A NEEDLE GUIDANCE SYSTEM AND METHOD

FIELD OF INVENTION

[1] The present invention relates broadly, but not exclusively, to a needle guidance system and method.

BACKGROUND

[2] Interventional prostate procedures, such as biopsies, may be performed through either the transrectal or transperineal approach. The transperineal approach has been proven to have much lower rates of infection and sepsis. However, barriers to more widespread adoption remain, such as the costs of conversion, as well as the skill required. Transperineal procedures are most commonly ultrasound-guided due to the ease of access to ultrasound imaging systems. During ultrasound-guided transperineal procedures, the clinician maneuvers a transrectal biplane probe within the patient's rectum, while simultaneously inserting a needle into the patient's prostate through the perineum. Performing the procedure freehand is difficult because there are many moving parts, requiring significant hand-eye coordination. The ultrasound probe needs to be held in one hand and aligned to the needle while the needle is steered with the other hand and has to be accurately placed at the target location. There is no direct visualization of the needle, except via two-dimensional ultrasound views in the transverse and sagittal planes. There is no guarantee that the needle lies on the sagittal plane.

[3] Limiting the number of needle entry points on the perineum is crucial for procedures performed under local anaesthesia. This is because the perineum is a very sensitive area, and having multiple entry points poses the possibility that the needle may enter an area that has not been anaesthetized, resulting in a more uncomfortable experience for the patient. In addition, visual access to the perineum is required so that clinicians can check the perineum during the procedure.

[4] Robotic guidance of the needle and probe can lower the skill required to perform the procedure. The robotic system allows for motorized movement of a needle guide and the ultrasound probe. However, in order to ensure costs are commensurate with the cost of a biopsy in most markets, the procedure has to be

performed under local anaesthesia, in an office setting. This places constraints on the size / spatial configuration and cost of the robotic system.

[5] For example, one of the constraints on the size of the robotic arm is that there should ideally be clear visual access to the perineum during the procedure performed under local anaesthesia. This allows the physician to check on the perineum during the procedure. Hence, bulky parts of the robotic arm should not be in the line of sight between the physician and the perineum. There also should be sufficient clearance above the ultrasound probe for the insertion of the biopsy needle, for optimal access to the prostate. For example, the biopsy needle may be angulated upwards to access the anterior of the prostate, and hence the handle of the biopsy needle may be very close to the ultrasound probe.

[6] For transperineal procedures involving large prostates, especially when the region of interest is at the base, the ultrasound probe and needle both need to be inserted to a sufficient depth. Most commercial endocavity biplane ultrasound probes have a transducer section, which is narrower, and the handle section, which is larger. The maximum depth of insertion of the ultrasound probe is such that the handle (which is larger) is abutting the anus. In order not to compromise this, the robotic mechanism also should not take up space on the narrow section of the ultrasound probe. As for the needle insertion, the depth of insertion could be up to around 150 mm beyond the perineum or deeper. Hence, the handle of a 200 mm-long biopsy needle, for example, may reach a position within approximately 50 mm of the perineum. There should not be any part of the robotic arm obstructing the passage of the biopsy needle.

[7] Other devices attempt to simplify the transperineal procedure by physically limiting the trajectory of the needle such that it is always on the sagittal plane of the biplane probe. However, there are a few drawbacks to coupling the needle and probe. Firstly, to check the position of the needle holistically in multiple ultrasound planes, the probe must be moved. However, this may cause the needle to be dragged along and result in a change of the needle position (which has to be checked). Secondly, angulation to access the anterior of the prostate is limited. The needle cannot tilt any more than the probe can, which is constrained by the rectum. Thirdly, the movement of the ultrasound probe as it pivots for the needle to reach various target positions can result in deformation of the prostate.

[8] Commercial ultrasound systems have an offset between the transverse and sagittal ultrasound transducers such that the transverse transducer is always distal to the sagittal transducer. As a result, if the needle depth is observed in sagittal view, the needle position cannot be observed in transverse view. If the needle position can be observed in transverse view, its depth cannot be observed as it fully spans the sagittal view.

[9] It is desirable to be able to check the needle position and depth at the same time. While this is possible with various 3D ultrasound systems, these are more expensive than biplane probes. Affordability is key for procedures performed under local anaesthesia in the office setting.

[10] A need therefore exists to provide a system and a method that can address at least some of the above problems.

SUMMARY

[11] According to a first aspect of the present invention, there is provided a needle guidance system. The needle guidance system includes a first assembly including at least one probe holder configured to receive a probe and a first rotation member coupled to the probe holder and configured to rotate the probe holder such that the probe rotates about a longitudinal axis of the probe, and a second assembly including at least one needle guide configured to receive a needle, a guide holder attached to the needle guide and configured to secure the needle guide and a second rotation member coaxial with the first rotation member, wherein the second rotation member is coupled to the guide holder and configured to rotate the guide holder such that the needle rotates about the longitudinal axis of the probe.

[12] The first and second rotation members may be configured to operate independently of each other.

[13] The second assembly may be movable along the longitudinal axis of the probe relative to the first assembly.

[14] The needle guidance system may include a tilt mechanism coupled to the guide holder and the second rotation member. The tilt mechanism may be configured to tilt the needle relative to the longitudinal axis of the probe.

[15] The tilt mechanism may include at least one linear assembly coupled to the guide holder. The linear assembly may be configured to move a position of the guide holder in a direction relative to the longitudinal axis of the probe.

[16] In some embodiments, each rotation member may include a curved rail, a carriage slidably mounted on the curved rail, and a plurality of bearings disposed between the curved rail and the carriage such that the carriage is slidable along an inner surface of the curved rail.

[17] In some embodiments, each rotation member may include a curved rail having V-shaped edges along longitudinal axes of the curved rail and a carriage movably mounted to the curved rail. The carriage may have a plurality of rollers configured to engage with the V-shaped edges. The plurality of rollers may be rotatable to move the carriage along an arc defined by the V-shaped edges of the curved rail.

[18] The needle guidance system may include a belt drive mechanism configured to drive each rotation member. The belt drive mechanism may include a belt coupled to the carriage, wherein the belt conforms to a bottom surface of the curved rail, at least two idler pulleys, wherein each of the idler pulleys is disposed on an end of the curved rail, and wherein the belt runs along on the idler pulleys, and at least one drive pulley coupled to the belt, wherein the drive pulley is driven by a motor.

[19] The curved rail may include a truncated arc.

[20] The needle guidance system may include an arm coupled to the tilt mechanism and the guide holder. The tilt mechanism may include first and second linear assemblies. A first position of the arm may be rotatably coupled to the first linear assembly, and a second position of the arm may be rotatably and slidably coupled to the second linear assembly.

[21] In some embodiments, the second assembly may be configured to align the needle guide with a sagittal plane of the probe and the tilt mechanism may be configured to change a direction of the needle guide on the sagittal plane.

[22] In a first two-entry point configuration, the guide holder may include a first pivot pin, wherein the needle guide is pivotally mounted on the first pivot pin, and

wherein a first end of the needle pivots relative to an axis of the first pivot pin. The second assembly may further include an entry plate having a first end pivotally attached to the second rotation member and configured to pivot relative to a longitudinal axis of the second rotation member and an entry guide linkage pivotally attached to a second end of the plate by a second pivot pin and configured to pivot relative to the second pin, wherein the entry guide linkage defines a passage configured to receive the needle guide and limit a pivot angle of the mounted needle guide.

