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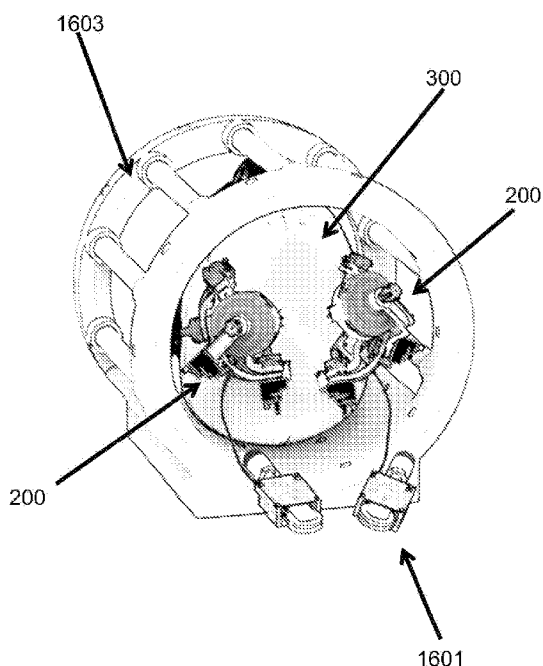


Fig. 16

(57) Abstract: A positioner comprising a nested pair of robots suitable for MRI-guided live-imaging, head-mounted bilateral stereotactic neurosurgery. Specifically, the positioner is suitable for locating a needle holder for tubular/needle-like instrument during neurosurgical operation. While maintaining a sufficient workspace ($\pm 35^\circ$), the positioner remains lightweight (203 g) and compact ($\varnothing 81 \text{ mm} \times 97 \text{ mm}$ height), enabling skull-mounted usage within most standard imaging head coils. The five-bar linkage architecture allows the reservation of exposure space around the incision port (burr hole on the skull) for operation/observation. The robot system operates in two stages: i) manual coarse adjustment within a large workspace performed interactively by the surgeon, followed by ii) automated fine adjustment within a localized motion range performed by soft fluid-driven actuators.

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A STEREOTACTIC POSITIONER FOR A SURGICAL NEEDLE HOLDER HAVING NESTED ROBOTS

Field of Invention

The present invention relates to the field of robotic positioners for a tubular surgical tool holder in stereotactic surgery that can be mounted onto the body of a patient.

Background of the Invention

A typical robotic positioner for control of a cannula device or biopsy needle in stereotactic surgery relies on a large stereotactic frame that is rigidly mounted to the skull to allow orientation of the instrument w.r.t. a 3D coordinate system. Recent advances in MRI hardware, imaging protocols, and coils have led to its emergence as an effective choice for real-time image-guided interventions. However, it is difficult to automate devices in an MR environment as typical robotics tends to be made of metallic or magnetic parts that cause interference in MR images. Also, most robotic are designed without the concern of limited space inside MRI machines where the patient would be.

Some positioners such as those proposed under the brand Clearpoint™ requires the surgeon to manually adjust the positioner using long distance manual handles. The surgeon has to place the needle positioner in the target position by trying again and again, with the help of repetitive MR-imaging, until he got it right.

One device has been proposed in WO2019144904A1 by the same inventor, wherein two slender deep brain stimulation needles of 300 mm and a diameter of 1.3 mm are individually guided by twin stereotactic frames. Each of the frames comprises an upper actuator and lower actuator that are mounted to common stage, and the stage is mounted to the skull of a patient by screws. The twin frames cannot be mounted separately to the skull in different angles, and the movement of the actuators over each other go beyond the original footprint of the device, making the space required for the full range of movement of the frames larger than it may seem.

It is desirable to propose surgical positioners for stereotactic positioning of rod-like end effectors that are robust in structure and take up relatively little space, leaving room to accommodate a twin device in applications such as deep brain stimulation surgery.

Summary of the invention

In the first aspect, the invention proposes a positioner for a surgical needle holder, comprising a second robot installed into a first robot; the second robot useable to hold the surgical needle holder and move the surgical needle holder across a workspace in such a way that the surgical needle holder remains in stereotactic alignment to a centre of motion; the first robot useable to hold and move the second robot across a workspace in such a way that the surgical needle holder remains in stereotactic alignment to the centre of motion.

Optionally, first robot has a spherical 5-bar-serial-structure. Other first robots may be used, even those in the prior art, such that the second robot offers an upgrade to these prior art robots.

Preferably, therefore, the second robot is replaceable.

Typically, the second robot is capable of adjusting the position of the surgical needle holder about the centre of motion independently of the mechanism of the spherical 5-bar-serial-structure.

An embodiment includes a pair of nested robots for holding and moving a surgical needle holder. The robots may be able to move the surgical needle holder in different resolutions of movement. For example, the spherical 5-bar-serial-structure is responsive to manual control to move the needle holder, while the second robot may be software-automated for adjusting the position of the surgical needle holder more finely.

Preferably, the positioner further comprises an emitter of light in a pre-determined colour indicating that the position of the surgical needle holder is within a margin of error to a pre-determined target position; wherein the range of a space defined by the margin of error is the same or smaller than the workspace in which the second robot is capable of moving the surgical needle holder.

This feature relieves the need of the surgeon from having to rely on multiple MR-imaging to see if he has moved the needle holder into a position with an error margin to the desired needle holder position.

Preferably, the positioner further comprises a curved base-bar; the arc angle of the curve of the base-bar being such that the base-bar is capable for contacting a location on the head of an average person by the whole curve.

Although not strictly so in every case, this feature generally urges the manufacturer to produce a positioner that is likely to be of a size suitable for mounting to the head of a patient, and providing sufficient space for mounting a twin positioner or any

other suitably sized device on another part of the head, and provides the possibility of fitting into a typical MRI head coil the patient's head mounted with twin positioners.

Preferably, the spherical 5-bar-serial-structure comprises: the curved base-bar; the curved base-bar having two ends; one end of the curved base-bar rotatably connected to the proximal end of a first 2-bar-serial-linkage arm; and the other end of the curved base-bar rotatably connected to the proximal end of a second 2-bar-serial-linkage arm; the distal end of the first arm and the distal end of the second arm cooperate by mutual tension into behaving as a distal link of the spherical 5-bar-serial-structure; wherein the spherical 5-bar-serial-structure holds and moves the second robot in alignment with the distal link.

The distal link may not necessarily be formed of a physical linkage. A functional distal link operates as well as a physical distal link. Furthermore, it provides the advantage of dis-jointing the distal link when required

Typically, the distal end of the first arm holds the surgical needle holder; the distal end of the second arm holds the second robot; the mutual tension is a force pushing the surgical needle holder and the second robot in opposite directions against a device preventing the separation of the surgical needle holder from the second robot.

This provides that the second robot moves in unison with the first robot when the needle holder is pushed manually, and avoids the needle holder from moving the second robot relative to a first robot that is still.

Preferably, the second robot comprises a movement guide held in the distal end of the second arm; the distal end of the first arm capable of cooperating with the movement guide to provide the needle holder two degrees of movement across a curved plane about the same centre of the spherical 5-bar-serial-structure independent of corresponding movement in the second arm.

The movement guide may be, as explained in the embodiments, in the form of a dome and slider having a curvature that guides movement of the needle holder across the workspace and about the centre. Any other method of guiding the movement of the needle holder in two degrees of movement across a curved plane about the centre may be used.

Optionally, the movement of the needle holder, which is independent of corresponding movement of the second arm, is provided by automation.

Preferably, the automation is by hydraulics actuation of polymer bellows; the base joints and elbow joints are ceramic and polymer based revolute joints; and comprising a granular jamming pack for immobilizing the position of the needle holder relative to the second arm.

The above features contribute to the positioner into being suitable for deployment in an MR environment without interfering with MR imaging.

In a second aspect, the invention proposes a nesting movement-guide for installation into a nested movement-guide, the nesting movement-guide configured to hold and move a surgical needle holder in stereotactic alignment to a centre or motion; and the nested movement-guide configured to hold and move the nesting movement-guide and the surgical needle holder, such that the surgical needle holder remains in stereotactic alignment to the centre or motion.

Preferably, movements of the nesting movement-guide are responsive to automation by software.

In a further aspect, the invention proposes a method of positioning a surgical needle holder into alignment with a surgical target in a patient's body, comprising the steps of: moving a be-nested movement guide which is holding a nesting movement guide, the nesting movement guide holding a surgical needle holder remotely from and about an opening in the patient's body coincident with the centre of motion of the be-nested movement guide; such that the surgical needle holder is in alignment with the opening and with the surgical target by a margin of error; moving the nesting movement guide about the opening as a centre of motion of the nesting movement guide independently of corresponding movements of the be-nested movement guide; such that the surgical needle holder is in alignment with the opening and with the surgical target by a reduced margin of error

Preferably, moving the nesting movement guide comprising applying software controlled automation,

Optionally, the method comprises a preceding step of: installing the nesting movement guide into the be-nested movement guide. Typically, this includes adjusting the distance of the nesting movement guide from the centre of motion of the nested movement guide such that the centre of motion of the nested movement guide is the same as the centre of motion of the nesting movement guide.

Brief Description of the Figures

It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention, in which like integers refer to like parts. Other arrangements of the invention are possible, and consequently the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

Figure 1 illustrates a piece of prior art;

Figure 2 illustrates an embodiment of the invention;

Figure 3 is used to explain an effect of applying the embodiment;

Figure 4 illustrates the principle of a structure used in the embodiment;

Figure 5 also illustrates the principle of a structure used in the embodiment;

Figure 6 illustrates a part of the embodiment;

Figure 7 illustrates the mechanism used in the embodiment;

Figure 8 illustrates a part of the embodiment;

Figure 9 is an exploded view of the embodiment;

Figure 10 is another exploded view of the embodiment;

Figure 11 illustrates a function provided in the embodiment;

Figure 12 is another exploded view of the embodiment;

Figure 13 is another exploded view of the embodiment;

Figure 14 illustrates another feature in the embodiment;

Figure 15 also illustrates an effect of applying the embodiment;

Figure 16 illustrates an application of the embodiment;

Figure 17 shows a further embodiment of the invention;

Figure 18 shows yet a further embodiment of the invention;

Figure 19 shows the embodiment of Figure 18 in greater detail;

Figure 20 shows the embodiment of Figure 18 on its own with a needle holder;

Figure 21 shows the embodiment of Figure 18 nested in a prior art device;

Figure 22 shows the embodiment of Figure 18 nested in a prior art device; and

Figure 23 shows the embodiment of Figure 18 nested in a possible prior art device.

Detailed Description of Specific Embodiments

Examples of stereotactic neurosurgeries include biopsy, deep brain stimulation (DBS) which may involve applying electrical impulses to specific locations in the brain or placement of therapeutic objects into a deep location in the brain, ablation, and so on. Examples of tubular instruments include surgical needles, cannula devices, biopsy needles or ablation rods and so on. These instruments shall be collectively referred as “surgical needles” in the rest of this description. The skilled reader should understand this includes all the elongate or tubular devices, rigid or soft, that are inserted through incisions made into any part of the body.

For a surgical needle to reach inside a patient's head, a burr hole 301 is made into his skull 300 to provide access. Figure 2 shows a positioner which is configured for mounting to the skull 300 of the patient, comprising nested robots for holding a needle guide, also known as a needle holder 201, in stereotactic alignment to the burr hole 301 as the Remote Centre of Motion (RCM 501). A remote fixed point, with no physical revolute joint over there, around which a mechanism or part of it can rotate is called remote centre of motion.

