1+b_4Y_2)$, where possible values for the weights a_4 and b_4 are: $a_4 = (T_6-T_4)/(T_6-T_3)$ and $b_4 = (T_4-T_3)/(T_6-T_3)$. Similarly, $c_4 = (T_5-T_4)/(T_5-T_3)$ and $d_4 = (T_4-T_3)/(T_5-T_3)$. Note that this method must be implemented with some time lag, since it utilizes data before and after the missing entry for the interpolation.

With brief reference to FIGURE 11, in an alternative embodiment for performing the synchronization operation **134**, the latest data can be persisted until the next data point for that stream arrives. This technique can be performed in real-time without any time lag, but may suffer from slightly reduced accuracy as compared with the interpolation approach of FIGURE 7.

While the calibration needle **16**/ultrasound probe **12** motion is occurring, the following data streams are continuously captured (or intermittently, repeatedly, or otherwise captured): the calibration needle EM sensor **26** position and orientation; the ultrasound probe EM sensor **36** position and orientation; and the ultrasound probe ultrasound sensor **40** information (i.e., signal/SNR, coordinates within US image, frame and line trigger information etc.).

Referring now to FIGURE 12, the US image frame corresponding to the maximum signal/SNR is chosen and the US sensor coordinates in that image frame are recorded. As shown in FIGURE 12, a magnitude of the received signal on the ultrasound transducer **28** is analyzed versus the EM readings from the EM sensor **26/36** of the calibration needle **16**/ultrasound probe **12** that is translated/rotated. The peak signal strength (or relative signal strength, or any other suitable signal) of the ultrasound transducer **28** is identified and the corresponding image frame and EM readings of the calibration needle **16** and the ultrasound probe **12** are noted.

The corresponding ultrasound probe EM sensor **18** and calibration needle EM sensor **26** coordinates are then chosen, by time-synchronizing the ultrasound data stream with the EM data stream.

The spatial position of the EM sensor **26** on the calibration needle **16** is registered with the spatial position of the ultrasound transducer **28** on the calibration needle **16** using X-ray/fluoroscopy, which can be a one-time process. This transformation is incorporated as part of the $T_{NeedleEM \rightarrow RefEM}$ matrix in Equation 1. The US-EM transformation (i.e., the desired probe calibration, $T_{US \rightarrow ProbeEM}$) can be obtained from the linear equation (equation 1) using the above estimated quantities.

It will be appreciated that the measurement time described above is on the order of milliseconds or less. In one example, the measurement time could be the precise time of sonication of the calibration needle **16**. In another example, the measurement time could be some close time such as the start of an ultrasound image.

EXAMPLE OF USE OF A CALIBRATED PROBE IN AN INTERVENTIONAL PROCEDURE

In one example, the interventional procedure is a tracked biopsy procedure, where the anatomical target is defined on a pre-procedural MR image dataset, while the actual intervention (biopsy) is done under 2D US. The below equations describe how the EM, US and MR data streams are all registered together:

$T_{NeedleEM \rightarrow RefEM} \times p_{NeedleEM}(x,y,z)$ [for live needle stream] … (eqn. 2)

$T_{ProbeEM \rightarrow RefEM} \times T_{US \rightarrow ProbeEM} \times p_{US}(x,y,0)$ [for live 2D US stream] … (eqn. 3)

At the beginning of each procedure, the ultrasound probe **12** is “swept” or ”rotated” over a series of angles [θ] to acquire multiple 2D images and form a 3D US dataset of the anatomical region of interest. Since each 2D US image in this 3D dataset is indexed to the reference EM sensor **24** of the tracking device **14** (equation 3), the 3D US dataset is obtained directly in the ‘RefEM’ frame of reference:

Therefore, $p_{3DUS} = p_{RefEM}$ (i.e., a point in the 3D US dataset is already in ‘RefEM’ space)

$T_{MR \rightarrow 3DUS} \times p_{MR}(x,y,z)$ [for 3D MR dataset] … (eqn. 4)

$T_{MR \rightarrow 3DUS}$ is obtained using image-based registration methods, using, for example, features identifiable in both MR and US. In this manner, the US probe calibration ($T_{US \rightarrow ProbeEM}$) is used to transform the US and MR image data streams into the EM coordinate space.

It will be appreciated that the illustrative computational, data processing or data interfacing components of the apparatus **10** may be embodied as a non-transitory storage medium storing instructions executable by an electronic processor (e.g., the processor **50**) to perform the disclosed operations. The non-transitory storage medium may, for example, comprise a hard disk drive, RAID, or other magnetic storage medium; a solid state drive, flash drive, electronically erasable read-only memory (EEROM) or other electronic memory; an optical disk or other optical storage; various combinations thereof; or so forth.

The disclosure 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 disclosure be constructed 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 apparatus (**10**) for calibrating electromagnetic (EM) tracking of an associated ultrasound probe (**12**), the apparatus comprising:

an EM tracking device including a field generator (**14**) configured to generate an EM field in an EM-encoded space;

an EM sensor (**18**) disposed on the ultrasound probe;

a calibration needle (**16**);

an EM sensor (**26**) disposed on the calibration needle;

at least one processor (**50**); and

a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a EM tracking calibration method including:

determining a location of the calibration needle in an ultrasound imaging space at a measurement time using the ultrasound probe;

determining an EM-tracked location of the calibration needle at the measurement time from EM tracking by the EM tracking device of the EM sensor disposed on the calibration needle; and

generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the EM-tracked location of the calibration needle at the measurement time.

2. The apparatus (**10**) according to claim 1, wherein the EM tracking calibration method further includes:

determining, with the generated registration, a location of at least one ultrasound image in a common coordinate system within the ultrasound imaging space.

3. The apparatus (**10**) according to either one of claims 1 and 2, further comprising:

at least one ultrasound transducer (**28**) disposed on the calibration needle (**16**);

wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

performing an ultrasonic sweep using the ultrasound probe;

detecting a signal emitted by the ultrasound transducer in response to being sonicated by an ultrasound beam emitted by the ultrasound probe wherein the measurement time is a time stamp of the detected signal; and

determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam and comparison of the measurement time with a trigger time of the ultrasound beam.