[23] In a second two-entry point configuration, the needle guidance system may further include a ball joint fixedly coupled to the tilt mechanism via the arm, wherein the needle guide is moveably attached to the ball joint and is further configured to receive a first end of the needle, and a conical plate configured to receive a second end of the needle.

[24] In embodiments of the present invention, there is provided a first needle guidance method including receiving, by the needle guidance system, a signal defining a plurality of target points on a target, in response to receiving the signal by the needle guidance system: selecting, by the needle guidance system, a target point based on the signal from the plurality of target points, rotating the probe, by the first rotation member, such that the selected target point lies on a sagittal plane of the probe, rotating the guide holder, by the second rotation member, such that the needle lies on the sagittal plane of the probe, and tilting the guide holder, by the tilt mechanism, such that the needle points towards the target point.

[25] In embodiments of the present invention, there is provided a second needle guidance method including: receiving, by the needle guidance system, a signal defining a plurality of target points on a target, in response to receiving the signal by the needle guidance system: i) selecting a target point based on the signal from the plurality of target points, ii) rotating the ultrasound probe, by the first rotation member, such that the selected target point lies on a sagittal plane of the ultrasound probe, iii) moving the entry plate to define a first entry point, and iv) tilting the guide holder, by the tilt mechanism, such that the needle points towards the selected target point, wherein the needle is constrained by the entry guide linkage such that the needle passes through the first entry point.

[26] The second needle guidance method may further include: repeating steps i) to iii) to define a second entry point, and repeating step iv) such that the needle points towards the selected target point and passes through the second entry point.

[27] The first and second needle guidance methods may further include the following steps: a) rotating, by the needle guidance system, the ultrasound probe through a plurality of predetermined rotational positions, b) at each of the plurality of predetermined rotational positions, capturing a respective sagittal ultrasound image of a target by the ultrasound probe, c) based on a selected depth of a transverse plane, identifying intersection points between the plurality of captured sagittal ultrasound images and the transverse plane, each intersection point having a respective pixel value, and d) reconstructing the ultrasound image at the transverse plane based on the identified intersection points.

[28] Reconstructing the ultrasound image at the transverse plane based on the identified intersection points may include interpolating points on the transverse plane between adjacent ultrasound images.

[29] Interpolating points on the transverse plane between adjacent ultrasound images may include: for each point on the transverse plane between adjacent ultrasound images, identifying a first intersection point on a first sagittal ultrasound image to the left of said point and a second intersection point on a second sagittal ultrasound image to the right of said point, calculating a first pixel value of the first intersection point based on a bilinear interpolation, calculating a second pixel value of the second intersection point based on a bilinear interpolation, and calculating the pixel value of said point based on a linear interpolation of the first and second pixel values.

[30] The first and second needle guidance methods may further include: e) determining a contour of the target at the selected depth, f) repeating steps c), d) and e) over a plurality of depths, the plurality of depth covering the target, and g) generating a three-dimensional representation of the target based on the plurality of contours at the corresponding plurality of depths.

[31] The first and second needle guidance methods may further include: determining, based on the reconstructed transverse ultrasound image, if a needle trajectory falls outside of the sagittal plane, determining if the needle deviates from

the target point, and if it is determined that the needle deviates from the target point, adjusting the needle guide such that the needle points towards the target point.

[32] According to a second aspect of the present invention, there is provided a method of constructing an ultrasound image. The method includes: a) rotating an ultrasound probe through a plurality of predetermined rotational positions, b) at each of the plurality of predetermined rotational positions, capturing a respective sagittal ultrasound image of a target by the ultrasound probe, c) based on a selected depth of a transverse plane, identifying intersection points between the plurality of captured sagittal ultrasound images and the transverse plane, each intersection point having a respective pixel value, and d) reconstructing the ultrasound image at the transverse plane based on the identified intersection points.

[33] Reconstructing the ultrasound image at the transverse plane based on the identified intersection points may include interpolating points on the transverse plane between adjacent ultrasound images.

[34] Interpolating points on the transverse plane between adjacent ultrasound images may include: for each point on the transverse plane between adjacent ultrasound images, identifying a first intersection point on a first sagittal ultrasound image to the left of said point and a second intersection point on a second sagittal ultrasound image to the right of said point, calculating a first pixel value of the first intersection point based on a bilinear interpolation, calculating a second pixel value of the second intersection point based on a bilinear interpolation, and calculating the pixel value of said point based on a linear interpolation of the first and second pixel values.

[35] The method may further include simultaneously displaying the reconstructed transverse ultrasound image and a selected sagittal ultrasound image of the target.

[36] The method may further include: e) determining a contour of the target at the selected depth, f) repeating steps c), d) and e) over a plurality of depths, the plurality of depth covering the target, and g) generating a three-dimensional representation of the target based on the plurality of contours at the corresponding plurality of depths.

[37] The method may further include repeating steps a)-d) after a predetermined period and updating the transverse ultrasound image.

BRIEF DESCRIPTION OF THE DRAWINGS

[38] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[39] Fig. 1 shows a perspective view of a needle guidance system, in accordance with an embodiment.

[40] Fig. 2A shows an enlarged perspective view of a needle guide of the system of Fig. 1 coupled to a guide holder.

[41] Fig. 2B shows another enlarged perspective view of the needle guide of the system of Fig. 1 coupled to the guide holder.

[42] Fig. 3 shows an enlarged perspective view of a linear assembly of the system of Fig. 1.

[43] Fig. 4 shows a perspective view of the needle guide coupled to a tilt mechanism via an arm, in accordance with an embodiment.

[44] Fig. 5 shows an enlarged perspective view of a rotation member in a first configuration, in accordance with an embodiment.

[45] Fig. 6A shows an enlarged perspective view of the rotation member in a second configuration, in accordance with an embodiment.

[46] Figs. 6B and 6C show side cross-sectional views of the rotation member in the second configuration, in accordance with an embodiment.

[47] Fig. 7A shows a front plan view of the rotation member in the second configuration coupled to a belt drive mechanism, in accordance with an embodiment.

[48] Fig. 7B shows a side perspective view of the rotation member in the second configuration coupled to the belt drive mechanism, in accordance with an embodiment.

[49] Fig. 8A shows a visualization of needle trajectories passing through two entry points, according to an embodiment.

[50] Fig. 8B shows an enlarged perspective view of the needle guidance system in a first two-entry points configuration, in accordance with an embodiment.

[51] Fig. 8C shows an enlarged perspective view of the needle guide in various positions while slotted in the entry guide linkage, in accordance with an embodiment.

[52] Fig. 8D shows another enlarged perspective view of the needle guide in various positions while slotted in the entry guide linkage, in accordance with an embodiment.

[53] Figs. 9A to 9C show enlarged side perspective views of the needle guide coupled to the guide holder in the first two-entry points configuration, in accordance with an embodiment.

[54] Fig. 9D shows a front isometric view of the needle guidance system in the first two-entry points configuration when an entry plate is shifted to the left, in accordance with an embodiment.

[55] Fig. 9E shows a front isometric view of the needle guidance system in the first two-entry points configuration when the entry plate is shifted to the right, in accordance with an embodiment.

[56] Fig. 10 shows a flowchart illustrating a workflow of a user setting up the needle guidance system in the first two-entry points configuration, in accordance with an embodiment.