The positioner has an outer robot which has a spherical 5-bar-serial-structure, and a fine-adjustment robot 202 installed in the distal link of the spherical 5-bar-serial-structure. The needle holder 201 is extended through the fine-adjustment robot 202. The surgical needle holder 201 is able to hold and move a surgical needle rectilinearly. An accurate reach to the surgical target 303 requires the trajectory provided by the needle holder 201 to be straight and aligned with the burr hole 301 and the surgical target 303. Both robots have the same RCM 501 and both moves the needle holder 201 only within the curved surface of an imaginary sphere in a stereotactic manner, and are placed such that the RCM 501 is coincident with the burr hole 301. The outer robot can be used manually to move the needle holder 201 about the burr hole 301 into a position that is aligned with the surgical target 303 within an accepted margin of error. Software is then used to automate the fine-adjustment robot 202 for moving the needle holder 201 into a position which is more accurately aligned to the surgical target 303.

Use of a spherical 5-bar-serial-structure encourages a limit to the size of the positioner such that most embodiments would become suitable to fit onto a patient's head within the head coil of an MRI machine. However, this also limits the distance between the tip of the needle holder 201 and the RCM 501. The movement of a short distance between the tip of a needle holder 201 and the RCM 501 acting like a pivot to a relatively longer distance between the RCM 501 and the surgical target 303 might be too sensitive for manual adjustment. This is illustrated in Figure 3, showing the surgical target 303 on the other side of the RCM 501. The further the surgical target 303 is from the RCM 501, the greater the swing of a long needle length after the RCM 501 for every small movement of the tip of the needle holder 201.

It is easier to visualize the mechanism of a spherical 5-bar-serial-structure by first considering a planar 5-bar-serial-structure which is illustrated in Figure 4. The simplest planar 5-bar-serial-structure comprises five identical, elongate, flat bars. The ends of every bar are each connected to the end of another bar in a joint that is rotatable in a plane parallel to the stacked ends of the two bars, and the axis of each

joint is perpendicular to the plane of the respective stacked ends. The distal-joint, marked by a circle, can be in different positions within this plane. The bar facing the lead-joint is the base-bar 207 and is secured to a surface to provide anchorage against which the other four bars move. In other words, the structure comprises an immobilised base-bar 207 having two ends; from each of the two ends extends an arm of two serially linked bars, i.e. a 2-bar-serial-linkage; and the distal ends of the two arms are connected to provide the distal-joint of the 5-bar loop. For ease of distinction, the joint in the middle of each arm is called an elbow-joint 203, and the joint between the proximal end of each arm and the base-bar 207 is called a base-joint 205. Pulling the distal-joint into any position requires an accommodating change in positions of the other four bars and in the angles at all the joints. The planar 5-bar-serial-structure can only move within in a plane orthogonal to the axes, with two degrees of freedom along a z-axis and an x-axis. Any force attempting to lift the distal-joint out of the plane is resisted mechanically by the two arms extending in different directions from the base-bar 207.

A simple spherical 5-bar-serial-structure is similar to the planar 5-bar-serial-structure but has an additional feature that the axes of the five joints are aligned to the centre of an imaginary sphere of a pre-determined radius, which is illustrated in Figure 5. The bars are elongate blades having a wide section and a thin edge, and the blades are curved along the blade length. As illustrated in Figure 6, each joint between every curved bar is formed of a pivot extending perpendicularly through a plane at the stacked ends of the two relevant blades. The axes 601 of the joints at both ends of each bar are convergent on the concave side of the bar to a common origin, which shall be the centre of the imaginary sphere. This structure limits movements of the elbows joints and the distal-joints to a curved plane on the surface of the imaginary sphere, such that the axes 601 are always directed towards the centre of the sphere.

Preferably, the bars are reinforced with at least one rib extending across the length of the bar at the bar's mid-width to avoid sagging in the concave side of the bar.

There is a limit to the movements of the distal joint across the curved plane, which is due to the length or the arc angle of the spherical 5-bar-serial-structure, and this defines the workspace of the spherical 5-bar-serial-structure. Generally, the greater the arc angle of the bars, the greater the workspace but the bulkier the whole spherical 5-bar-serial-structure, which may even occupy the surgical field around the burr hole 301. It is recommended that the arc angle of both proximal bars be 70 degrees and both distal bars 60 degrees for a good balance between the overall range of the workspace and the size of the positioner 200, i.e. suitable for mounting onto a skull 300 inside an MRI head coil and giving a workspace of ± 38 degrees (obtained by kinematic analysis). Typically, to avoid letting the needle holder 201 be

positioned on the limit of the workspace, mechanical constraints are applied onto the joints to constrain the workspace to ± 30 degrees. It may be noted that the curve along the blade length does not have to have the same curvature as the surface of the imaginary sphere as long as the axes 601 of the joints are aligned to the centre of the imaginary sphere, e.g. the bar ends may be bent at an angle to the body of the bar.

The preferred type of joint for connecting the bars is the revolute joint, which provides a one-degree-of-freedom between the two connected bars, about the joint axis, and restricts sliding movements of the bars over each other. The orientation of the needle holder 201 with respect to the imaginary sphere or the robot frame can be calculated from the angles of the base-joint 205 and elbow-joint 203 of just one of the arms, as illustrated in Figure 7. Therefore, the base-joint 205 and elbow-joint 203 of one of the arms are installed with an optical encoder 211 each to monitor and provide data on the angle between the relevant bars, from which the position of the needle holder 201 is deducible in real-time. For convenience, the arm that is installed with the optical encoders 211 is called the encoder arm 215, and the other arm is called the passive arm 217.

Preferably, the joints of both arms but at least those of the passive arm 217 can be locked down to immobilize the arms. A friction based joint brake 213 mechanism, as illustrated in Figure 8, is provided as a brake 213 on the base-joint 205 and elbow-joint 203 of the passive arm 217 to prevent rotation of the respective revolute joints, which is enough to immobilize the spherical 5-bar-serial-structure and therefore the outer robot. Figure 8 illustrates such a joint brake 213 system, which comprises a pair of friction rings 603 (also shown in Figure 6) to press against a rubber layer between outer rod and inner rod of the revolute joint and prevents the rotation of both the rods of the revolute joint instantaneously to ensure precision positioning. The friction rings 603 were configured as two stacked layers which surround the inner and outer surface of the joint with anti-clockwise and clockwise arranged arcs, covering three quarters of the joint's circumference per ring. Each ring is fixed at one end while the other end is connected to a Bowden cable 605 which pulls the ring downwards into contact with the joint. This creates a bidirectional braking effect with prevents the joints from over running the desired position due to imbalanced braking of the rods in the revolute joint. To reinforce the braking effect, the inner surface of the rings is made from rubber material to increase the grip of the brakes 213.

Preferably, fibre-optic lighting is incorporated into the optical encoder 211 that may be used to indicate to the surgeon the extent of error with respect to orientation of the surgical target 303. For example, if the current position of the needle holder 201 is more than 20 degrees off target, the optic fibre emanates a red light. If the error is

between 20 degrees and 5 degrees the optic fibre emanates a purple light. If the error is less than < 5 degrees the optic fibre emanates a green light.

Preferably, the fine-adjustment robot 202 is a soft robot, made of deformable and soft materials which are usually organic and MR inert. The fine-adjustment robot 202 is placed beneath the distal end of the encoder arm 215. Figure 9 shows the distal bar on the encoder arm 215 having an upward bend at mid-length of the bar, and the bar is lengthened slightly to accommodate the fine-adjustment robot 202. The needle holder 201 is held in the distal end of the encoder arm 215 and in alignment to the RCM 501, and inserted into the fine-adjustment robot 202 which is held by the passive arm 217. The needle holder 201 has no independent movements except for rotating about its own axis; it cannot tilt relative to this distal bar in any direction. Instead, adjustment of the needle holder 201 position is facilitated by change of angle in the elbow-joint 203 and the base-joint 205 of the encoder arm 215, which can be detected by the optical encoders 211 mounted onto these joints.

Figure 9 also illustrates the fine-adjustment robot 202 in an exploded view. It can be seen that the fine-adjustment robot 202 comprises a housing that is round from the plan view, although different shapes may be used in other embodiments. The passive arm 217 holds the housing by the housing-base 911.

The housing has an axis which is directed to the RCM 501. The top of the housing is a lid 901 that has a centre opening through which the needle holder 201 is inserted into the fine-adjustment robot 202. All the relevant parts in the fine-adjustment robot 202 housing are provided with a central opening each, and are axially aligned so that the needle holder 201 may extend through these openings. The housing-base 911 has an opening which is also axially aligned for a surgical needle in the needle holder 201 to extend through. Together, the diameter of each of the openings allow a ± 5 degrees positional variation of the needle trajectory, which is the workspace of the fine-adjustment robot 202, as illustrated in Figure 10.

Beneath the lid 901 of the housing is a granular jamming pack 903 for locking down the needle holder 201 to the fine-adjustment robot 202, i.e. when fine-adjustment of the position of the needle holder 201 has been completed, the positioner 200 is immobilized for insertion of surgical needles.

The granular jamming pack 903 is fixed firmly to the top of a dome 905 by strong glue or other securing means. The dome 905 looks like an upside-down dish and is securely fixed to the housing. The underside surface of the dome 905 is provided with a curvature that matches the curvature of the workspace of the imaginary sphere. Beneath the dome 905 is a slider 907, which comprises three blades

extending radially from the centre of the slider 907, oriented such that the edge of the blades are aligned radially to the axis of the housing. The top surface of the blades, together, defines a curvature that fits exactly to the curvature of the inner surface of the dome 905, and therefore also matches the curvature of the workspace. When the positioner 200 is assembled, the slider 907 is placed over the needle holder 201 and secured at a specific point along the elongate body or stem of needle holder 201.

Beneath the slider 907, the stem of the needle holder 201 is inserted between three actuators 909. The actuators are equally distributed about the axis of the housing and, therefore the stem of the needle holder 201, at 120 degrees apart. The actuators 909 are made of MR-inert polymeric and elastomeric materials. Each actuator has an axisymmetric bellow-shape for providing a piston-type mechanism. The bellow shape is given by the difference in diameter between a series of alternate inner folds and outer folds along an axis. Each actuator can be actuated individually by fluidic inflation/deflation. To restrict undesired radial expansion, the circumferences of the apices of the larger folds are hardened by another polymeric material, causing deformation to take place preferentially towards elongation instead of radial expansion.

The length of needle holder 201 upward from the slider 907 is pushed out of the opening of the dome 905 towards distal end of the encoder arm 215 but the slider 907 is too big to go through the opening in the dome 905. The slider 907 prevents excess lengths of the needle holder 201 from extending out of the dome 905.

Figure 11 and Figure 12 show how the actuators 909 push against the stem of the needle holder 201 inserted between the actuators 909. The direction of the force of each actuator slants upwardly, i.e. a lateral force vector towards a lower part of the stem of the needle holder 201 and an upward force vector against the slider 907 mounted on the needle holder 201. The actuators 909 are constantly supplied a minimum amount of hydraulic pressure so that the slider 907 is always pushing up against the dome 905. However, as this minimal amount of hydraulic pressure is also applied in three directions, 120 degrees apart, onto the stem of the needle holder 201, the forces cancel out laterally. The other end of each actuator is placed down on housing-base 911, which provides a platform for the actuators 909 to push down on for a counter force to the upward force on the slider 907, and up against the dome 905 which is securely fixed to the housing.

In this way, the needle holder 201 and the encoder arm 215 are constantly tensioned and prevented from sagging, which helps to ensure that the needle holder 201 is held at constant distance from the RCM 501. This allows the angles of the elbow-

joint 203 and base joint of the encoder arm 215 to be used to deduce the orientation of the needle holder 201 to the RCM 501 accurately.

There is no need for the needle holder 201 and the fine-adjustment robot 202 to be physical linked to supply a spherical 5-bar-serial-structure movement mechanism to guide the movement of the needle holder 201. The minimum pressure exerted by the actuators upwardly on the slider 907 against the dome 905 is sufficient to keep the needle holder 201 and the fine-adjustment robot 202 in a tensioned relationship, so that they cooperate and move in unison as if there is a physically linked distal joint between the distal ends of the encoder arm 215 and passive arm 217. It does not matter where the slider 907 and needle holder 201 are positioned relative to the dome 905 inside the fine-adjustment robot 202 housing, since the RCM 501 of the dome 905 and slider 907 is the same as the RCM 501 of the outer robot.