4. The apparatus (**10**) according to either one of claims 1 and 2, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

performing an ultrasonic sweep using the ultrasound probe;

detecting an ultrasonic transmission from the calibration needle in response to the ultrasonic sweep wherein the measurement time is a time stamp of the detected ultrasonic reflection; and

determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission and comparison of the measurement time with a trigger time of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission.

5. The apparatus (**10**) according to either one of claims 1 and 2, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

acquiring an ultrasound image in the ultrasound imaging space; and

determining the location of the calibration needle in the ultrasound imaging space by detecting an image of the calibration needle in the ultrasound image, wherein the measurement time is an acquisition time stamp of the image of the calibration needle in the ultrasound image.

6. The apparatus (**10**) according to any one of claims 1-5, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

determining candidate locations of the calibration needle using the ultrasound probe with a plurality of different relative positions of the ultrasound probe and the calibration needle and, for each candidate location, determining a corresponding ultrasound-induced signal strength associated with the determination of the candidate location;

determining the location of the calibration needle in the ultrasound imaging space as the candidate location having the highest corresponding signal strength; and

determining the measurement time as a time stamp of the candidate location having the highest corresponding signal strength.

7. The apparatus (**10**) according to claim 6, further comprising:

a robotic apparatus (**21**) configured to move at least one of the calibration needle (**16**) and the ultrasound probe (**12**) relative to the other of the calibration needle and the ultrasound probe;

wherein determining the candidate locations includes operating the robotic apparatus to move the calibration needle relative to the ultrasound probe to traverse the plurality of different relative positions of the ultrasound probe and the calibration needle.

8. An apparatus (**10**) for calibrating tracking of an associated ultrasound probe (**12**), the apparatus comprising:

a tracking device (**14**) configured to locate tracking sensors in a tracking space;

an ultrasound probe tracking sensor (**18**) disposed on the ultrasound probe (**12**);

a calibration needle (**16**);

a calibration needle tracking sensor (**26**) disposed on a calibration needle;

at least one processor (**50**); and

a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a tracking calibration method including:

determining a location of the calibration needle in an ultrasound imaging space at a measurement time using the ultrasound probe;

determining a tracked location of the calibration needle at the measurement time from tracking by the tracking device of the calibration needle tracking sensor disposed on the calibration needle; and

generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the tracked location of the calibration needle at the measurement time.

9. The apparatus (**10**) according to claim 8, wherein the tracking calibration method further includes:

determining, with the generated registration, a location of at least one ultrasound image in a common coordinate system within the ultrasound imaging space.

10. The apparatus (**10**) according to either one of claims 8 and 9, further comprising:

at least one ultrasound transducer (**28**) disposed on the calibration needle (**16**);

wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

performing an ultrasonic sweep using the ultrasound probe;

detecting a signal emitted by the ultrasound transducer in response to being sonicated by an ultrasound beam emitted by the ultrasound probe wherein the measurement time is a time stamp of the detected signal; and

determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam and comparison of the measurement time with a trigger time of the ultrasound beam.

11. The apparatus (**10**) according to either one of claims 8 and 9, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

performing an ultrasonic sweep using the ultrasound probe;

detecting an ultrasonic transmission from the calibration needle in response to the ultrasonic sweep wherein the measurement time is a time stamp of the detected ultrasonic reflection; and

determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission and comparison of the measurement time with a trigger time of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic transmission.

12. The apparatus **(10)** according to either one of claims 8 and 9, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

acquiring an ultrasound image in the ultrasound imaging space; and

determining the location of the calibration needle in the ultrasound imaging space by detecting an image of the calibration needle in the ultrasound image, wherein the measurement time is an acquisition time stamp of the image of the calibration needle in the ultrasound image.

13. The apparatus **(10)** according to any one of claims 8-12, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

determining candidate locations of the calibration needle using the ultrasound probe with a plurality of different relative positions of the ultrasound probe and the calibration needle and, for each candidate location, determining a corresponding ultrasound-induced signal strength associated with the determination of the candidate location;

determining the location of the calibration needle in the ultrasound imaging space as the candidate location having the highest corresponding signal strength; and

determining the measurement time as a time stamp of the candidate location having the highest corresponding signal strength.

14. The apparatus **(10)** according to claim 13, further comprising:

a robotic apparatus (**21**) configured to move at least one of the calibration needle (**16**) and the ultrasound probe (**12**) relative to the other of the calibration needle and the ultrasound probe;

wherein determining the candidate locations includes operating the robotic apparatus to move the calibration needle relative to the ultrasound probe to traverse the plurality of different relative positions of the ultrasound probe and the calibration needle.

15. An apparatus (**10**) for calibrating tracking of an associated ultrasound probe (**12**), the apparatus comprising:

a tracking device (**14**) configured to locate tracking sensors in a tracking space;

an ultrasound probe tracking sensor (**18**) disposed on the ultrasound probe;

a calibration needle (**16**);

a calibration needle tracking sensor (**26**) disposed on a calibration needle;

an ultrasound transducer (**28**) disposed on the calibration needle;

at least one processor (**50**); and

a non-transitory storage medium storing instructions readable and executable by the at least one processor to perform a tracking calibration method including:

performing an ultrasound sweep comprising a plurality of ultrasound beams emitted in different directions by the ultrasound probe;

detecting a transducer signal generated by the ultrasound transducer in response to sonication of the ultrasound transducer during the ultrasound sweep;

determining a measurement time as a time stamp of the detected transducer signal;

determining a location of the calibration needle in an ultrasound imaging space at the measurement time from a direction of the ultrasound beam that sonicated the ultrasound transducer and comparison of the measurement time with a trigger time of the ultrasound beam that sonicated the ultrasound transducer and the time-of-flight along the ultrasound beam;

determining a tracked location of the calibration needle at the measurement time from tracking by the tracking device of the calibration needle tracking sensor disposed on the calibration needle; and generating a registration relating the location of the calibration needle in the ultrasound imaging space at the measurement time and the tracked location of the calibration needle at the measurement time.