[57] Fig. 11 shows a flowchart illustrating a workflow of the needle guidance system in a configuration where the needle is aligned with a sagittal plane of an ultrasound probe, in accordance with an embodiment.

[58] Fig. 12 shows a flowchart illustrating a workflow of the needle guidance system in the first two-entry points configuration, in accordance with an embodiment.

[59] Fig. 13 shows a block diagram of an exemplary computer system of the needle guidance system, in accordance with an embodiment.

[60] Fig. 14 shows a flowchart illustrating a workflow for constructing an ultrasound image, in accordance with an embodiment.

[61] Fig. 15 shows a flowchart illustrating a workflow for reconstruction of a transverse plane, in accordance with an embodiment.

[62] Fig. 16 shows a flowchart illustrating a workflow of an algorithm calculating a value of a pixel, in accordance with an embodiment.

[63] Fig. 17 shows a flow diagram depicting how a reconstructed transverse view is used during a prostate procedure, in accordance with an embodiment.

[64] Fig. 18 illustrates a set of images of a sagittal plane forming a fan shape plane, in accordance with the embodiment.

[65] Figs. 19A shows an exemplary image of a prostate of a subject in different planes at a scanning step, in accordance with an embodiment.

[66] Fig. 19B shows an exemplary image of the prostate of the subject in different planes at a positioning step, in accordance with an embodiment.

[67] Fig. 19C shows an alternate image of the prostate of the subject in different planes at the positioning step, in accordance with an embodiment.

[68] Fig. 20A shows a flowchart illustrating how the user positions a needle(s) with the reconstructed transverse plane and uses a needle deflection adjustment feature, in accordance with the embodiment.

[69] Fig. 20B shows another exemplary image of the prostate of the subject in different planes at the positioning step, in accordance with the embodiment.

[70] Fig. 20C shows yet another exemplary image of the prostate of the subject in different planes at the positioning step, in accordance with the embodiment.

DETAILED DESCRIPTION

[71] Embodiments will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

[72] Fig. 1 shows a perspective view of a needle guidance system 100, or simply referred to as a robotic arm hereafter. In embodiments of the present disclosure, the needle guidance system 100 includes two main assemblies: a probe rotation assembly 101 and a needle rotation assembly 103. The probe rotation assembly 101 enables rotation of an ultrasound probe 102 and includes at least one probe holder 104 and a first rotation member 106. The moving part of the first rotation member 106 is attached to the probe holder 104. The probe holder 104 fixedly secures the ultrasound probe 102. Typically, a longitudinal axis of the ultrasound probe 102 is centered on the first rotation member 106. On the other hand, the needle rotation assembly 103 enables rotation of a needle (not shown in Fig. 1) and includes a guide holder 107, at least one needle guide 108 and a second rotation member 110. The guide holder 107 is configured to secure the needle guide 108. The first and second rotation members 106, 110 are configured to rotate the ultrasound probe 102 and the needle guide 108 (which in turn rotates the needle when inserted into the needle guide 108 or defines a rotational position of the needle with respect to the ultrasound probe 102 before inserting the needle into the needle guide 108) about the longitudinal axis of the ultrasound probe 102, respectively. In a non-limiting implementation, rotation of the moving parts of the first and second rotation members 106, 110 are at least ±70° to enable full access to a prostate of a subject. Further, the second rotation member 106 can be coaxial with the first rotation member 106. When in use, the needle can be rotated together with the ultrasound probe 102 such that the needle is always lying on a sagittal plane of the ultrasound probe 102 during rotation of the ultrasound probe 102. Alternatively, the first and second rotation members 106, 110 can be configured to operate independently of each other such that the ultrasound probe 102 can rotate without rotating the needle, or vice versa.

[73] Additionally, the needle rotation assembly 103 includes a tilt mechanism 111. The tilt mechanism 111 enables the needle to be tilted relative to the longitudinal

axis of the ultrasound probe 102. The tilt mechanism 111, for example, can include two linear assemblies, a Ya assembly 112 and a Yb assembly 114. The Ya and Yb assemblies 112, 114 can move at least one point on the needle up and down along the sagittal plane of the ultrasound probe 102 on which the needle lies. As such, the combined movement of the Ya and Yb assemblies 112, 114 can allow up/down movement and angulation of the needle. Typically, movement of the needle is between 15 mm to 65 mm radially from the centre of the ultrasound probe 102. In an exemplary configuration, the Ya & Yb linear assemblies 112, 114 are coupled to the moving part of the second rotation member 110 and the guide holder 107. For example, the Ya & Yb linear assemblies 112, 114 can be coupled to the guide holder 107 via an arm 116. The Ya & Yb linear assemblies move a position of the arm 116. Each position of the arm 116 corresponds to a position of the needle. Hence, moving a position of the arm 116 will result in a corresponding movement of a position of the needle.

[74] As depicted in Figs. 2A and 2B, the arm 116 may include two elongated axes, which guide the trajectory of the needle. The two axes are configured such that the needle is always aligned with its sagittal plane (radial to the ultrasound probe axis). One of the elongated axes is the guide holder 107, and the other is the needle guide 108. The guide holder 107 can be rigidly attached to the arm 116 and can include a slot which the needle guide 108 fits into and can optionally slide along. Alternatively, the guide holder 107 may be movably attached to the arm 116 such that the guide holder 107 can move with respect to the arm 116 via swiveling, sliding, etc. The needle guide 108 fits within the guide holder 107 and has a channel through which the needle can slide into. The needle guide 108 can be removed from the guide holder 107 for cleaning or may be a disposable piece. Further, it would be recognized by the person skilled in the art that the guide holder 107 can also be configured to be removably attached to the arm 116.

[75] Fig. 3 shows an enlarged perspective view of the linear assembly 112, 114. Each of the two linear assemblies 112, 114 (e.g., Ya assembly 112 and Yb assembly 114) can be a linear drive system. The linear assembly 112, 114 includes a carriage 302 coupled to a linear slide 304 and a leadscrew nut 305. The linear slide 304 helps to ensure the smooth motion of the carriage 302 in a linear direction (indicated by the double headed arrow "A" in Fig. 3), perpendicular to the ultrasound probe axis. The linear slide 304 includes a linear bearing 306 sliding on a linear rail 308. The leadscrew nut 305 allows the carriage 302 to be driven up and down. In operation,

the leadscrew nut 305 rotates on a leadscrew 309, which is parallel to the linear slide 304. The leadscrew 309 is in turn rigidly attached to a first gear (not shown in Fig. 3). The first gear is coupled to a second gear on a DC motor (not shown in Fig. 3). Hence, when the motor shaft rotates, the first and second gears rotate, allowing for the rotation of the leadscrew 309. The rotation of the leadscrew 309 translates to the linear motion of the leadscrew nut 305, which can only move in the linear direction A as it is coupled to the linear slide 304 via the carriage 302. Consequently, the carriage 302 is driven up and down along the leadscrew 309.

[76] With reference to Fig. 4, the arm 116 may be rotatably coupled to the Yb assembly 114 at a first position of the arm 116 and rotatably and slidably coupled to the Ya assembly 112 at a second position of the arm 116. The carriage 302a of the Ya assembly 112 can be rigidly connected to a first shaft 402a while the carriage 302b of the Yb assembly 114 can be rigidly connected to a second shaft 402b. The arm 116 can include at least one round hole which contains a bearing that enables the arm 116 to rotate on the first shaft 402a and/or the second shaft 402b. The arm 116 can have a corresponding elongated slot of the same width as the shaft diameter, which the shaft 402a, 402b slides within.