In the simplest embodiment, the base-bar 207 perches by the edge of the blade with the help of a mounting base 209. The mounting base can be as simple as two L-shape plates on either end of the base-bar 207. The mounting base 209 has a few holes into which titanium screws may penetrate to engage screw holes made into the skull 300 (or other flat bone for surgeries on other parts of the body as the case may be). The mounting base 209 also provides the base-bar 207 a possibility of being lifted and turned downward slightly in order to point the axes 601 of the base joints towards the burr hole 301 for proper alignment.

The needle holder 201 can be moved across a smaller range of the workspace under the guidance of the dome 905 and the slider 907 fixed to the stem of the needle holder 201, within the edge of the hole in the dome 905. The slider 907 and dome 905 form a physical movement guide that keeps the needle holder 201 in stereotactic orientation to the RCM 501. The number of blades on the slider 907 is an optional design feature which may be replaced by, for example, a single curved surface extending in all directions about the stem of the needle holder 201 like an umbrella. The slider 907 only needs to move under the guidance of the inner surface of the dome 905 and the needle holder 201 stays within the stereotactic workspace. Preferably, the contact interface between the slider 907 and the dome 905 is pre-treated to reduce friction, such as by applying suitable slippery materials on or laser-treating both surfaces.

Figure 13 is another drawing that shows again the fine-adjustment robot 202 in exploded view, but only the parts relevant to immobilization of the needle holder 201. These parts comprise the granular jamming pack 903 surrounding the part of the needle holder 201 sticking out of the dome 905. As mentioned, the granular jamming pack 903 is securely fixed to the upper surface of the dome 905, by glue or any other

means. The granules 1401 in the pack 903 are able to flow like fluid before the pack 903 is activated by sucking the air out of the pack 903. When the granular jamming pack 903 is shrunk by extraction of air, the granules 1401 gather together and immobilized each other into a hard, solid form gripping the part of the needle holder 201 extending through the pack 903 tightly. This locks down the position of the needle holder 201 to the fine-adjustment robot 202 housing. This is illustrated in Figure 14 from left the drawing to right drawing. The hardened form is reversible into the fluidic form when air is reintroduced into the pack 903, which releases the grip on the needle holder 201. Optionally, the elbow-joint 203 and the base-joint 205 of the encoder arm 215 are also locked by applying friction locks of the type that has been applied to the joints on the passive arm 217, although locking the elbow-joint 203 and the base-joint 205 of the passive arm 217 with application of the granular jamming may be enough to immobilise the positioner 200. However, the granular jamming pack is not activated to lock down the needle holder 201 to the fine-adjustment robot 202 because the needle holder 201 needs to be able to rotate relative to the fine-adjustment robot 202 to accommodate changes in the angle between the encoder arm 215 and passive arm 217 in different positions.

When deployed, the positioner 200 is mounted onto the skull 300 in a location such that the centre of the imaginary sphere is coincident with the burr hole 301 as the RCM 501. The spherical 5-bar-serial-structure extends upwardly from the base-bar 207 in a curve that follows the imaginary sphere. The needle holder 201 is held at and co-axially with the distal-joint 501, and may be moved into another position across the workspace without losing alignment to the burr hole 301. The surgeon pushes or pulls the tip of the needle holder 201 which is usually covered with a screw cap to move the needle holder 201.

Therefore, the positioner 200 has three operational modes in relation to positioning the needle holder 201, a coarse adjustment mode, a fine-adjustment mode, and an immobilized or frozen mode.

Before surgery, the desired orientation is calculated in advance by taking images of the patient using MRI and other imaging techniques such as Computed Tomography (CT) scan, using markers placed on the patient to identify the coordinates of the surgical target 303. The position of the burr hole 301 and the expected mounting location of the positioner on the skull 300 and the linear alignment of the needle holder 201 to the burr hole 301 and the surgical target 303 are determined from the images. Subsequently, the positioner 200 is mounted onto the skull 300 of the patient in an appropriate location that should cover the target position. The positioner 200 is then registered or coordinated with the patient's head in the MRI imaging environment using the MR markers on the positioner 200.

Subsequently, the positioner is placed into the coarse adjustment mode. All the elbow-joints 203 and base-joints 205 are loose and responsive to changes in the position of the needle holder 201, and the actuators 909 are supplied with the minimum amount of hydraulic pressure to ensure maximum extension of the needle holder 201 out from the top of the housing of the fine-adjustment robot 202 and thereby co-axial alignment of the needle holder 201 on the encoder arm 215, as well as provide the tension-induced distal joint.

The surgeon pushes the needle holder 201 over the workspace defined by the spherical 5-bar-serial-structure into a position that causes the fibre-optic shows a green light, indicating a ± 5 degrees error to the surgical target 303, without need of review of the MR image (using prior art devices, the surgeon shall take multiple MRI images to determine the position of the needle holder 201). Before entering the fine-adjustment mode, the spherical 5-bar-serial-structure is immobilized by the surgeon stepping on a pedal 1601 to actuate braking mechanisms on the elbow joint and the base joint of the passive arm 217. Subsequently, in the fine-adjustment mode, a computer takes over and makes fine-adjustments to the position of the needle holder 201.

Depending on the type of surgery, the embodiment at ± 5 degrees accuracy can be sufficiently accurate to access a surgical target 303, such as in a case of inserting a needle to inject a substance to diffuse over a large target area. However, for surgery that requires very precise positioning, such as deep brain stimulation procedures which require needle position to be within 2 mm accuracy of the surgical target 303 deep within the head, the fine-adjustment robot 202 is used.

When the surgeon decides that the needle positioner 200 is in the desired position, the positioner 200 is immobilized to provide a stable platform that can resist position drifting of the needle holder 201. Therefore, a surgical needle can be inserted into the patient through the needle holder 201. Surgical needle insertion may be done manually or assisted by other robotic means which is not within the scope of this description.

Accordingly, fine-adjustment robot 202 does not use the spherical 5-bar-serial-structure to move the same needle holder 201; the tensioned-induced distal joint of the spherical 5-bar structure is not used during fine-adjustment. Instead, the fine-adjustment robot 202 uses a pre-manufactured movement guide to maintain the stereotactic orientation of the needle holder 201 when moving the needle holder 201 by position-responsive automation. Software control may cause one or two of the actuators to be supplied with more hydraulic pressure to move the needle holder 201

and the encoder arm 215, relative to the immobilized passive arm 217 and independent of the mechanism of the spherical 5-bar-serial-structure or the outer robot.

Fine-adjustment of the needle holder 201 position may takes place by software coordination of the actuators 909 completely under MR live-imaging, towards the pre-calculated position of the surgical target 303. If the surgical target 303 has moved, which can happen during surgery, re-positioning the needle already inside the brain may be done by pulling the needle out of the brain, unlocking the needle holder 201, releasing the brakes 213 on the elbow-joint 203 and base-joint 205 of the arms, and repositioning the needle holder 201 using the fine-adjustment robot 202 according to the position of the moved surgical target 303 observed by MR live-imaging. It is extremely unlikely that the surgical target 303 could move so far to be outside the ± 5 degree range of the fine-adjustment robot 202 movement space.

Figure 15 illustrates how, with the inclusion of the fine-adjustment workspace, the total workspace is expanded with an additional 5° , providing a total reachable workspace of $\pm 35^\circ$.

MRI application

Embodiments suitable for surgery performed under MRI real time imaging have dimensions small enough for being mounted on a patient inside an MRI coil and comprise parts that are MR neutral. The embodiment can be used to assist the surgeon in performing intra-op MRI-guided stereotactic neurosurgeries, such as needle/probe targeting involved interventions, which are used in biopsy, injection, ablation, catheter placement, stereoelectroencephalography (sEEG) and DBS. Intra-op MRI guided DBS has anatomical targets situated in the deep region of brain (average 90.4 mm underneath the skull 300), with target error tolerance at less than 3 mm.

For brain surgery with live-imaging in an MRI machine, the positioner 200 can be made to fit and operate within the compact space of an imaging head coil when mounted onto the patient's skull 300, e.g. 81 mm diameter $\times$ 97 mm height which provides excellent light-weightiness of 203 g (using a suitable stiff polymeric material) and also a possibility of a twin positioner 200 to be placed alongside in bilateral surgery, and still providing sufficient workspace (± 35 degrees),

Figure 16 shows how twin positioners 200, which are detached from each other physically and independently controlled in function, are mounted to the skull 300 of

patient inside an MRI head coil 1603. Pedals 1601 for activating the Bowden cables 605 to apply the brakes 213 are illustrated.

As mentioned, the arc angle of the bars between the base-joint 205 and the elbow-joint 203 is recommended to be 70° and the arc angle of the bars between the elbow-joint 203 and the led joint to be 60° . This gives a workspace of $\pm 38^\circ$ coverable by coarse adjustment. To avoid working on the workspace boundary, mechanical constraints are applied onto the revolute joints so that the actual covered workspace is limited to $\pm 30^\circ$ for coarse adjustment.

To fulfil strict requirements for MR safety, the automated soft robot used for fine-adjustment is made of polymeric or elastomeric materials. For example, what would be metallic pistons in non-MRI embodiments are soft fluid-driven soft polymer actuators 909. The revolute joints are supported by high precision ceramic bearings on both sides, held into place by high-performance thermoplastic (i.e., PEEK) screw connections. The granules 1401 in the granular jamming pack 903 are 2 mm diameter PVC spheres

Likelihood of size-limitation of the outer robot

Without going into the specifics, it can be generalized that use of a spherical 5-bar-serial-structure for the outer robot encourages a positioner size that is likely to fit onto the head of a person, and within the MR-head coil. Any section of a perfectly round ring can fit to any part of a larger curved surface such as the skull 300, which is why the base-bar 207 of a limited radius would fit to any location on the skull 300 above the ears and brow. Assuming the bars have the same arc angle, the bars cannot be nearly as long as a quadrant of a circle of the same radius or else, the 2-bar-serial-linkage arm would stretch a semi-circle and be on par with the RCM 501 in a tangent. However, the arc angle has to be more than $1/8$ of the circle or else, the arm only extends up to a quadrant, right above the RCM 501, without extending further. Furthermore, the radius of the imaginary sphere determines the distance between the burr hole 301 to the base-bar 207 and the highest point perpendicular to burr hole 301. Hence, to make sure the RCM 501 is coincident with the burr hole 301, the radius bars is limited by the curvature of the skull 300 such that the outer robot is more likely than not to be small enough to fit onto the head and inside the head coil.

The 5 bar-structure also provides a cantilever which is mounted to one side of the burr hole 301, and holding the needle holder 201 on one side, without any support structure on the other side of the burr hole 301. The needle holder 201 is held lifted from the burr hole 301 and there is no pivot placed on the burr hole 301 or RCM 501. The part of the skull 300 across the burr hole 301 is an open space for visual and

physical access to the burr hole 301, as well as concurrent installation of a second positioner 200 in close proximity to the first one. As the two positioners are not limited by a shared physical base, each of the two positioners may be independently placed on the skull 300 in a suitable orientation to the respective surgical target 303. This possibility is particularly useful for live MR-image-assisted deep brain stimulation (DBS). This requires burr holes 301 made into the skull 300 on two sides of the Sagittal plane. The positioner 200 having less structure can be made small enough to fit two of the positioners 200 onto the skull 300 of a patient and within the small enclosure of a head coil in an MRI frame.

The movement limit of the distal joint of the spherical 5-bar-serial-structure can be appreciated in a glance, as there is little that goes beyond the foot print of the positioner. In addition, being able to place a twin positioner separately and independently, aligned to another part of the skull 300, reduces the chance of the distal joint extending to far as to encroach into the space of the other positioner.