16. The apparatus (**10**) according to claim 15, wherein the tracking calibration method further includes:

determining, with the generated registration, a location of at least one ultrasound image in a common coordinate system within the ultrasound imaging space.

17. The apparatus (**10**) according to either one of claims 15 and 16, further comprising:

at least one ultrasound transducer (**28**) disposed on the calibration needle (**16**);

wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

performing an ultrasonic sweep using the ultrasound probe;

detecting a signal emitted by the ultrasound transducer in response to being sonicated by an ultrasound beam emitted by the ultrasound probe wherein the measurement time is a time stamp of the detected signal; and

determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam and comparison of the measurement time with a trigger time of the ultrasound beam.

18. The apparatus (**10**) according to either one of claims 15 and 16, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

acquiring an ultrasound image in the ultrasound imaging space; and

determining the location of the calibration needle in the ultrasound imaging space by detecting an image of the calibration needle in the ultrasound image, wherein the measurement time is an acquisition time stamp of the image of the calibration needle in the ultrasound image.

19. The apparatus (**10**) according to any one of claims 15-18, wherein determining the location of the calibration needle in the ultrasound imaging space at the measurement time using the ultrasound probe includes:

determining candidate locations of the calibration needle using the ultrasound probe with a plurality of different relative positions of the ultrasound probe and the calibration needle and, for each candidate location, determining a corresponding ultrasound-induced signal strength associated with the determination of the candidate location;

determining the location of the calibration needle in the ultrasound imaging space as the candidate location having the highest corresponding signal strength; and

determining the measurement time as a time stamp of the candidate location having the highest corresponding signal strength.

20. The apparatus (**10**) according to claim 19, further comprising:

a robotic apparatus (**21**) configured to move at least one of the calibration needle (**16**) and the ultrasound probe (**12**) relative to the other of the calibration needle and the ultrasound probe;

wherein determining the candidate locations includes operating the robotic apparatus to move the calibration needle relative to the ultrasound probe to traverse the plurality of different relative positions of the ultrasound probe and the calibration needle.

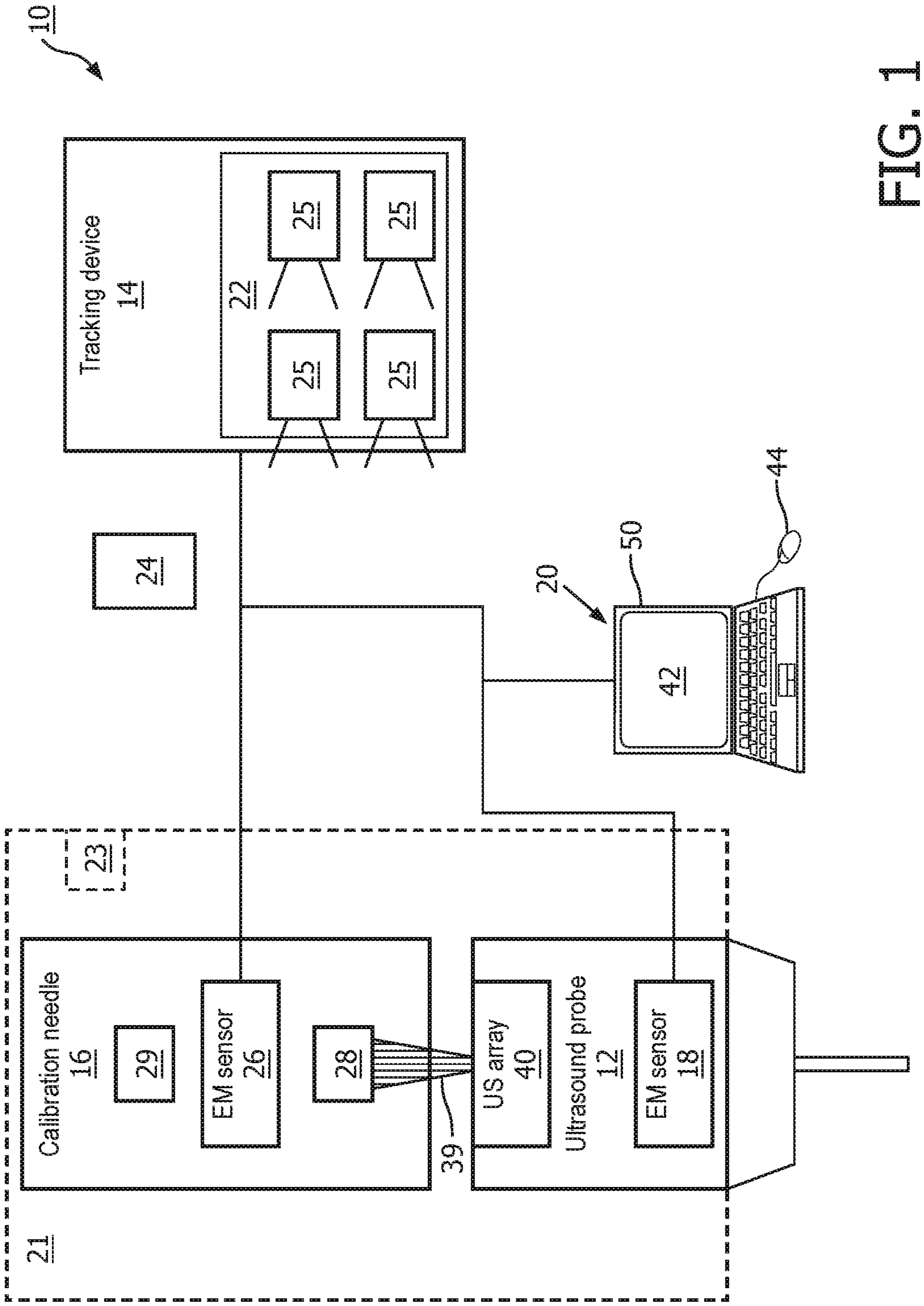

10
Tracking device
14
22
25
25
25
25
24
20
50
44
42
23
21
Calibration needle
16
29
EM sensor
26
28
39
US array
40
Ultrasound probe
12
EM sensor
18