[77] It should be understood that the needle guidance system 100 can operate without the presence of the ultrasound probe 102 or the needle. For example, a user can operate the needle guidance system 100 to rotate the needle guide 108 to a desired position and insert the needle into the needle guide 108 thereafter.

[78] The needle guidance system 100 described above can provide at least the following technical advantages:

1) The configuration of the needle guidance system 100 requires the fewest motorized axes for robotic movement of both the ultrasound probe 102 and the needle, which can reduce or minimises cost and size as compared to the conventional systems.
2) Since the first and second rotation members 106, 110 can operate independently of each other, the needle and ultrasound probe 102 can be rotated separately. Hence, the ultrasound probe 102 can be rotated to check different ultrasound planes without the position of the needle being shifted. This can avoid unnecessary injury on the subject that is caused by the movement of the needle when the ultrasound probe 102 is rotated.

3) The movement of the Ya and Yb linear assemblies 112, 114 allows angulation of the needle to access the anterior of the prostate. The use of two linear assemblies 112, 114 can also reduce or minimise costs (compared to a curved mechanism for angulation).
4) As the ultrasound probe 102 is rotated around its longitudinal axis, the envelope of the ultrasound probe 102 within the rectum remains constant, hence minimizing prostate deformation.
5) The rotation of the ultrasound probe 102 in a stable and repeatable manner enables the reconstruction of the transverse view from the sagittal view even for commercial biplane probes. This enables visualization of the needle depth and position simultaneously.

[79] Fig. 5 shows an enlarged perspective view of a rotation member 500, in accordance with embodiments of the present disclosure. The rotation member 500 can be in the form of a curved structure which includes a curved rail 502 and at least one carriage 504. The curved rail 502 is typically centered on the longitudinal axis of the ultrasound probe 102. Further, the carriage 504 is configured to travel radially on both sides of the curved rail 502. The carriage 504 contains bearings 506 exerting a normal reaction force in the radial as well as axial directions such that the carriage 504 is slidable along an inner surface of the curved rail 502. The rotation member 500 can be connected to an adjacent rotation member 500 via a connector bar which ensures that the carriages 504 of the connected rotation members 500 are moving in tandem along the inner surface of the curved rails 502. Typically, the carriage 504 and curved rail 502 are configured such that they do not extend beyond 15 mm above the longitudinal axis of the ultrasound probe 102 such that there is no interference with the placement of the needle. The span of the carriage does not extend beyond 40º. Hence, when it rotates to either side (up to at least 70º), it does not protrude beyond the surface of the curved rail, which spans 180º.

[80] As shown in Figs. 6A to 6C, in another exemplary configuration of the rotation member 600, the curved rail 602 has an edge profile 601, 603 that is V-shaped, on both the front and back. The rotation member 600 can include rollers 604 which roll on both the upper and lower surfaces of the edge profile 601, 603, on both the front and back. A first set of rollers abuts the upper edge of the edge profile 601, 603, and a second set of rollers abuts the lower edge of the edge profile 601, 603. The rollers 604 are constrained within a carriage 606 but are able to rotate about their axis. In other words, the rollers 604 engage the edge profile 601, 603 such that the carriage

moves along an arc defined by the V-shaped edge profile 601, 603. For example, the rollers 604 can be constrained by having a cylindrical stem portion which sits within a bearing, which in turn sits within a cylindrical hole in the carriage 606. There can be multiple (e.g., 3 – 5) rollers 604 on each side of the curved rail 602 to provide stability for the carriage. Axial constraint of the rollers 604 can be achieved by a combination of shoulders and screws 608. The axis of the roller 604 and the cylindrical hole in which it rotates is such that the roller surface is coincident with the edge profile. A small angle exists between the axis of rotation and the roller surface. This accounts for the variation in radius of the edge profile, and the angle of the edge profile itself. The normal force exerted by the rollers 604 against the V-shaped edge profile 601, 603 enables constraint of the carriage 606 in the axial and radial directions. The carriage 606 is still able to rotate about the axis of the rotation member 600 purely via rotation of the rollers 604. The rolling (instead of sliding) action can minimize the friction in the rotation member 600, allowing play (i.e. loose movement) to be minimized, hence facilitating a high degree of accuracy in movement. There is no protrusion of the rollers 604 above the curved rail 602. This enables the surface of the curved rail 602 to be covered easily, preventing the ingress of fluid.

[81] Further, as shown in Figs. 7A and 7B, a rotation member 700 can be driven by a belt drive mechanism 701. The belt 702 can be a friction belt or toothed timing belt. The belt 702 is rigidly connected to a connector bar or the carriage 706 of the rotation member 700. For example, the belt 702 can be clamped to the carriage 706. The belt 702 then conforms to the underside (i.e., bottom surface) of the curved rail 703. At either end, there are idler pulleys 704 which the belt goes around, reversing its direction. The belt 702 is coupled to a drive pulley 705, which is in turn driven by a DC motor. There may be additional idler pulleys along the path of the belt 702 to take up tension and assist with shaping the path of the belt 702. When the motor shaft turns, the belt 702 shifts, pulling the carriage 706 along the curved rail 703. The belt 702 slides along the underside of the curved rail 703, and this can be facilitated by a low-friction layer, such as a lubricant or a low-friction foil on the back of the belt 702. The advantage of such a belt drive mechanism 701 is that no part of the belt drive mechanism 701 protrudes above the curved rail 703 even at the extremes of motion. This contrasts with, for example, a conventional direct gear-driven mechanism where the driving gear is at the centre of the curved rail and the underside of the carriage is a complementary partial gear. Assuming bi-directional motion, the end-position of the partial gear must be at least double the range of

motion. In other words, for a desired range of travel of 70º, the conventional partial gear will reach a point at least 140º from the midline, protruding above the curved rail. The rotation member 700 can include a limit sensor 708 at one end of the range of motion for each rotation member 700. This can be, for example, a photoelectric sensor activated by obstruction of the light path mounted at a fixed and known position of the rotation member 700. The activation of the photoelectric sensor can also be detected by a controller of a computer and sent via the controller to the computer. In the software, this provides a reference for a zero position. Hence, the absolute position of the moving part of the rotation member 700 is known. It should be understood that other than the photoelectric sensor, the limit sensor 708 can encompass other types of sensors that can achieve the intended function of the limit sensor 708.

[82] Additionally, having a curved rail 502, 602, 703 that is not a full circle (i.e., truncated arc) is helpful as it creates an open space above the ultrasound probe 102. This allows for visual access to the perineum as well as space for the biopsy needle, especially when targeting the anterior of the prostate. Furthermore, many commercial ultrasound probes have an offset between the narrower transducer section and the larger handle section. Hence, if the curved rail 502, 602, 703 is a full circle about the handle of the ultrasound probe, there may be a large circle formed which is likely to obstruct the view of the perineum as well as the space for the biopsy needle. Further, the rotation member (i.e., with a full circle curved rail) that is on the narrow transducer section of the ultrasound probe would not have a very large radius, but would compromise the depth of insertion of the ultrasound probe into the patient's rectum.

[83] It should be understood that the configuration of the rotation member 500, 600, 700 is not limited to the two configurations described above but may also encompass other configurations without departing from the scope of the present disclosure.