Other applications

Any surgery requiring surgical needles to be inserted into a hole cut into the body near a sufficiently flat piece of bone is suitable for application of the positioner 200. A potential application is eyeball surgery which uses needles to repair the eye, including extracting cataract lens and deposit artificial lens. The socket on the outer part of the eye or the brow bone above the eye can be fixed with a mount base that has a similar shape. In particular, there is no need for any pivot to be placed on the eyeball for the movements of the needle holder 201. Also, the surgeon may benefit from a full view of the needle inserting into the eyeball from the open side of the cantilever. The ability of the mounted positioner 200 to be free from dis-orientation if the patient moves is likely to be a cherished advantage. For imaging during such surgery, MRI imaging is probably not needed. Hence, one or more cameras can be provided on the sides of the needle holder 201 pointing to the RCM 501 and beyond to follow the view of the needle. Based on the small size of the eyeball compared to the skull 300, the positioner 200 can be made even smaller for eyeball surgery.

Besides direct actual needles, the positioner 200 can also be used to hold laser devices to direct a laser in laser surgery, as such surgeries may benefit from the accuracy in of a body-mounted, robot-assisted, finely-adjustable positioner 200.

Further embodiments

Figure 17 shows an embodiment in which there are no nested robots. Only the spherical 5-bar-serial-structure or outer robot is used to hold and move the needle

holder 201. The needle holder 201 is placed co-axially in a rotatable distal joint that is formed by a pivoted connection between the distal ends of the two arms. The axis of the distal joint is also directed at the RCM, as well the axes of the other four joints. This allows the surgeon to move the needle holder 201 across a workspace defined by the imaginary sphere.

The left of Figure 18 shows a rudimentary robot that is stood on the skull of a patient using a tripod, where the needle holder 201 is held in stereotactic alignment to a burr hole on the skull as the RCM. Such a robot may be, for example, a device of part of the prior art. In an embodiment of the invention the proposed fine-adjustment robot 202 can be supplied separately to such existing prior art robot as an additional module to improve the prior device. All that is needed is to supply a dome and slider that can hold the needle holder 201 (needle holders are third party products usually) to be adjusted once the existing device has brought the needle holder 201 within a margin of error to the target position. The modular fine-adjustment robot 202 is illustrated separately in Figure 19, having only the housing and the contents in the housing including the slider for attending to the needle holder 201, the dome and the actuators. The granular jamming pack may or may not be necessary, depending on whether the outer robot is holding the needle holder 201 or not. If the needle holder 201 is held entirely in the fine-adjustment robot 202, then there may not be a need for the granular jamming pack.

Generally, the workspace of the fine-adjustment robot 202 depends on the distance between the RCM and the fine-adjustment robot 202. The nearer the fine-adjustment robot 202 is placed to the RCM the greater the workspace provided within the opening on the dome.

The skilled reader should understand that there may be other ways of provide a housing-contained movement guide for a needle holder 201 to be moved about an RCM. As movements of the movement guide do not exceed the foot print of the housing, the housing can be used as a robot, in between a needle holder 201 and an existing robot.

Therefore, the embodiments include a detachable, preferably housing-contained, nesting movement guide that can be nested or mounted into a be-nested or be-mounted movement guide, such as the spherical 5-bar-serial-linkage, as a second robot nested in the first robot. Preferably, the nesting movement guide being replaceable in, or re-installable into, the be-nested or be-mounted movement guide. The registration or orientation between the nesting movement guide and the be-nested or be-mounted movement guide being within the knowledge of the skilled

reader and not within the scope of this description, and therefore the registration does not need further elaboration.

It is not necessarily that the nesting movement guide is capable of fine-adjustment of the position of the needle holder. For example, all that is improved by the nesting movement guide may be provision of software automation that a coarse be-nested movement guide is not equipped with automation features.

Similarly, it is not necessary that the nesting movement guide is definitely smaller in size than the be-nested movement guide; all that is required is the nesting movement guide is installed to improve or complement the movements or even enlarge workspace of the be-nested movement guide (see Figure 15). In this way, the embodiment brings about a possibility of improving or upgrading existing, coarse robots or coarse needle positioners, as optional upgrading modules.

The left drawing in Figure 21 shows a stereotactic track which is similar to that used in a Clearpoint™ robot which is manually adjusted. The right drawing in Figure 21 shows that it is possible for a fine-adjustment robot to be placed into the needle holder of the Clearpoint™ device to add to the existing functions. The illustration shows the fine-adjustment robot placed beneath the existing needle holder. On one hand, the closer the fine-adjustment holder, the greater the workspace. On the other hand, the position of the fine-adjustment robot should depend on the curvature of the dome and slider, or any equivalent workspace movement guide, inside the fine-adjustment module. At a suitable height, the curvature of the stereotactic movement guide matches the curvature of the workspace the existing Clearpoint™ robot, sharing a centre of the possible movement. All these details may be sorted out by the skilled reader in a real situation and do not need further elaboration here. For a description of the Clearpoint™ robot, please see <https://www.clearpointneuro.com/array>, which a description of the The Clearpoint™ SmartFrame Array.

Figure 22 illustrates a man undergoing back surgery in a non-MR environment, in which a manually operated larger stereotactic robot is used to operate on a surgical target through a hole or incision made into his back. The fine-adjustment robot is used to upgrade the larger stereotactic robot but being installed in between the larger stereotactic robot and the needle holder. In this way, the fine-adjustment robot can be used to upgrade existing larger stereotactic robots by allowing software driven fine-adjustments.

It is also possible that the fine-adjustment robot 201 is used to upgrade other incision tools which are not stereotactic robots or movement guides, as suggested schematically in Figure 23. Figure 23 shows an planar sliding support for a needle

holder or laser device that is not stereotactic in its movement, such as one shown in <https://ieeexplore.ieee.org/document/9197534>. The fine-adjustment robot 201 can be used to improve the fine adjustment of the needle holder or laser device by software automation.

If the fine-adjustment robot is not operated by hydraulics used in an MR-environment, other ways of moving the needle holder in fine-adjustment may be used, such as by electric, ultrasonic, piezoelectric, pneumatic, and electromagnetic, could be suggested in the embodiment.

While there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design, construction or operation may be made without departing from the scope of the present invention as claimed.

Claims

1. A positioner for a surgical needle holder, comprising
a second robot installed into a first robot;

the second robot useable to hold the surgical needle holder and move
the surgical needle holder across a workspace in such a way that the surgical
needle holder remains in stereotactic alignment to a centre of motion;

the first robot useable to hold and move the second robot across a
workspace in such a way that the surgical needle holder remains in
stereotactic alignment to the centre of motion.
2. A positioner for a surgical needle holder as claimed in claim 1, wherein
first robot has a spherical 5-bar-serial-structure.
3. A positioner for a surgical needle holder as claimed in claim 1, wherein
second robot is replaceable.
4. A positioner for a surgical needle holder as claimed in claim 1, further
comprising

an emitter of light in a pre-determined colour indicating that the position
of the surgical needle holder is within a margin of error to a pre-determined
target position; wherein

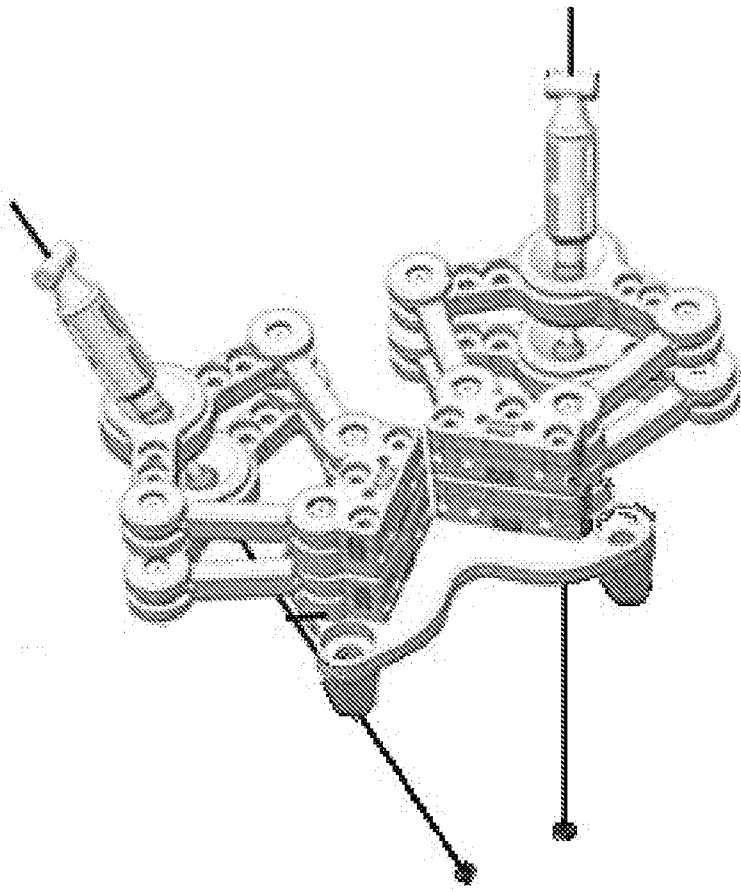
the second robot is capable of moving the surgical needle holder within
the range of a space defined by the margin of error.

5. A positioner for a surgical needle holder as claimed in claim 1, further comprising:
- a curved base-bar; the arc angle of the curve of the base-bar being such that the base-bar is capable for contacting a location on the head of an average person by the whole curve.
6. A positioner for a surgical needle holder as claimed in claim 5, wherein the spherical 5-bar-serial-structure comprises:
- the curved base-bar;
- the curved base-bar having two ends;
- one end of the curved base-bar rotatably connected to the proximal end of a first 2-bar-serial-linkage arm; and
- the other end of the curved base-bar rotatably connected to the proximal end of a second 2-bar-serial-linkage arm;
- the distal end of the first arm and the distal end of the second arm cooperate by mutual tension into behaving as a distal link of the spherical 5-bar-serial-structure; wherein
- the spherical 5-bar-serial-structure holds and moves the second robot in alignment with the distal link.

7. A positioner for a surgical needle holder as claimed in claim 6, wherein
the distal end of the first arm holds the surgical needle holder;
the distal end of the second arm holds the fine-adjustment robot;
the mutual tension is a force pushing the surgical needle holder and
the second robot in opposite directions against a device preventing the
separation of the surgical needle holder from the second robot.
8. A positioner for a surgical needle holder as claimed in claim 6, wherein the
second robot comprises
a movement guide held in the distal end of the second arm;
the distal end of the first arm capable of cooperating with the
movement guide to provide the needle holder two degrees of movement
across a curved plane about the same centre of the spherical 5-bar-serial-
structure independent of corresponding movement in the second arm.
9. A positioner for a surgical needle holder as claimed in claim 8, wherein
the movement of the needle holder, which is independent of
corresponding movement of the second arm, is provided by automation.
10. A positioner for a surgical needle holder as claimed in claim 9, wherein
the automation is by hydraulics actuation of polymer bellows;
the base joints and elbow joints are ceramic and polymer based
revolute joints; and comprising
a granular jamming pack for immobilizing the position needle holder
relative to the second arm.

11. A nesting movement-guide for installation into a nested movement-guide, the nesting movement-guide configured to hold and move a surgical needle holder in stereotactic alignment to a centre or motion; and the nested movement-guide configured to hold and move the nesting movement-guide and the surgical needle holder, such that the surgical needle holder remains in stereotactic alignment to the centre or motion.
12. A nesting movement-guide as claimed in claim 11, wherein movements of the nesting movement-guide are responsive to automation by software.
13. A method of positioning a surgical needle holder into alignment with a surgical target in a patient's body, comprising the steps of:
moving a be-nested movement guide which is holding a nesting movement guide, the nesting movement guide holding a surgical needle holder remotely from and about an opening in the patient's body coincident with the centre of motion of the be-nested movement guide; such that the surgical needle holder is in alignment with the opening and with the surgical target by a margin of error;
moving the nesting movement guide about the opening as a centre of motion of the nesting movement guide independently of corresponding movements of the be-nested movement guide; such that the surgical needle holder is in alignment with the opening and with the surgical target by a reduced margin of error.