FIG. 1

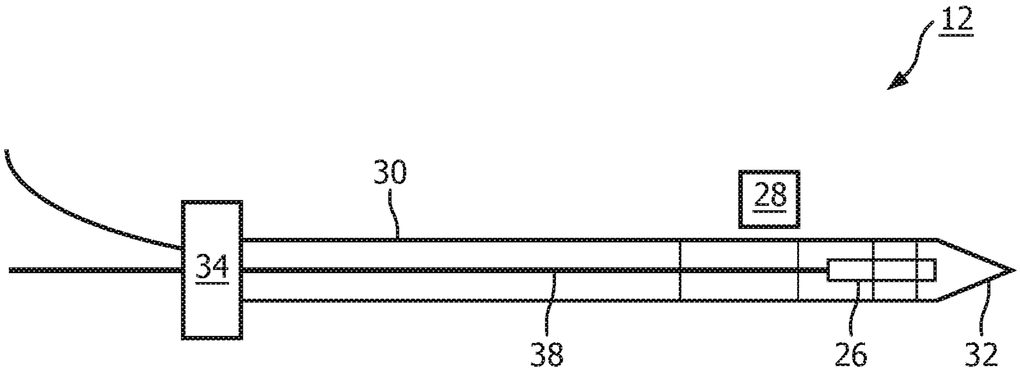

12
30
28
34
38
26
32

FIG. 2

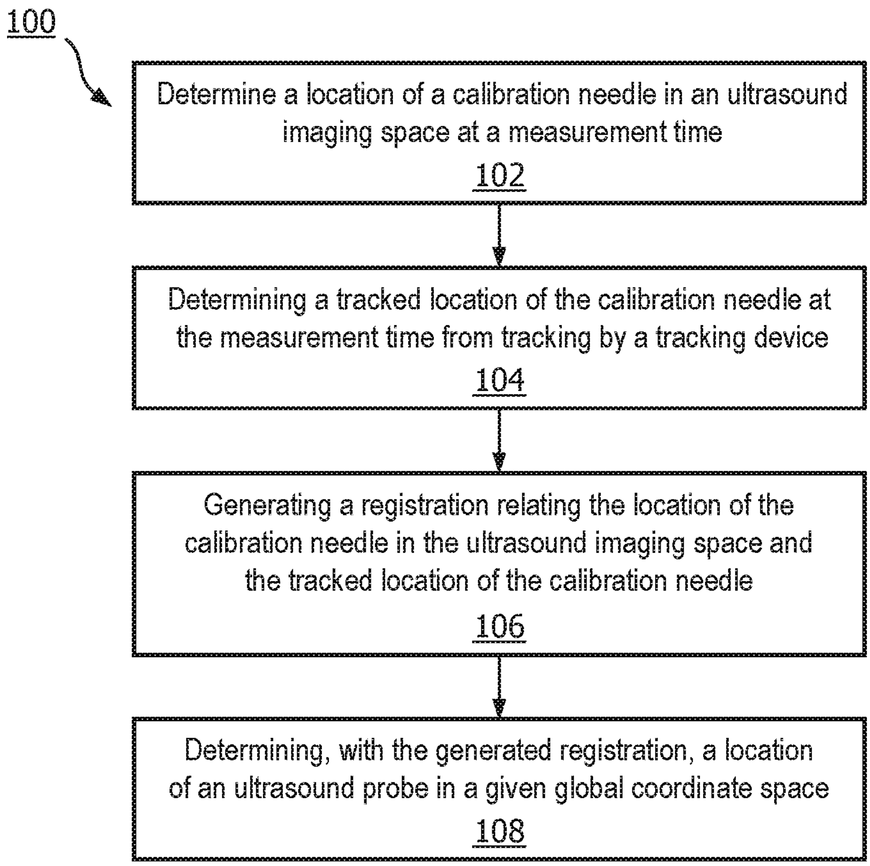

100
Determine a location of a calibration needle in an ultrasound imaging space at a measurement time
102
Determining a tracked location of the calibration needle at the measurement time from tracking by a tracking device
104
Generating a registration relating the location of the calibration needle in the ultrasound imaging space and the tracked location of the calibration needle
106
Determining, with the generated registration, a location of an ultrasound probe in a given global coordinate space
108

FIG. 3

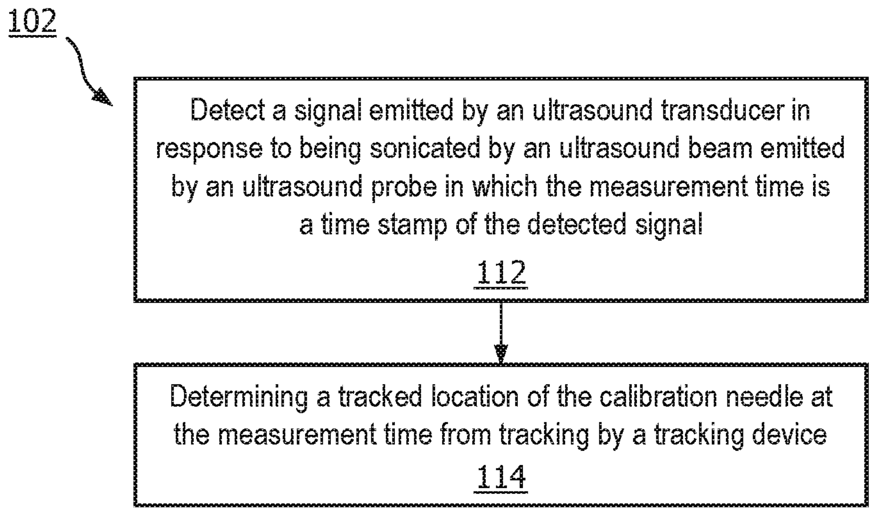

102
Detect a signal emitted by an ultrasound transducer in response to being sonicated by an ultrasound beam emitted by an ultrasound probe in which the measurement time is a time stamp of the detected signal
112
Determining a tracked location of the calibration needle at the measurement time from tracking by a tracking device
114