[84] The Ya and Yb assemblies 112, 114, as well as the rotation members 500, 600, 700, are both driven by DC motors. The DC motors are encoded, and this encoder count is sent via a controller to a computer. The number of rotations of the motor shaft correlates to a specific change in relative position of the moving parts due to the drive mechanism. There is a limit sensor at one end of the range of motion for each assembly 101, 103. This can be, for example, a photoelectric sensor

activated by obstruction of the light path mounted at a fixed and known position. The activation of the sensor can also be detected by the controller and sent via the controller to the computer. In the software, this provides a reference for a zero position. Hence, the absolute position of the moving part of the assemblies 101, 103 is known.

[85] In addition, the needle guidance system 100 can include additional mechanisms to allow the needle to move out of its sagittal plane (also referred to hereafter as the "two-entry points configuration"). As such, needle trajectories can be directed to only two entry points on the perineum. The position of these two entry points may be approximately 30 to 40 mm above the center of the ultrasound probe, and between 8 to 15 mm lateral on either side of the probe. There are two main contributing functions that limit the number of needle entry points on the perineum to only two points. As shown in Fig. 8A, the first function is to direct the needle trajectories 802 to a single entry point 804, 806. The second function is to define the two such entry points on the left 804 and right 806 of the longitudinal axis of the ultrasound probe.

[86] Fig. 8B shows an enlarged perspective view of the needle guidance system in a first two-entry point configuration. In this configuration, the needle guide 108 guides the back of the needle 810 and is pivotally mounted on a first pivot pin 812. The first pivot pin 812 is coupled to the arm 116 which is coupled to the Ya and Yb linear assemblies 112, 114. Further, an entry plate 814 is pivotally attached to the second rotation member 110 and is configured to pivot relative to a longitudinal axis of the second rotation member 110. The entry plate 814 is also pivotally attached to an entry guide linkage 816 via a second pivot pin 818. The front end of the needle guide 108 passes through the entry guide linkage 816, which rotates about a pivot on the entry plate 814. As such, the needle 810 can be rotated out of its sagittal plane. To direct needle trajectories towards a single entry point (i.e., the first function), the entry point is defined by two orthogonal directions. As illustrated in Figs. 8C and 8D, the first direction (denoted by "B" in Fig. 8C) is generally lateral, corresponding to the normal of a plane rotating about the axis of the second pivot pin 818 (see Fig. 8C). The second direction (denoted by "C" in Fig. 8D) is the radial height of the entry point within the plane of the first direction B (see Fig. 8D).

[87] To facilitate movement in the first direction B (described above), with reference to Fig. 9A, the axis of the second pivot pin 818 points to the virtual entry

point, and this axis is coincident with the plane formed by the slot in the entry guide linkage 816. The needle guide 108 can only slide within the slot defined by the entry guide linkage 816, i.e. within a plane that intersects the entry point. As the second rotation member 110 and Ya & Yb linear assemblies 112, 114 move, the guide holder 107 moves along with them. The guide holder 107 is free to rotate out of its sagittal plane about the axis of the first pivot pin 812. However, the degree to which the needle guide 108 follows and rotates is constrained by a slot of the entry guide linkage 816 at the front. To facilitate movement in the second direction C (described above), the needle guide 108 slides in the slot of the entry guide linkage 816, within the plane due to the movement of the needle guide 108 caused by Ya & Yb linear assemblies 112, 114. (e.g., tilting). The movement of the Ya and Yb linear assemblies is calculated such that the trajectory of the needle still passes through the entry point. Specifically, the shaft 402a on the Ya assembly and shaft 402b on the Yb assembly should be correctly positioned to tilt the arm 116 at the desired angle and move the needle guide holder 107 to the correct height. The projection of the entry point and needle axis on the sagittal plane would then be in line. Transforming this to the plane of the slot on the entry guide linkage 816, the actual needle axis and entry point would be in line as well. Considering the two directions in combination, this forms a spherical mechanism, where the needle 810 can be considered to always be normal to the surface of a sphere centered on the entry point.

[88] Prior to use, the user may install the needle guide 108 on the robotic arm. The back of the needle guide 108 fits within the guide holder 107, and the front of the needle guide 108 fits within the slot on the entry guide linkage 816. The needle guide 108 is then secured to the guide holder 107. In this way, the needle guide 108 forms a connection between the guide holder 107 and the entry guide linkage 816, defining a trajectory for the needle 810.

[89] Figs. 9B to 9E illustrate close up views of the needle 810 shifted to a fixed position. To define the two points on the left and right of the ultrasound probe 102 (i.e., the second function), the position of the two entry points on the perineum is first determined. The entry plate 814 then rotates to two fixed positions corresponding to the determined positions, on the left (as shown in Fig. 9D) and right (as shown in Fig. 9E) of the longitudinal axis of the ultrasound probe 102. The rotation of the entry plate 814 to the left and right positions can be actuated by a lever rotated by the user. The pivot point of the entry guide linkage 816 is a fixed normal distance away

from each of the two virtual entry points on the perineum. Alternatively, the position of the entry plate 814 can be fixed while two entry guide linkages 816 are pivotally attached to the entry plate 814 which are both a fixed normal distance away from the respective entry points.

[90] In a second two-entry point configuration (not shown in the figures), the needle guidance system 100 can include a virtual "ball point" and a conical plate in front. The back end of the needle 810 passes through the needle guide 108, which is affixed to the Yb assembly 114 via a ball joint. The movement of the Yb assembly 114 guides the back end of the needle 810. The front end of the needle 810 rests within a fixed conical plate. With one point at the back and one point at the front, the trajectory of the needle can be determined.

[91] In the two-entry point configurations described above, the two entry points are defined at a front plane of the needle guidance system 100. For example, the user can shift the front portion of the needle guidance system 100 such that the front plane is in contact with the perineum. A physical reference may be used to determine this plane, e.g., the tip of the needle guide 108. The front portion of the needle guidance system 100 (e.g., the needle rotation assembly 103) may slide forward relative to the back portion of the needle guidance system 100 (e.g., the probe rotation assembly 101), for example, on sliding rails (not shown in the Figures). The relative position of the two portions can be determined by a linear sensor system. For example, a target can be connected to the front portion and a linear inductive sensor can be connected to the back portion. As the front portion moves relative to the back portion, the change in the sensor reading translates to the relative position. This reading is sent via the controller to the computer, which is determined by the software. The front portion of the needle guidance system 100 may be locked in position relative to the back portion of the needle guidance system 100 once the correct position has been determined. This locking action may be actuated by a lever rotated by the user. Optionally, the same lever may be used to actuate both the rotation of the entry plate 814 to the two fixed positions as well as for the locking of the front portion of the robot. This helps to minimize the steps for the user. Further, it should be understood that the sliding rails are described by using the two embodiments described above as examples and can be implemented in all embodiments of the present invention.