14. A method of positioning a surgical needle holder into alignment with a surgical target in a patient's body, as claimed in claim 13, wherein moving the nesting movement guide comprising applying software controlled automation.
15. A method of positioning a surgical needle holder into alignment with a surgical target in a patient's body, as claimed in claim 13, comprising a preceding step of installing the nesting movement guide into the be-nested movement guide.
16. A method of positioning a surgical needle holder into alignment with a surgical target in a patient's body, as claimed in claim 13, comprising a step of adjusting the distance of the nesting movement guide from the centre of motion of the nested movement guide such that the centre of motion of the nested movement guide is the same as the centre of motion of the nesting movement guide.



PRIOR ART

Fig. 1

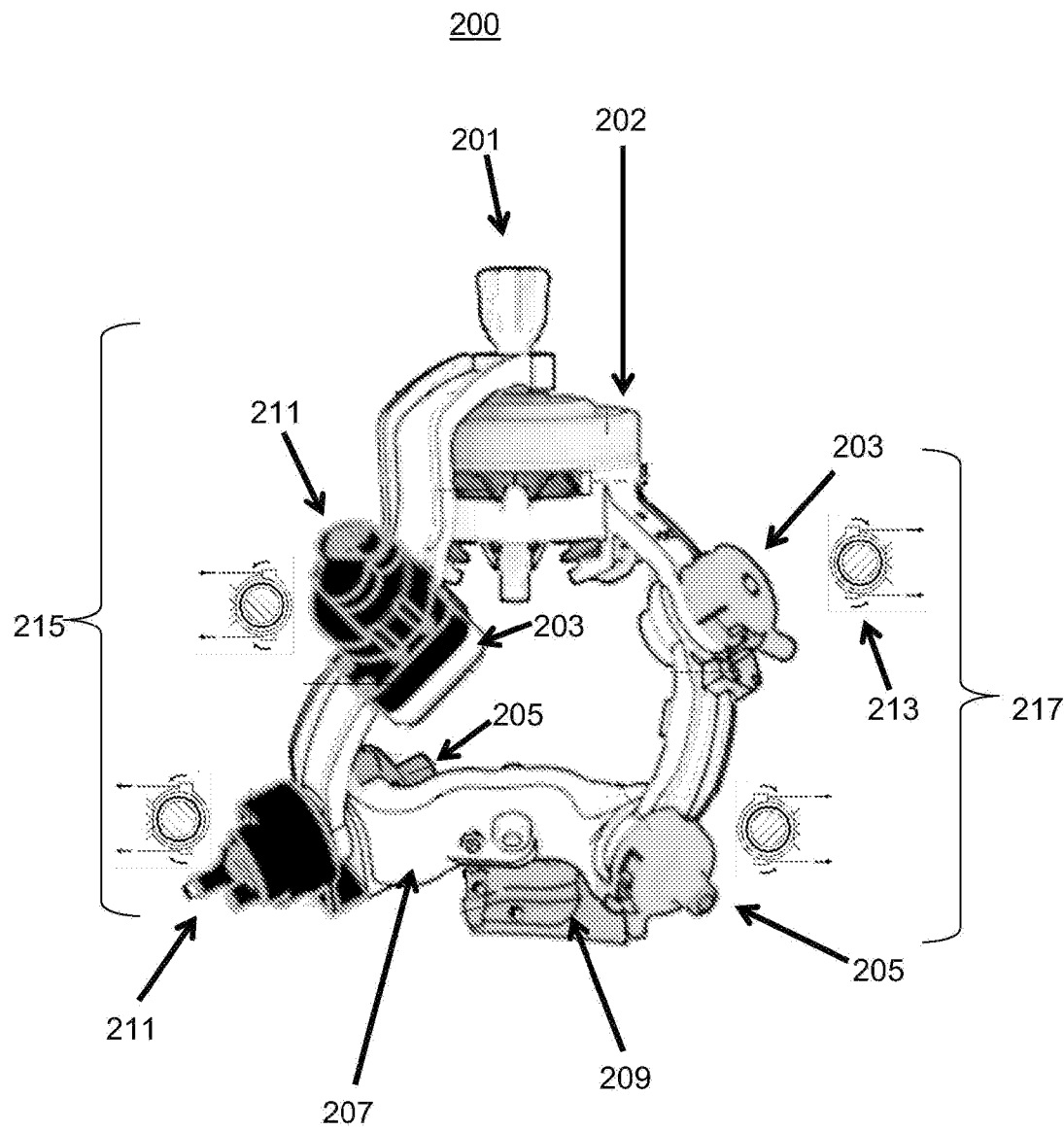


Fig. 2

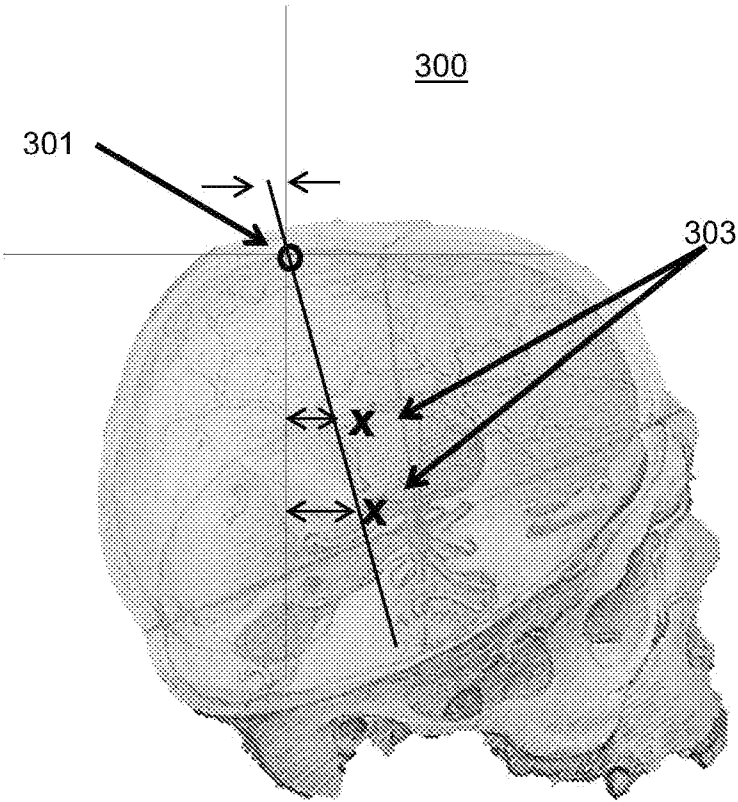


Fig. 3

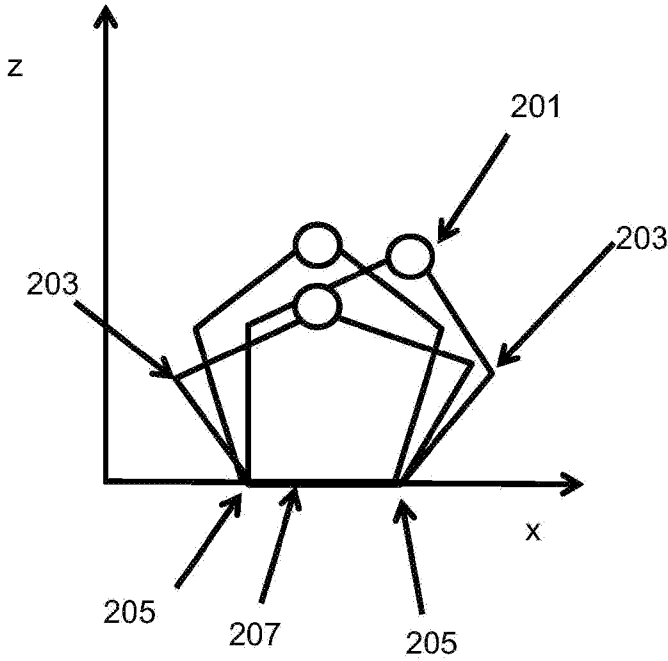


Fig. 4

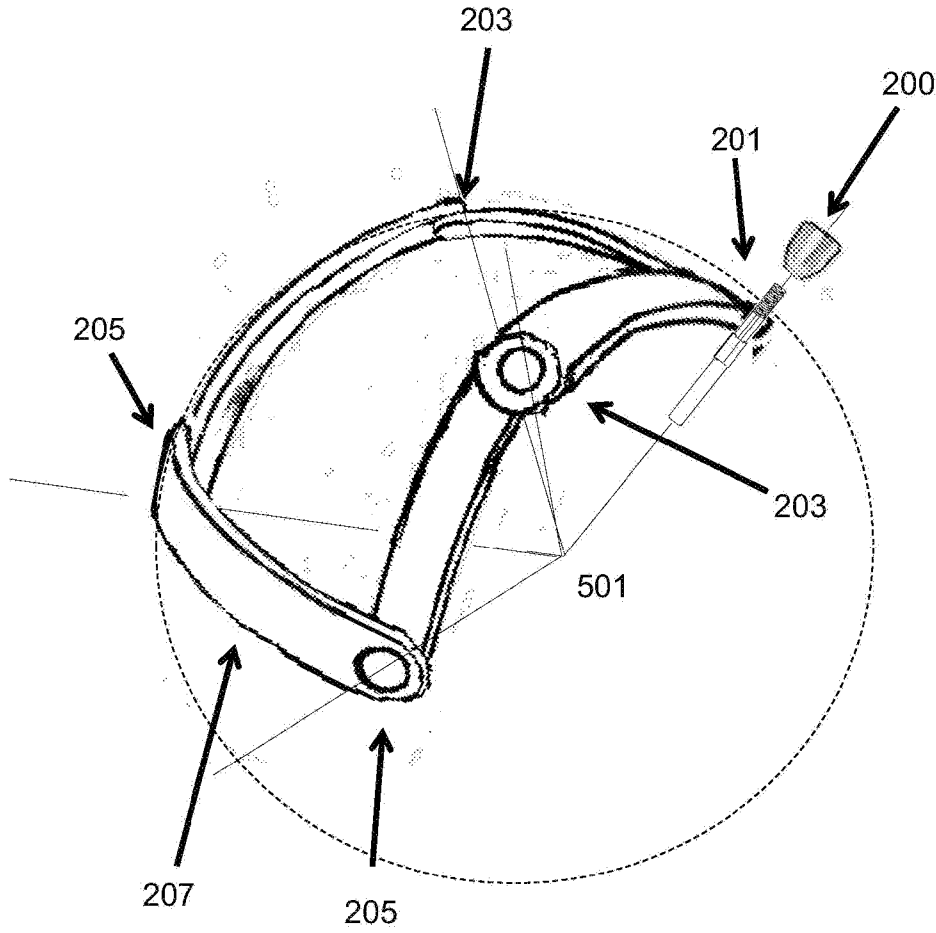
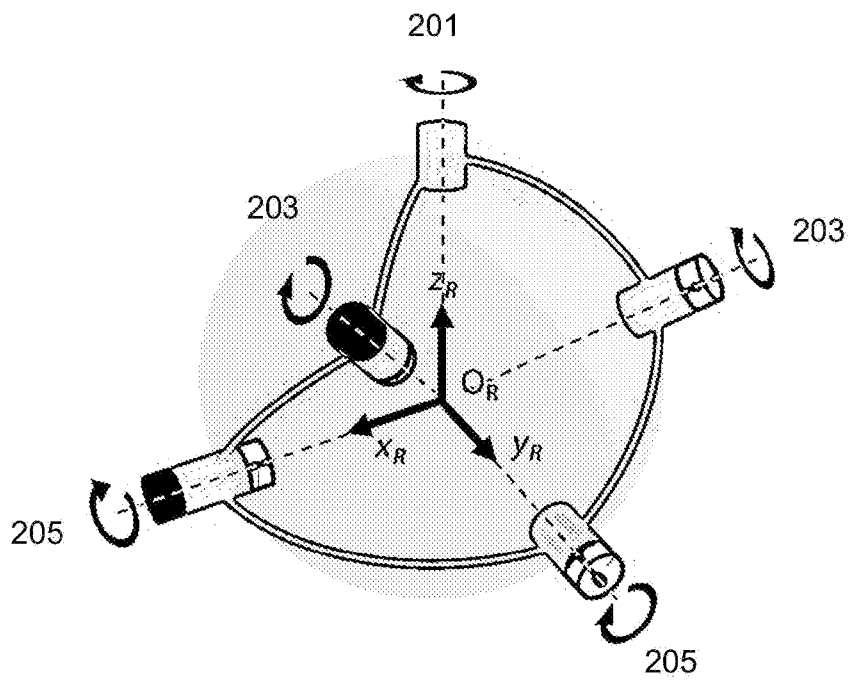
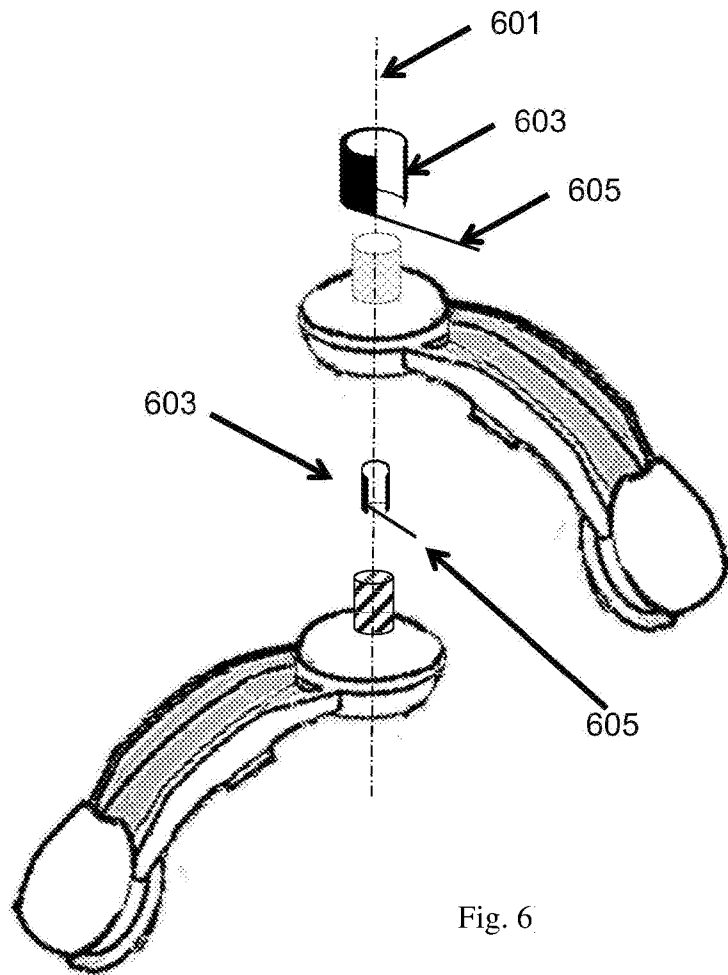