FIG. 4

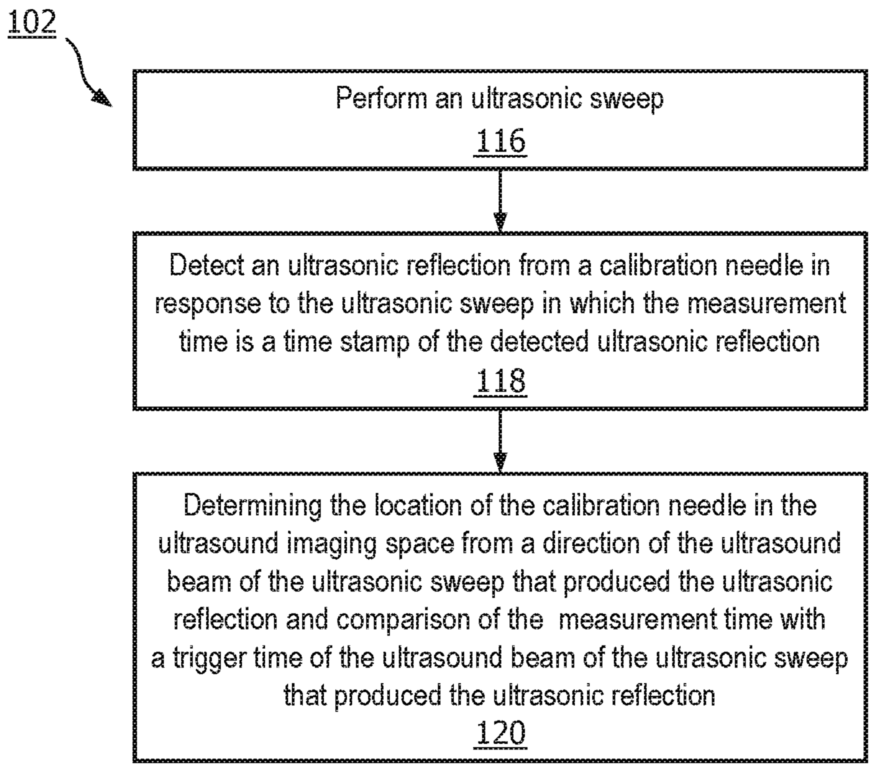

102
Perform an ultrasonic sweep
116
Detect an ultrasonic reflection from a calibration needle in response to the ultrasonic sweep in which the measurement time is a time stamp of the detected ultrasonic reflection
118
Determining the location of the calibration needle in the ultrasound imaging space from a direction of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic reflection and comparison of the measurement time with a trigger time of the ultrasound beam of the ultrasonic sweep that produced the ultrasonic reflection
120

FIG. 5

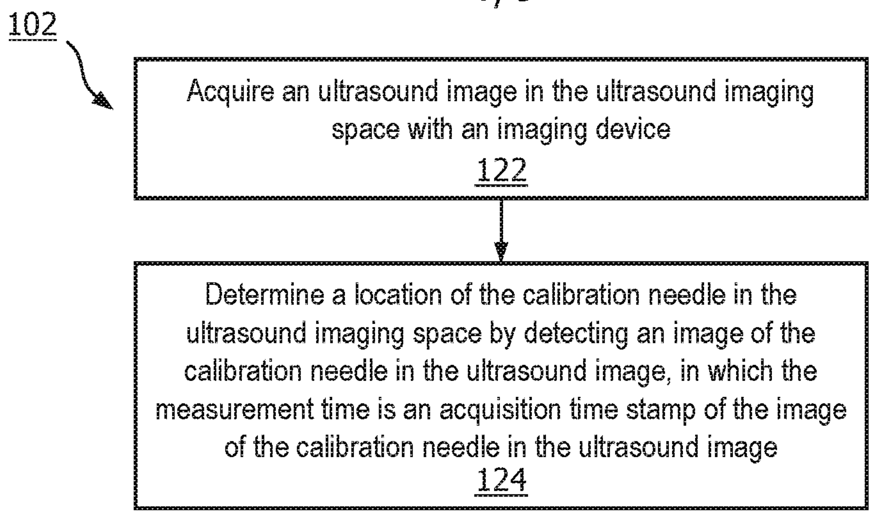

102
Acquire an ultrasound image in the ultrasound imaging space with an imaging device
122
Determine a location of the calibration needle in the ultrasound imaging space by detecting an image of the calibration needle in the ultrasound image, in which the measurement time is an acquisition time stamp of the image of the calibration needle in the ultrasound image
124