[92] Fig. 10 shows a flowchart depicting a workflow of how the user sets up the mechanism for two entry points as described above. At step 1000, the user shifts the entry plate 814 to either the left or right side of the ultrasound probe 102. Shifting of the entry plate 814 can be done manually by hand or by sending an instruction to move the entry plate 814 via a computing device communicatively coupled to the needle guidance system 100. At step 1002, the user slots the needle guide 108 through the entry guide linkage 816. At step 1004, the user slots the needle guide 108 into the guide holder 107. At step 1006, the user secures the needle guide 108 to the guide holder 107. At step 1008, the user shifts the front portion of the needle guidance system 100 such that the tip of the needle guide 108 touches the perineum of the subject. At step 1010, the user locks the front portion of the needle guidance system 100 in place. The needle may then be inserted for positions on one side (i.e. left or right) of the prostate at step 1012. At steps 1014 and 1016, the front portion of the needle guidance system 100 can be unlocked and moved backwards so that the needle guide 108 does not get dragged against the subject's skin when moved laterally. At step 1018, the user shifts the entry plate 814 to the other side of the ultrasound probe 102 (left side if the user shifted the entry plate 814 to the right side at step 1000 or right side if the user shifted the entry plate 814 to the left side at step 1000). At steps 1020 and 1022, the front portion of the needle guidance system 100 can be moved forward and locked. At step 1024, the needle may then be inserted for positions on the other side of the prostate.

[93] The two-entry point configurations of the needle guidance system 100 enable the trajectory of the needle 810 to be guided, and ensure that the needle 810 points towards either of the two defined entry points at all times. Hence, this can limit the number of positions of needle entry on the perineum to just two. This is despite the freedom of positioning the needle 810 due to angulation, which enables the needle 810 to reach different areas of the prostate. Since there are only two entry points where the needle 810 punctures the perineum, the probability that a puncture point falls outside the locally anesthetized area is reduced. As such, the pain that the patient will experience during the procedure may be reduced. Further, there is greater visual access to the patient's perineum since the needle 810 is located away from the perineum. This allows clinicians to assess if there are more than two puncture points due to patient movement and monitor the bleeding from the patient. Additionally, by having the two entry points spaced apart laterally on either side of the center plane, it is possible to avoid hitting the urethra during needle insertion.

[94] With reference to Fig. 11, an example workflow of the needle guide system 100 comprises the following steps. In a first step 1100, the user defines all target positions. In a next step 1102, the user sends a signal to the needle guidance system 100 to move to a next position. In response to receiving the signal from the user, the needle guidance system 100 determines the target point based on the signal. In a third step 1104, the needle guidance system 100 rotates the ultrasound probe 102 such that the target point lies on a sagittal plane of the ultrasound probe 102. The rotation of the ultrasound probe 102 is performed by the first rotation member 106. In a fourth step 1106, the needle guide 108 is rotated such that the needle 810 lies on the sagittal plane of the ultrasound probe 102. The rotation of the needle 810 is performed by the second rotation member 110. In a fifth step 1108, the needle 810 is tilted (i.e., moved radially or angulated) such that the needle 810 points towards the target point. The tilting of the needle 810 is performed by the tilt mechanism 111. In a fifth step 1110, the needle 810 is inserted through the needle guide 108 by the user.

[95] Fig. 12 shows an example workflow of the needle guidance system 100 in the first two-entry point configuration. After steps 1100, 1102 and 1104, in the fourth step 1200, the needle guide 108 is angulated so that the needle 810 would land at the target position, passing through the entry point. In the fifth step 1202, the needle guide 108 is constrained by the entry guide linkage 816 so that the needle 810 passes through the defined entry point. In a sixth step 1204, the needle 810 is inserted through the needle guide 108. The status of the entry points can be monitored by sensing devices such as photo interrupter and feedback to the computing device through the motion and controller unit.

[96] Fig. 13 shows a block diagram of an exemplary computer system 1300 used in conjunction with the needle guidance system 100. The computer system 1300 can include a computing device 1302 with touch screen for the user to control the needle guidance system 100, but the computing device 1302 is not limiting and may include other types of devices such as tablet or other smart devices. The computing device system 1302 contains software and is communicatively coupled to a controller 1304, which processes command(s) from the computing device 1302 and translates the command to control the motion of motors 1306, 1308 of the needle guidance system 100, for example, via motor controllers 1310, 1312. The controller 1304 can be powered by a 12V AC/DC adaptor 1314 but can encompass other means to power the controller 1304 depending on the user's requirement. The controller 1304 also acquires a live feed

of images from a ultrasound system 1316, which are provided to the computing device 1302. The image acquisition can be performed by the video output being acquired from the ultrasound system 1316 through a video output cable (e.g., HDMI cable, etc.). The video output signal can then be captured by means of a video frame grabber device 1318. The software on the computing device 1302 also has a user interface (not shown in Fig. 13), on which the ultrasound images are displayed. Further, an image space is registered to a physical space via an image calibration process. Hence, when the user selects a target point on the computing device 1302 (e.g., via the touch screen), the position in the physical space corresponding to the selected target point is known. The software also detects the position of a sensor (not shown in Fig. 13), which provides the position of the entry point relative to the ultrasound probe 102 along its axial direction. Hence, it is known where the entry point depth is in the physical space. The computing device 1302, via the controller 1304, then moves the mechanism(s) of the needle guidance system 100 such that the trajectory of the needle 810 would pass through the entry point and target point. The radial height of the entry point is controlled by the motor position for the Ya and Yb 112, 114 axes, while its lateral position is maintained by the entry guide linkage 816. It will be appreciated that while components of the system 1300 are shown as separate blocks in Fig. 13, two or more of such components can be integrated into a single device.

[97] Additionally, the ultrasound probe 102 can have a sagittal transducer and transverse transducer. The needle guidance system 100 acquires ultrasound images primarily from the sagittal transducer. The ultrasound probe 102 can be rotated to different angles for different sagittal views. The rotation (not translation) of the ultrasound probe 102 helps to minimize deformation of the prostate and maintain good ultrasound coupling. However, there are instances where the transverse view is useful. These include the contouring of the prostate, knowing where the planned needle positions are, and checking the actual position of the needle 810 or even the prostate.

[98] To facilitate the above, the transverse view can be reconstructed from a stack of sagittal images. Fig. 14 shows an exemplary workflow of a method to reconstruct an ultrasound image. The method includes the following steps: step 1400: rotating an ultrasound probe through a plurality of predetermined rotational positions, step 1402: at each of the plurality of predetermined capturing a respective sagittal ultrasound image of a target by the ultrasound probe, step 1404: based on a selected depth of a transverse plane, identifying intersection points between the plurality of captured sagittal ultrasound images and the transverse plane, each intersection point having a respective pixel value,

step 1406: reconstructing the ultrasound image at the transverse plane based on the identified intersection points, and step 1408: interpolating points on the transverse plane between adjacent ultrasound images.

[99] The reconstruction of the transverse view is based on the method as illustrated in Fig. 14 and is described in further details with reference to Fig. 15. At step 1500, the computing device 1302 sends an instruction via the controller 1304 to the needle guidance system 100 to rotate the ultrasound probe 102. At step 1502, needle guidance system 100 rotates the ultrasound probe 102 by a fixed interval upon receiving the instruction. The rotation may be performed in steps at regular intervals (ranging from 0.5º to 2º), or continuous rotation. At each position (or interval), the sagittal ultrasound image is captured in step 1504. The exact position of the ultrasound probe is known, for example by the encoder value of the motor which drives the mechanism(s) of the needle guidance system 100 (e.g., the probe rotation member 106) to rotate the ultrasound probe. This results in a set of images which form a fan shape (see Fig. 18). Based on this image set, and the known position at which each image is taken, the transverse view can be reconstructed by performing the following steps: step 1506 – software knows the rotational position of the needle guidance system 100 corresponding to that at which the image is captured; step 1508 – steps 1500 to 1506 are repeated until ultrasound images are captured for all intervals in the range; step 1510 – depth of the transverse plane is selected; and step 1512 – pixel lines are determined for each intersection of the sagittal images with the transverse plane. At step 1514, interpolation can be performed between the captured image slices to fill the gaps between the captured slices and provide a more realistic transverse view. As the images are in a fan shape, the distance between the slices is smaller closer to the centre of rotation. The algorithm for reconstruction takes this into account and is described as follows: for every pixel in the transverse image stack, the corresponding point "sp" is calculated in the sagittal image stack space. Since this point will not lie on the exact pixel value in the sagittal image, neighboring pixels in the sagittal images are identified and a series of bilinear and linear interpolations are used on these pixels to calculate the value of the pixel in the transverse image.