Fig. 5



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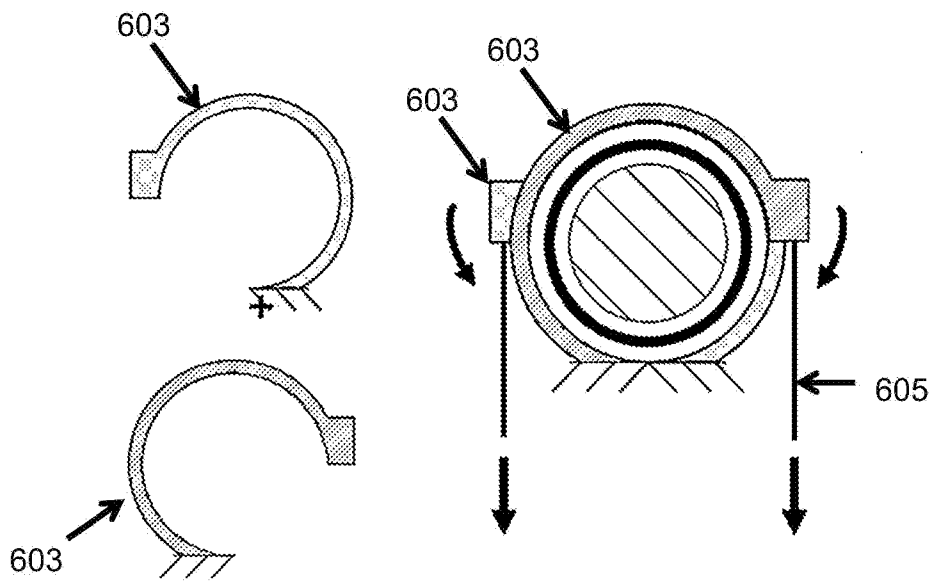