FIG. 6

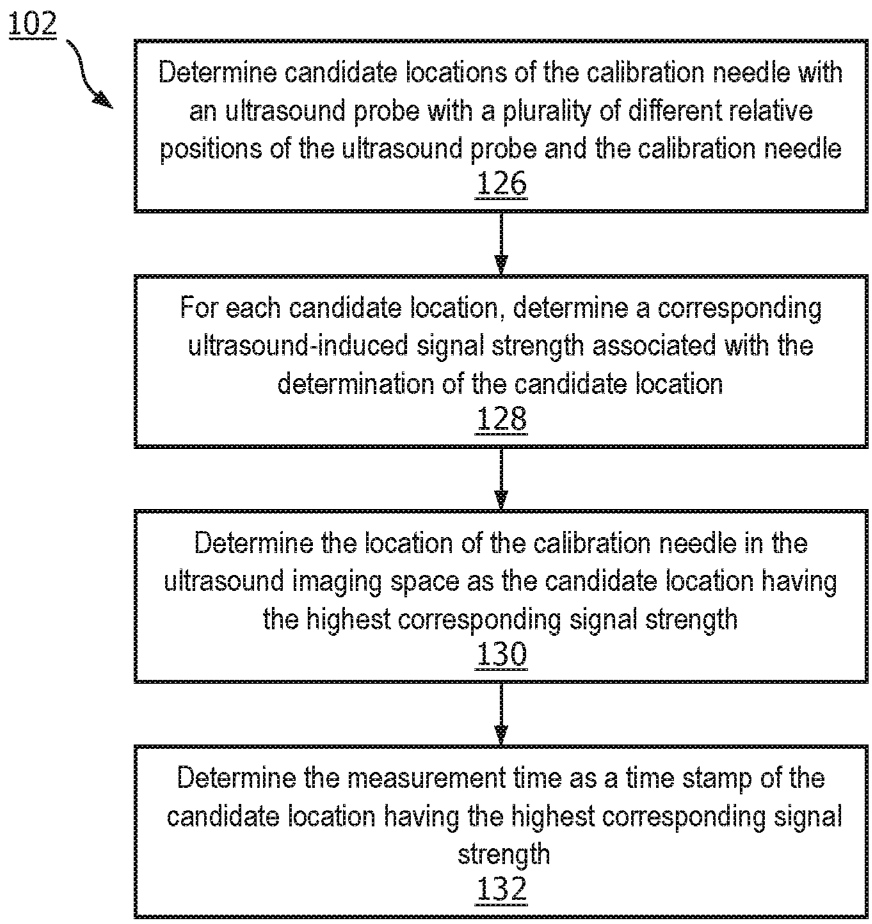

102
Determine candidate locations of the calibration needle with an ultrasound probe with a plurality of different relative positions of the ultrasound probe and the calibration needle
126
For each candidate location, determine a corresponding ultrasound-induced signal strength associated with the determination of the candidate location
128
Determine the location of the calibration needle in the ultrasound imaging space as the candidate location having the highest corresponding signal strength
130
Determine the measurement time as a time stamp of the candidate location having the highest corresponding signal strength
132

FIG. 7

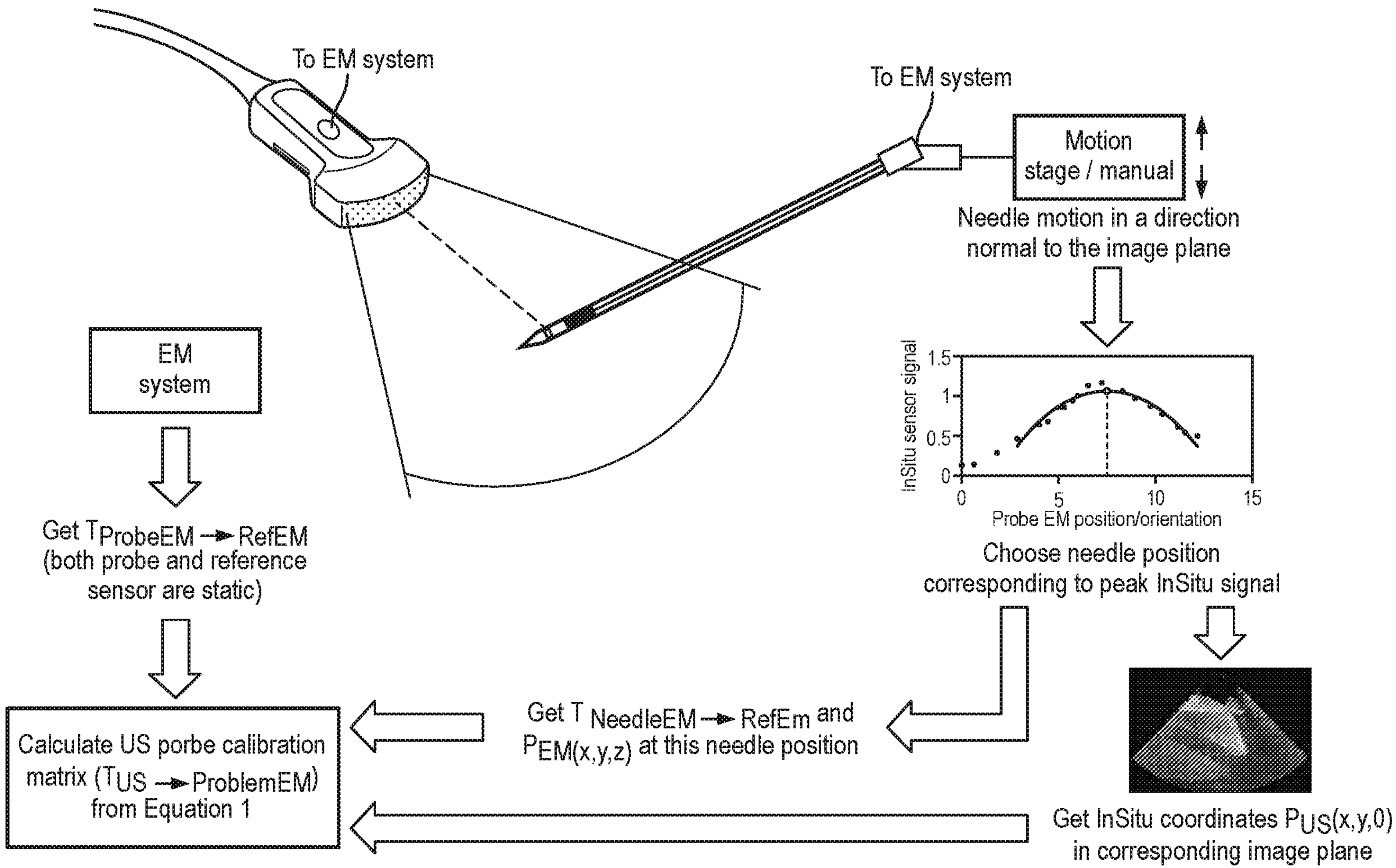
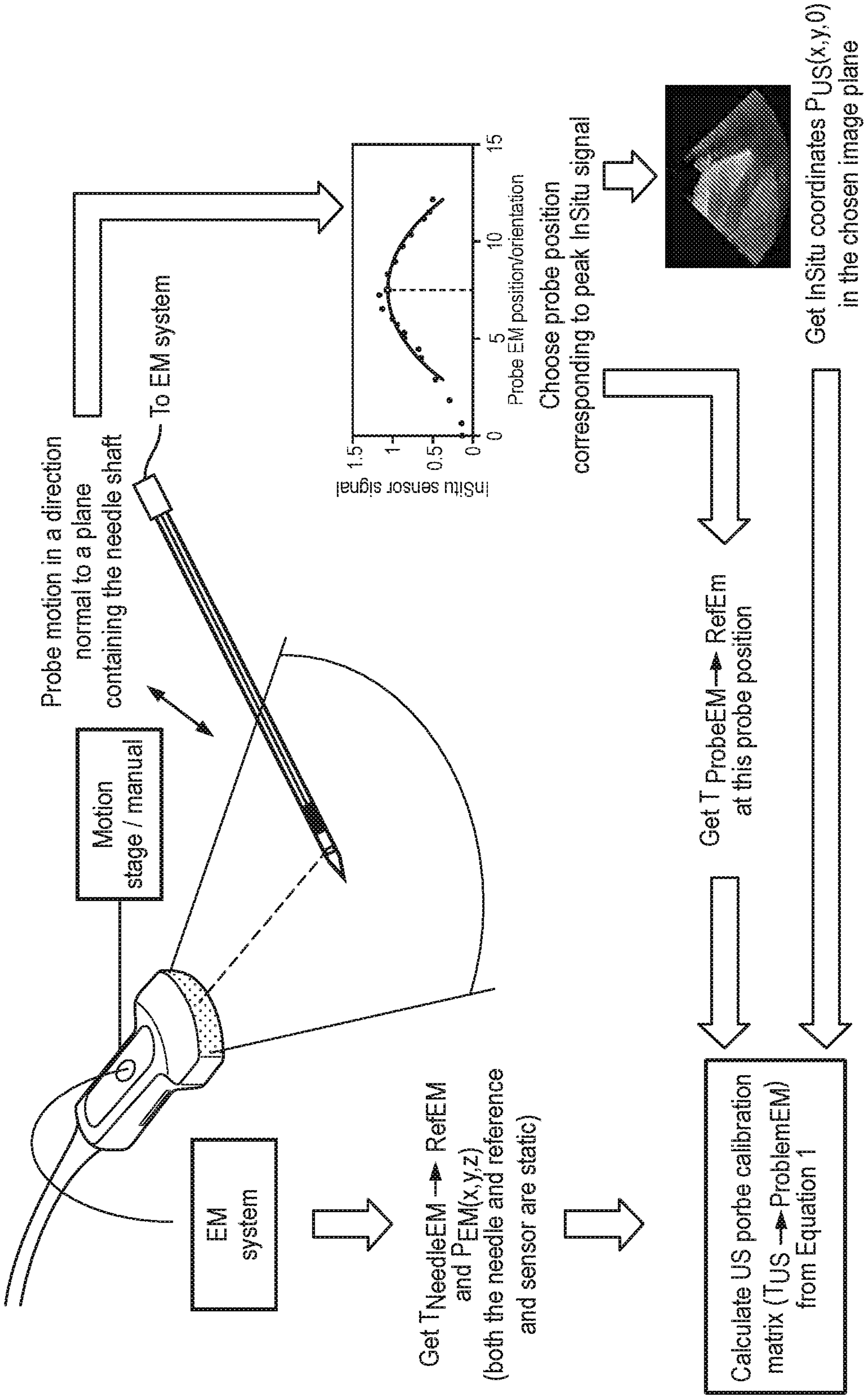