[100] As shown in Fig. 16, the workflow of the algorithm taking into account that the distance between slices is smaller closer to the centre of rotation is as follows:

1. Find the 2 neighboring slices of sp.
2. Find the corresponding points on both slices when sp is rotated to the corresponding slices. Let the points be referred to as spLeft and spRight.

3. Calculate the value of the pixel on the left slice using bilinear interpolation for the point spLeft.
4. Calculate the value of the pixel on the right slice using bilinear interpolation for the point spRight.
5. Calculate the value of the pixel in the transverse image stack by using linear interpolation of the values calculated in step 3 and 4.

[101] Fig. 17 shows an exemplary workflow of how the reconstructed sagittal view is used during, for example, a prostate procedure. At the start of the procedure, the ultrasound probe is rotated from one end of the range of rotation to the other. A series of image planes forming a fan-shape is acquired as described above and shown in Fig. 18. The transverse view will be reconstructed from this entire range of rotation. This will allow the prostate to be visible in the transverse view. Reconstruction of views in other planes may be performed, such as the sagittal view and coronal view. The reconstructed transverse (normal to the direction denoted as "D"), sagittal (normal to the direction denoted as "E") and coronal views (normal to the direction denoted as "F") are parallel to the planes shown in Fig. 18. This aids in visualization of the entire prostate. Contours of the prostate (shown in Fig. 19B) can be drawn on the reconstructed transverse view. Multiple contours on multiple transverse view planes allows for the generation of a 3D model of the prostate. In the reconstructed transverse view, the image space is fully defined. This means that the image size and position correspond directly to physical size and position. This can be attributed to the image calibration (for the sagittal image) and mechanical encoding (for the rotational position of the ultrasound probe). Hence, it is possible to plan needle positions on the transverse view, which correspond to positions in the physical space. To do so, the physician can choose the transverse plane of interest, corresponding to the desired depth of insertion. Thereafter, he can pick points on the transverse plane on the software user interface where he wants the biopsy cores to be taken by clicking on the relevant point. During positioning of needles, the needle guidance system 100 guides the needle trajectory to each of the planned positions (shown in Fig. 19C).

[102] Figs. 19A to 19C show exemplary displays of the reconstructed transverse plane 1902, sagittal plane 1904 and coronal plane 1906 (Figs. 19A and 19B). As shown in Fig. 19B, there can be lines 1908 indicating the contour of the prostate. On the software user interface (e.g., the touchscreen of the computing device 1302), the live sagittal view and reconstructed transverse view can be simultaneously displayed (Fig. 19C). As shown in Fig. 19C, on the sagittal view, there can be a line 1910 indicating the plane of the current

transverse view shown. Usually, the transverse plane view is the plane at which the planned position 1912 can be seen. However, it is also possible to have the planned position seen on other planes, e.g., sagittal plane, etc. Referring to Fig. 19C again, on the transverse view, there can be a line 1914 indicating the current plane of the current transverse view shown.

[103] Fig. 20A shows a workflow diagram for positioning of needles with the reconstructed transverse plane and needle deflection adjustment. During the positioning of needles, the needle trajectory may not lie fully within the sagittal plane. The user may also wish to see the lateral position of the needle 810. In these situations, the user may choose to sweep a sector of the prostate with the sagittal view. The user can choose the angle for which to perform this sweep. For example, the angle can be pre-defined, or the user can continue performing the sweep until the needle is visible in the ultrasound image. Thereafter, the user can send a signal to rotate the ultrasound probe 102 for the desired angle of rotation for the ultrasound probe 102, via the user interface (e.g., touchscreen of the computing device 1302). This will allow for the reconstruction of the transverse view for that sector, in which the needle can be seen. As the reconstructed transverse plane lies within the sagittal plane, the needle 810 can be visible within both the sagittal plane and the transverse plane at the same time. This overcomes the issue associated with commercial biplane probes, where there is an offset between the sagittal and transverse transducer. As shown in Fig. 20B, the reconstructed transverse plane view can include lines 2002, 2004 showing the extent of the sweep. In the example shown on Fig. 20B, the degree of the sweep is +/- 15 degrees.

[104] Advantageously, after the reconstruction of the transverse plane, adjustment for the deflection of the needle 810 can be performed. This is useful for situations where the needle deviates from the planned position. The user can click on the actual position of the needle 810 in the reconstructed transverse view. The position of the needle 810 within the reconstructed transverse view is known because the image space is fully defined, and this can be correlated to the physical space. The needle guidance system 100 can then move accordingly to compensate for this deflection. As such, the next time the user inserts the needle 810, guided by the needle guidance system 100, it should be closer to the target position.

[105] Additionally, even after positioning the needles, the user may choose to sweep the entire prostate such that the reconstructed transverse view is updated. This allows the user to see the actual position 2006 of the prostate, as shown in Fig. 20C. If the

actual position 2006 of the prostate no longer matches the original model 2008, the user can shift (translate or rotate) the model of the prostate 2008 to align them again. This can be performed in both the sagittal and the reconstructed transverse views, allowing for adjustment in all directions. Advantages can be achieved by using the reconstruction of the transverse plane described above with the needle guidance system 100, For example, the image space can be coupled to the physical space, even with the reconstructed transverse view. Further, the accurate rotation of the ultrasound probe 102 performed by the needle guidance system 100 allows for accurate reconstruction of the transverse view, which then allows for accurate planning of needle positions.

[106] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A needle guidance system, comprising:

a first assembly, comprising:

at least one probe holder configured to receive a probe; and

a first rotation member coupled to the probe holder and configured to rotate the probe holder such that the probe rotates about a longitudinal axis of the probe; and

a second assembly comprising:

at least one needle guide configured to receive a needle;

a guide holder attached to the needle guide and configured to secure the needle guide; and

a second rotation member coaxial with the first rotation member, wherein the second rotation member is coupled to the guide holder and configured to rotate the guide holder such that the needle rotates about the longitudinal axis of the probe.

2. The needle guidance system of claim 1, wherein the first and second rotation members are configured to operate independently of each other.

3. The needle guidance system of claim 1 or 2, wherein the second assembly is movable along the longitudinal axis of the probe relative to the first assembly.

4. The needle guidance system of any one of claims 1 to 3, further comprising:

a tilt mechanism coupled to the guide holder and the second rotation member, wherein the tilt mechanism is configured to tilt the needle relative to the longitudinal axis of the probe.

5. The needle guidance system of claim 4, wherein the tilt mechanism comprises at least one linear assembly coupled to the guide holder, the linear assembly being configured to move a position of the guide holder in a direction relative to the longitudinal axis of the probe.