Fig. 8

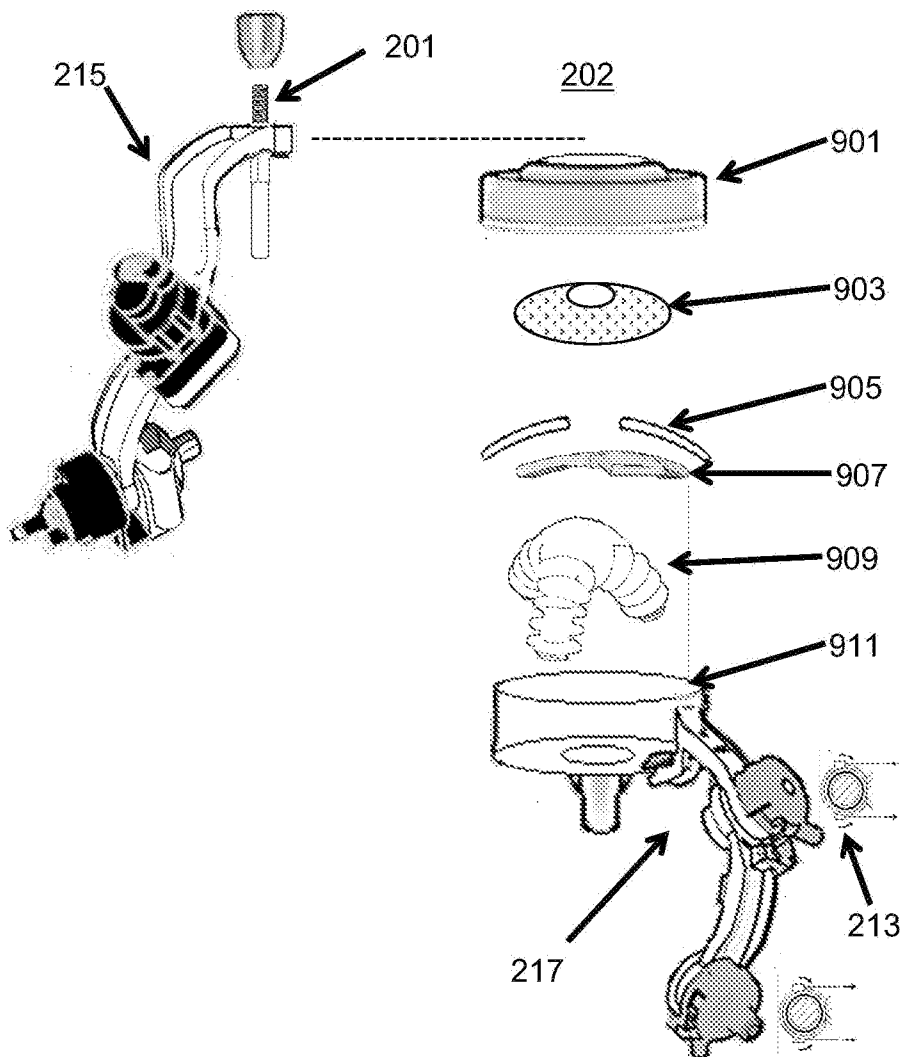


Fig. 9

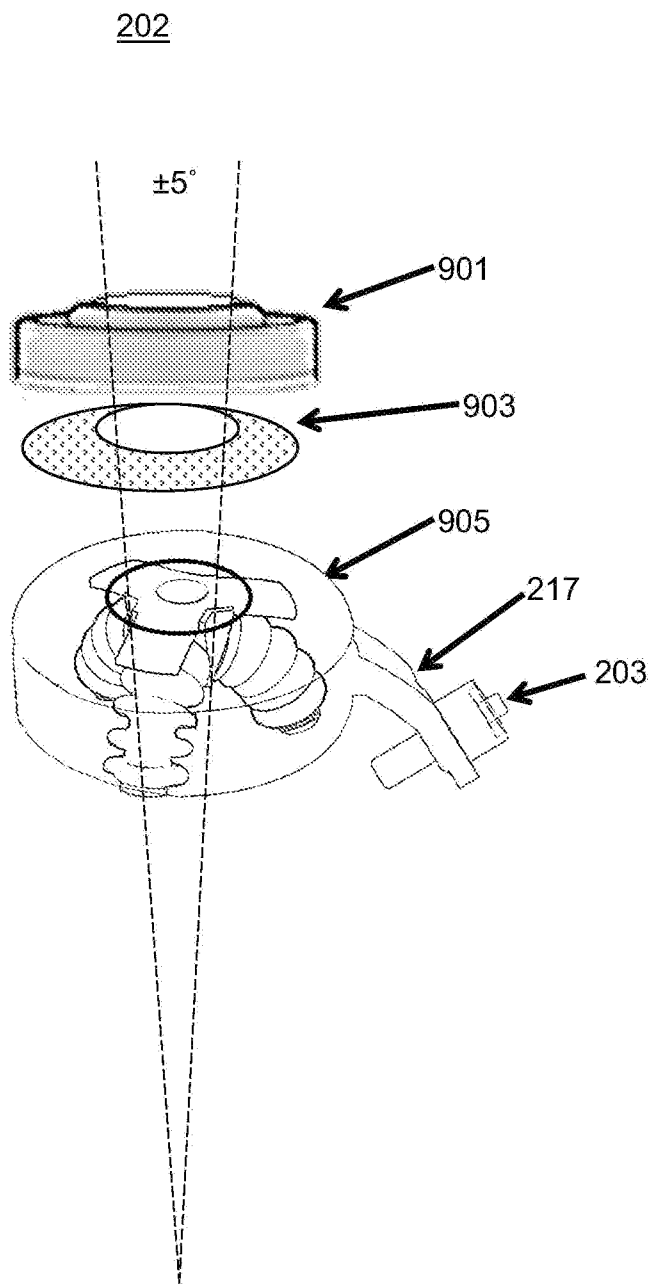


Fig. 10

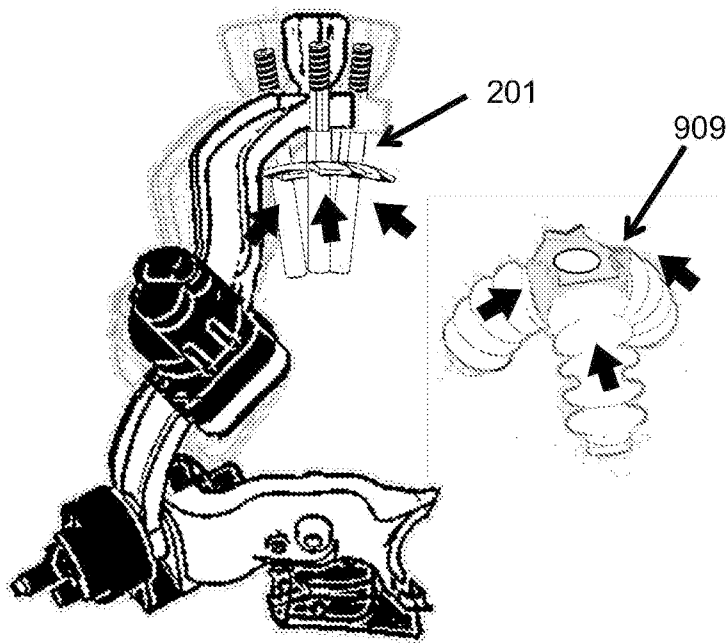


Fig. 11

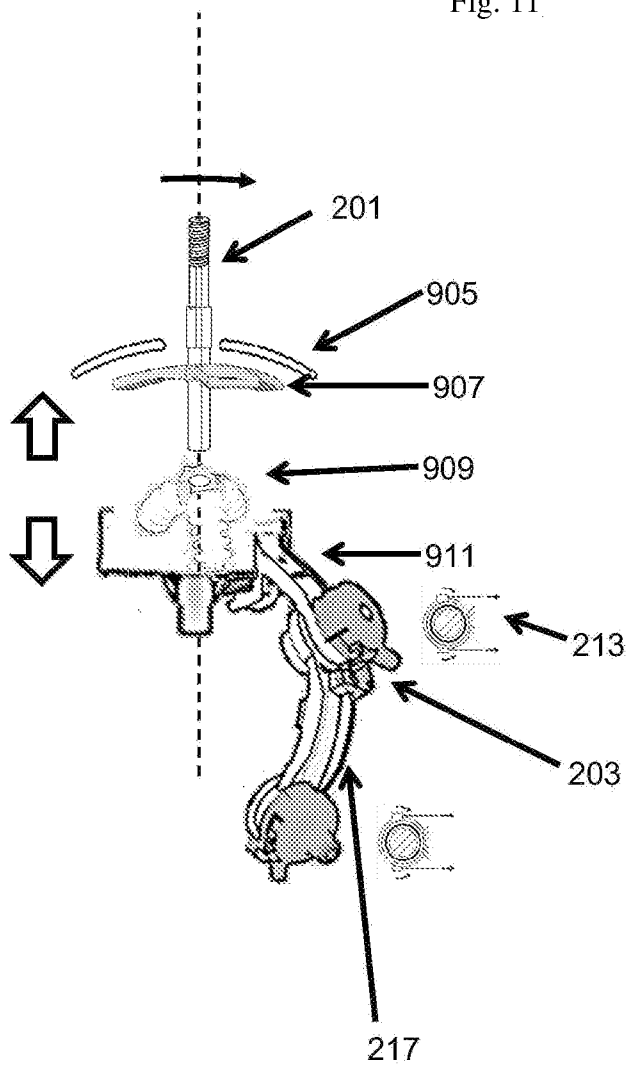


Fig. 12

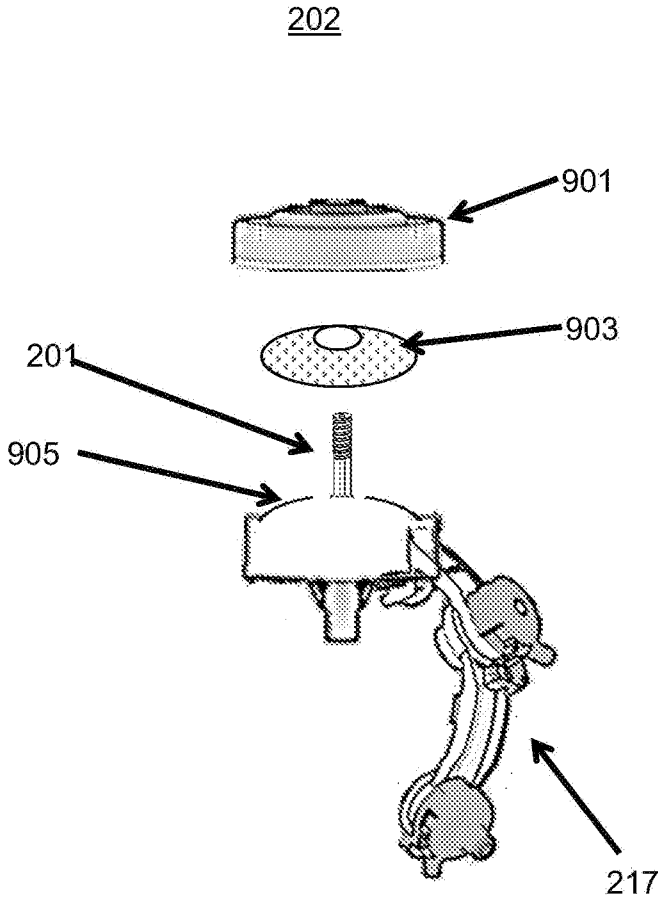


Fig. 13

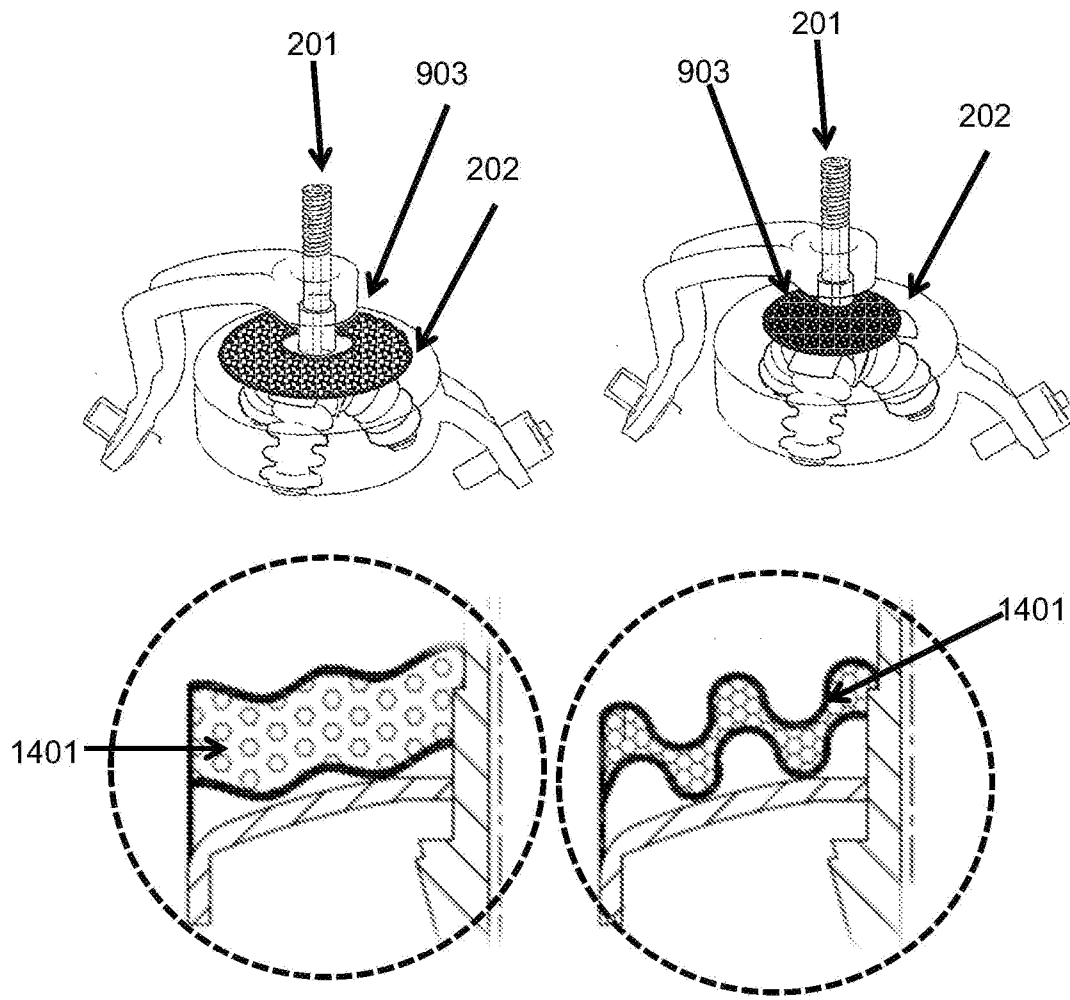


Fig. 14