To EM system
To EM system
Motion
stage / manual
Needle motion in a direction
normal to the image plane
EM
system
inSitu sensor signal
1.5
1
0.5
0
0
5
10
15
Probe EM position/orientation
Get TProbeEM → RefEM
(both probe and reference
sensor are static)
Choose needle position
corresponding to peak InSitu signal
Calculate US porbe calibration
matrix (TUS → ProblemEM)
from Equation 1
Get T NeedleEM → RefEm and
PEM(x,y,z) at this needle position
Get InSitu coordinates PUS(x,y,0)
in corresponding image plane

FIG. 8



EM system
Motion stage / manual
Probe motion in a direction normal to a plane containing the needle shaft
To EM system
InSitu sensor signal
Probe EM position/orientation
0
0.5
1
1.5
0
5
10
15
Choose probe position corresponding to peak InSitu signal
Get InSitu coordinates PUS(x,y,0) in the chosen image plane
Get TNeedleEM → RefEM and PEM(x,y,z) (both the needle and reference and sensor are static)
Get T ProbeEM → RefEm at this probe position
Calculate US porbe calibration matrix (TUS → ProblemEM) from Equation 1

FIG. 9

Time	US tracking data	EM tracking data
T_1		X_1
T_2		X_2
T_3	(X_1, Y_1)	X_3
T_4	$(a_1X_1 + b_4X_2, a_4Y_1 + b_4Y_2)$	$C_4X_3 + d_4X_4$
T_5	$(a_5X_1 + b_5X_2, a_5Y_1 + b_5Y_2)$	X_4
T_6	(X_2, Y_2)	X_5
T_7	$(a_7X_2 + b_7X_3, a_7Y_2 + b_7Y_3)$	X_6
T_8	(X_3, Y_3)	$C_8\ \ 6 + d_8\ \ 4$
T_9	$(a_9X_3 + b_9X_4, a_9Y_3 + b_9Y_4)$	X_7
T_{10}	$(a_{10}X_3 + b_{10}X_4, a_{10}Y_3 + b_{10}Y_4)$	X_8
T_{11}	(X_4, Y_4)	X_9
T_{12}	$(a_{12}X_4 + b_{12}X_5, a_{12}Y_4 + b_{12}Y_5)$	X_{10}
T_{13}	$(a_{13}X_4 + b_{13}X_5, a_{13}Y_4 + b_{13}Y_5)$	X_{11}
T_{14}	(X_5, Y_5)	X_{12}