6. The needle guidance system of any one of claims 1 to 5, wherein each rotation member comprises:

a curved rail;

a carriage slidably mounted on the curved rail; and

a plurality of bearings disposed between the curved rail and the carriage such that the carriage is slidable along an inner surface of the curved rail.

7. The needle guidance system of any one of claims 1 to 5, wherein each rotation member comprises:

a curved rail having V-shaped edges along longitudinal axes of the curved rail; and

a carriage movably mounted to the curved rail, the carriage having a plurality of rollers configured to engage with the V-shaped edges;

wherein the plurality of rollers are rotatable to move the carriage along an arc defined by the V-shaped edges of the curved rail.

8. The needle guidance system of claim 7, further comprising a belt drive mechanism configured to drive each rotation member, the belt drive mechanism comprising:

a belt coupled to the carriage, wherein the belt conforms to a bottom surface of the curved rail;

at least two idler pulleys, wherein each of the idler pulleys is disposed on an end of the curved rail, and wherein the belt runs along on the idler pulleys; and

at least one drive pulley coupled to the belt, wherein the drive pulley is driven by a motor.

9. The needle guidance system of any one of claims 6 to 8, wherein the curved rail comprises a truncated arc.

10. The needle guidance system of claim 4 or 5, wherein the second assembly further comprises:

an arm coupled to the tilt mechanism and the guide holder, wherein the tilt mechanism comprises first and second linear assemblies, and wherein a first position of the arm is rotatably coupled to the first linear assembly, and wherein a second position of the arm is rotatably and slidably coupled to the second linear assembly.

11. The needle guidance system of claim 10, wherein the second assembly is configured to align the needle guide with a sagittal plane of the probe and the tilt mechanism is configured to change a direction of the needle guide on the sagittal plane.

12. The needle guidance system of claim 10, further comprising:

a ball joint fixedly coupled to the tilt mechanism via the arm, wherein the needle guide is moveably attached to the ball joint and is further configured to receive a first end of the needle; and

a conical plate configured to receive a second end of the needle.

13. The needle guidance system of claim 10, wherein the guide holder comprises:

a first pivot pin, wherein the needle guide is pivotally mounted on the first pivot pin, and wherein a first end of the needle pivots relative to an axis of the first pivot pin;

wherein the second assembly further comprises:

an entry plate having a first end pivotally attached to the second rotation member and configured to pivot relative to a longitudinal axis of the second rotation member; and

an entry guide linkage pivotally attached to a second end of the plate by a second pivot pin and configured to pivot relative to the second pin, wherein the entry guide linkage defines a passage configured to receive the needle guide and limit a pivot angle of the mounted needle guide.

14. A needle guidance method comprising:

receiving, by the needle guidance system of claim 4, a signal defining a plurality of target points on a target;

in response to receiving the signal by the needle guidance system:

selecting, by the needle guidance system, a target point based on the signal from the plurality of target points;

rotating the probe, by the first rotation member, such that the selected target point lies on a sagittal plane of the probe;

rotating the guide holder, by the second rotation member, such that the needle lies on the sagittal plane of the probe; and

tilting the guide holder, by the tilt mechanism, such that the needle points towards the target point.

15. A needle guidance method comprising:

receiving, by the needle guidance system of claim 13, a signal defining a plurality of target points on a target;

in response to receiving the signal by the needle guidance system:

i) selecting a target point based on the signal from the plurality of target points;

ii) rotating the ultrasound probe, by the first rotation member, such that the selected target point lies on a sagittal plane of the ultrasound probe;

iii) moving the entry plate to define a first entry point; and

iv) tilting the guide holder, by the tilt mechanism, such that the needle points towards the selected target point, wherein the needle is constrained by the entry guide linkage such that the needle passes through the first entry point.

16. The method of claim 15, further comprising:

repeating steps i) to iii) to define a second entry point; and

repeating step iv) such that the needle points towards the selected target point and passes through the second entry point.

17. The method of any one of claims 14 to 16, further comprising the following steps:

a) rotating, by the needle guidance system, the ultrasound probe through a plurality of predetermined rotational positions;

b) at each of the plurality of predetermined rotational positions, capturing a respective sagittal ultrasound image of a target by the ultrasound probe;

c) based on a selected depth of a transverse plane, identifying intersection points between the plurality of captured sagittal ultrasound images and the transverse plane, each intersection point having a respective pixel value; and

d) reconstructing the ultrasound image at the transverse plane based on the identified intersection points.

18. The method of claim 17, wherein reconstructing the ultrasound image at the transverse plane based on the identified intersection points comprises interpolating points on the transverse plane between adjacent ultrasound images.

19. The method of claim 18, wherein interpolating points on the transverse plane between adjacent ultrasound images comprises:

for each point on the transverse plane between adjacent ultrasound images, identifying a first intersection point on a first sagittal ultrasound image to the left of said point and a second intersection point on a second sagittal ultrasound image to the right of said point;

calculating a first pixel value of the first intersection point based on a bilinear interpolation;

calculating a second pixel value of the second intersection point based on a bilinear interpolation; and

calculating the pixel value of said point based on a linear interpolation of the first and second pixel values.

20. The method of any of claims 17 to 19, further comprising:

e) determining a contour of the target at the selected depth;

f) repeating steps c), d) and e) over a plurality of depths, the plurality of depth covering the target; and

g) generating a three-dimensional representation of the target based on the plurality of contours at the corresponding plurality of depths.

21. The method of claims 17 to 20, further comprising:

determining, based on the reconstructed transverse ultrasound image, if a needle trajectory falls outside of the sagittal plane;

if the needle trajectory falls outside of the sagittal plane, determining if the needle deviates from the target point; and

if it is determined that the needle deviates from the target point, adjusting the needle guide such that the needle points towards the target point.

22. A method of constructing an ultrasound image, comprising:

a) rotating an ultrasound probe through a plurality of predetermined rotational positions;

b) at each of the plurality of predetermined rotational positions, capturing a respective sagittal ultrasound image of a target by the ultrasound probe;

c) based on a selected depth of a transverse plane, identifying intersection points between the plurality of captured sagittal ultrasound images and the transverse plane, each intersection point having a respective pixel value; and

d) reconstructing the ultrasound image at the transverse plane based on the identified intersection points.

23. The method of claim 22, wherein reconstructing the ultrasound image at the transverse plane based on the identified intersection points comprises interpolating points on the transverse plane between adjacent ultrasound images.

24. The method of claim 23, wherein interpolating points on the transverse plane between adjacent ultrasound images comprises:

for each point on the transverse plane between adjacent ultrasound images, identifying a first intersection point on a first sagittal ultrasound image to the left of said point and a second intersection point on a second sagittal ultrasound image to the right of said point;

calculating a first pixel value of the first intersection point based on a bilinear interpolation;

calculating a second pixel value of the second intersection point based on a bilinear interpolation; and

calculating the pixel value of said point based on a linear interpolation of the first and second pixel values.

25. The method of any one of claims 22 to 24, further comprising simultaneously displaying the reconstructed transverse ultrasound image and a selected sagittal ultrasound image of the target.

26. The method of any one of claims 22 to 25, further comprising:

e) determining a contour of the target at the selected depth;

f) repeating steps c), d) and e) over a plurality of depths, the plurality of depth covering the target; and

g) generating a three-dimensional representation of the target based on the plurality of contours at the corresponding plurality of depths.

27. The method of any of one of claims 22 to 26, further comprising repeating steps a)-d) after a predetermined period and updating the transverse ultrasound image.