FIG. 10

Time	US tracking data	EM tracking data
T_1		X_1
T_2		X_2
T_3	(X_1, Y_1)	X_3
T_4	(X_1, Y_1)	X_3
T_5	(X_1, Y_1)	X_4
T_6	(X_2, Y_2)	X_5
T_7	(X_2, Y_2)	X_6
T_8	(X_3, Y_3)	X_6
T_9	(X_3, Y_3)	X_7
T_{10}	(X_3, Y_3)	X_8
T_{11}	(X_4, Y_4)	X_9
T_{12}	(X_4, Y_4)	X_{10}
T_{13}	(X_4, Y_4)	X_{11}
T_{14}	(X_5, Y_5)	X_{12}
T_{15}	(X_5, Y_5)	X_{13}

FIG. 11

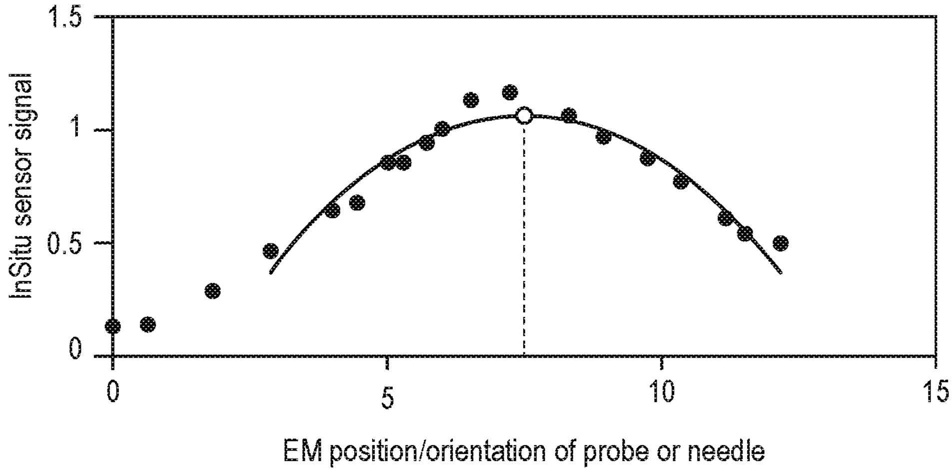

1.5
1
0.5
0
InSitu sensor signal
0
5
10
15
EM position/orientation of probe or needle

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/058037

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B8/00
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

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	LUAN KUAN ET AL: "Automatic and Robust Freehand Ultrasound Calibration Using a Tracked Pointer", JOURNAL OF JAPAN SOCIETY OF COMPUTER AIDED SURGERY, vol. 13, no. 4, 1 January 2011 (2011-01-01), pages 437-443, XP055464818, DOI: 10.5759/jscas.13.437 abstract, sections 1. and 2., figure 1 -----	1,2,8,9
X	WO 2014/016736 A2 (KONINKL PHILIPS NV [NL]) 30 January 2014 (2014-01-30)	1,2,8,9
A	page 2, paragraph 2 page 8, paragraph 2 - page 11, paragraph 1 page 12, paragraph 3 - page 13, paragraph 1; figures 1, 2, 4 ----- -/--	3,10,15

[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
5 April 2018	07/06/2018

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	Küster, Gunilla

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/058037

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HUI ZHANG ET AL: "Freehand 3D ultrasound calibration using an electromagnetically tracked needle", PROCEEDINGS OF SPIE, MEDICAL IMAGING 2006: VISUALIZATION, IMAGE-GUIDED PROCEDURES, AND DISPLAY, vol. 6141, 2 March 2006 (2006-03-02), pages 61412M-1, XP055464968, US ISSN: 0277-786X, DOI: 10.1117/12.654906 ISBN: 978-1-5106-1324-9 the whole document -----	1,2,8,9

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2017/058037

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

3, 10, 15-20(completely); 1, 2, 8, 9(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2017/058037

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014016736 A2	30-01-2014	CN 104507394 A	08-04-2015
		EP 2877096 A2	03-06-2015
		JP 6242394 B2	06-12-2017
		JP 2015522389 A	06-08-2015
		US 2015269728 A1	24-09-2015
		WO 2014016736 A2	30-01-2014

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 3, 10, 15-20(completely); 1, 2, 8, 9(partially)

   ultrasound probe calibration using a calibration needle, wherein an ultrasound transducer is disposed on the calibration needle

   ---

2. claims: 4, 11(completely); 1, 2, 8, 9(partially)

   ultrasound probe calibration using a calibration needle, wherein a passive ultrasound reflector is disposed on the calibration needle

   ---

3. claims: 5, 12(completely); 1, 2, 8, 9(partially)

   ultrasound probe calibration using a calibration needle, wherein automatic image processing is used to detect the needle location in the ultrasound image

   ---

4. claims: 6, 7, 13, 14(completely); 1, 2, 8, 9(partially)

   ultrasound probe calibration using a calibration needle, wherein a plurality of different relative positions of the ultrasound probe and the calibration needle are used, in particular by means of a robotic apparatus, to optimise signal strength

   ---

patsnap

专利名称(译)	快速和自动超声探头校准的系统和方法		
公开(公告)号	EP3558132A1	公开(公告)日	2019-10-30
申请号	EP2017832093	申请日	2017-12-18
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	BHARAT SHYAM BONILLAS VACA ANTONIO		
发明人	BHARAT, SHYAM BONILLAS VACA, ANTONIO		
IPC分类号	A61B8/00		
CPC分类号	A61B8/0841 A61B8/4254 A61B8/5261 A61B8/58 A61B8/4218 A61B8/587		
代理机构(译)	费尔利，PETER DOUGLAS		
优先权	62/437284 2016-12-21 US		
外部链接	Espacenet		

摘要(译)

一种用于校准相关超声探头（12）的电磁（EM）跟踪的装置（10），包括校准针（16），包括场发生器（14）和参考EM传感器（24）的EM跟踪装置，EM超声波探头上和校准针上的传感器（18,26）;至少一个处理器（50）;以及存储用于执行EM跟踪校准方法的指令的非暂时性存储介质，包括：使用超声探头在测量时间确定校准针在超声成像空间中的位置;在测量时确定校准针的EM跟踪位置;并且在测量时产生与超声成像空间中的校准针的位置和校准针的EM跟踪位置相关的配准。