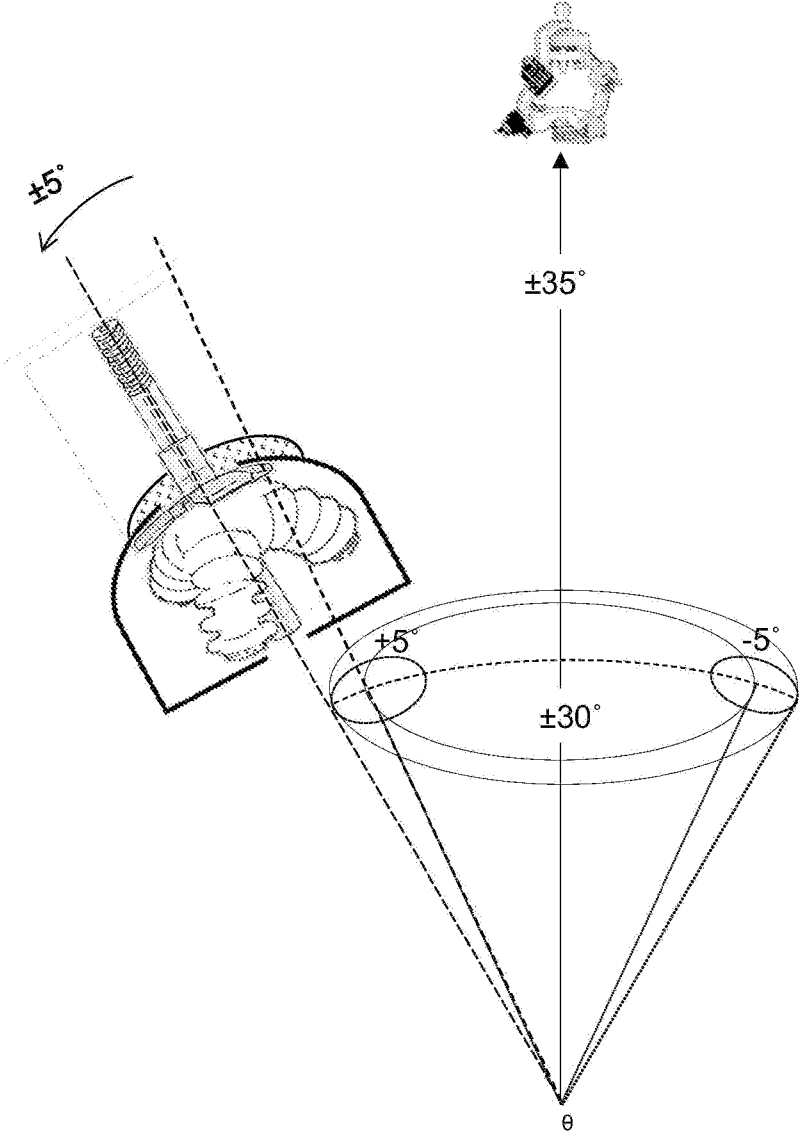


Fig. 15

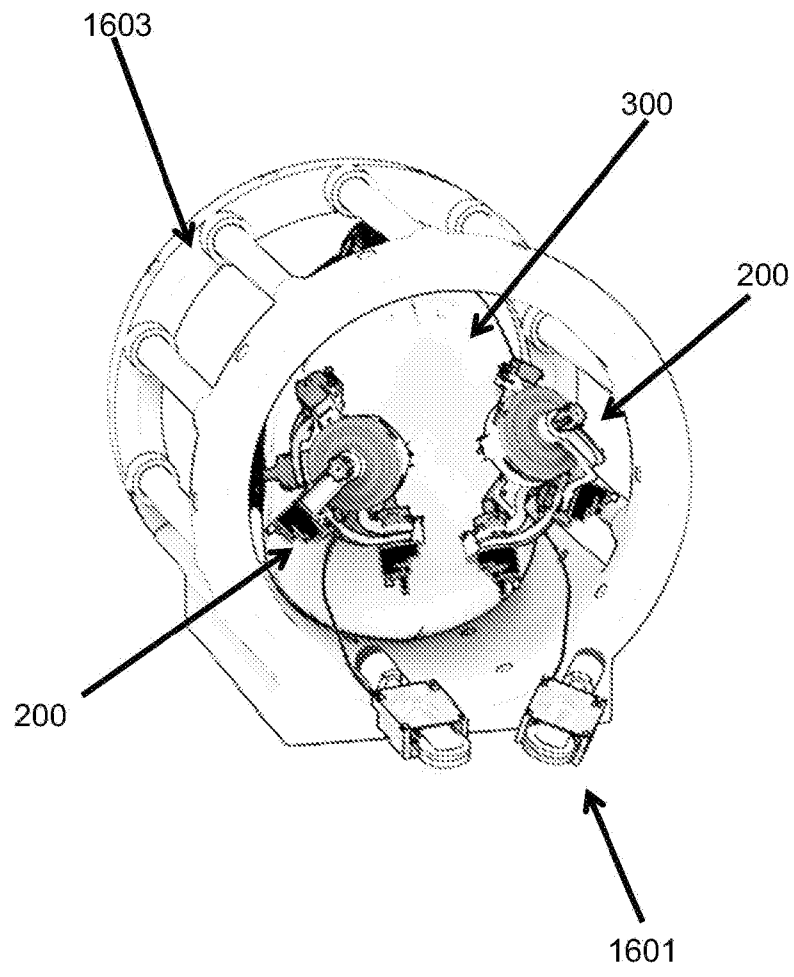


Fig. 16

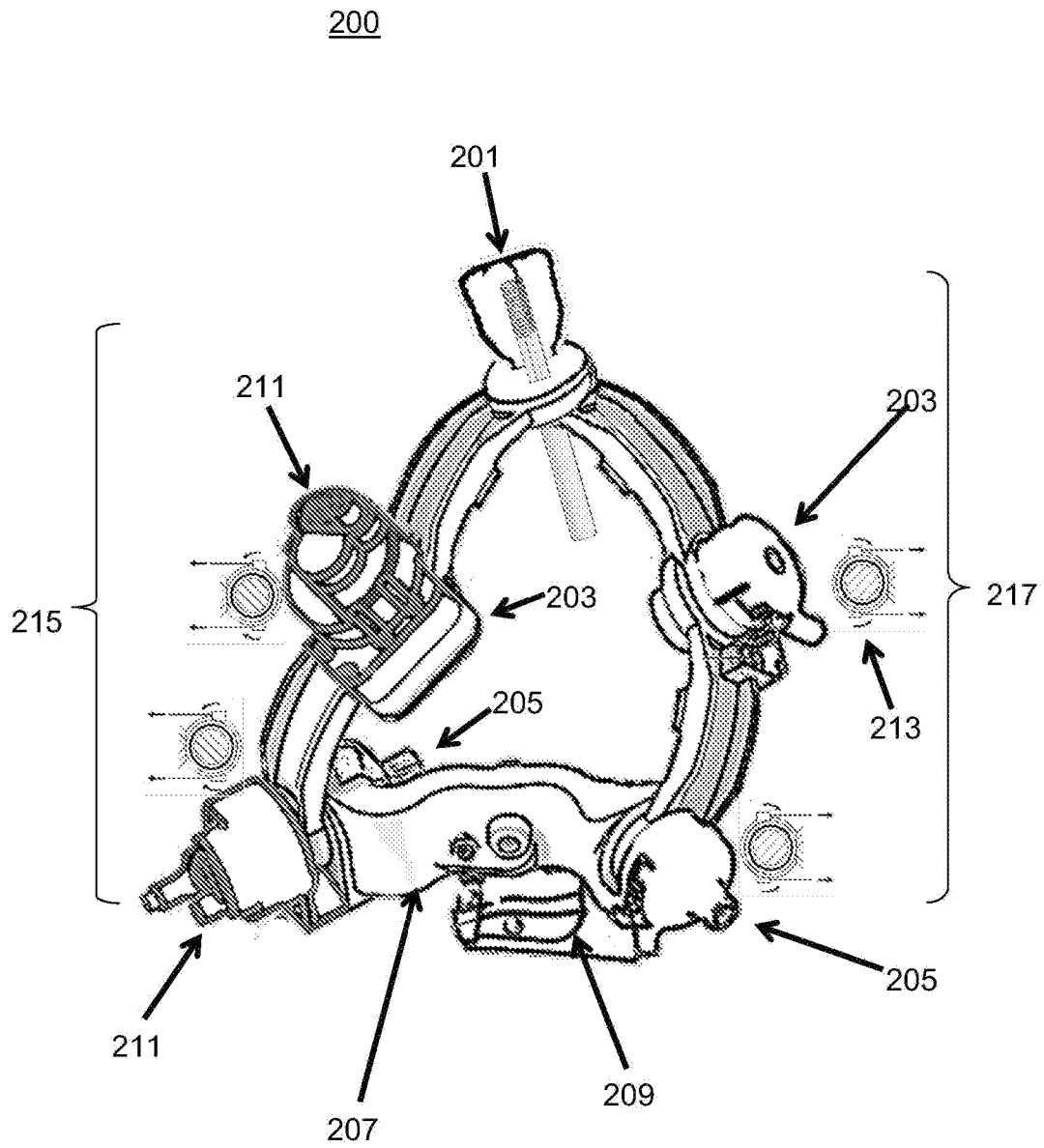


Fig. 17

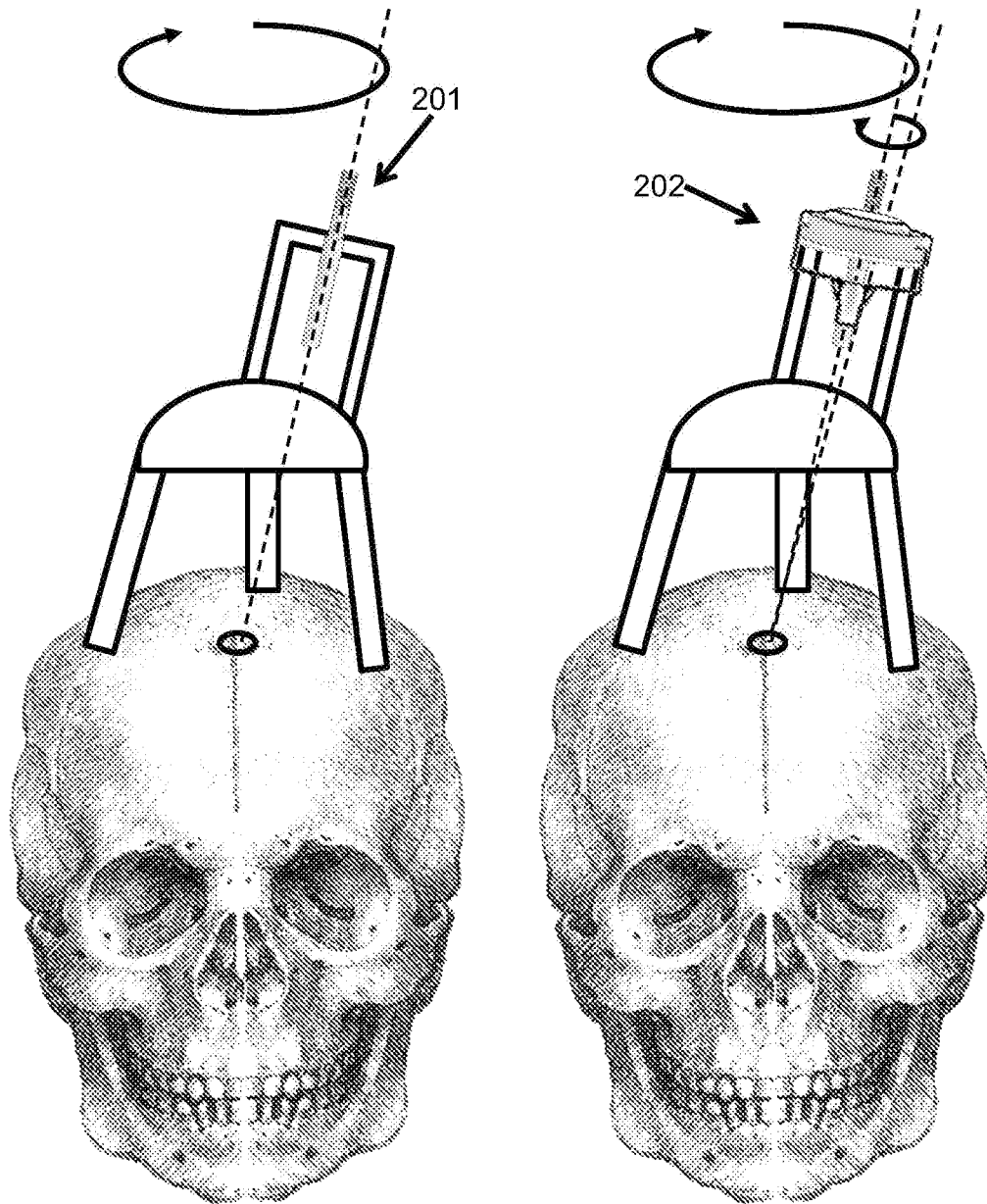


Fig. 18

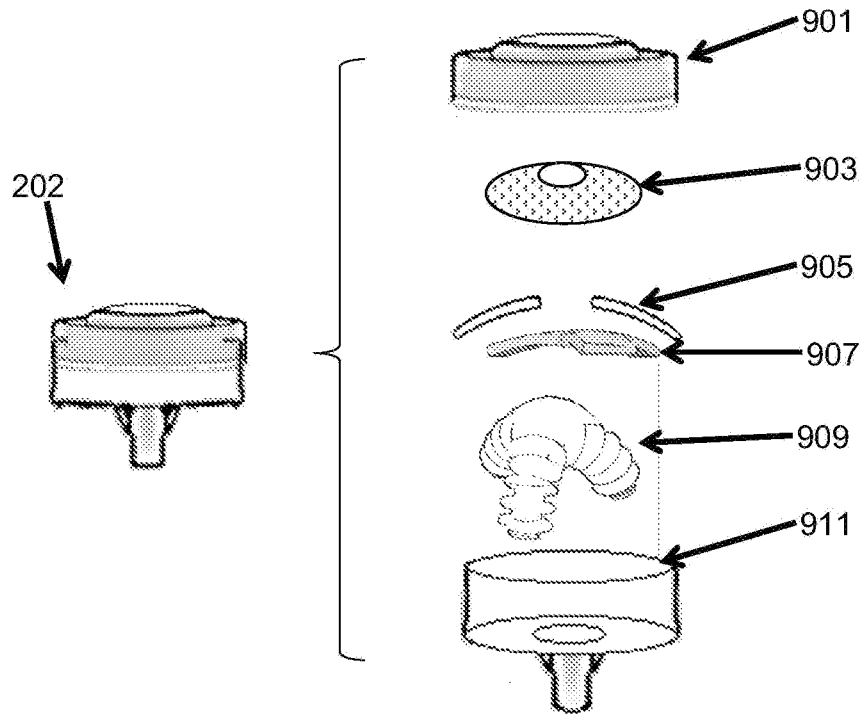


Fig. 19

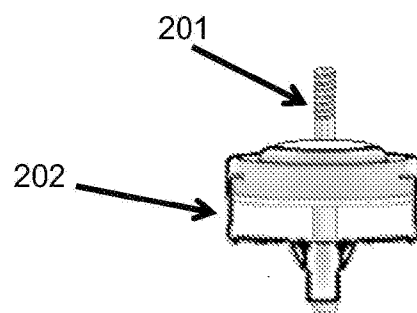


Fig. 20

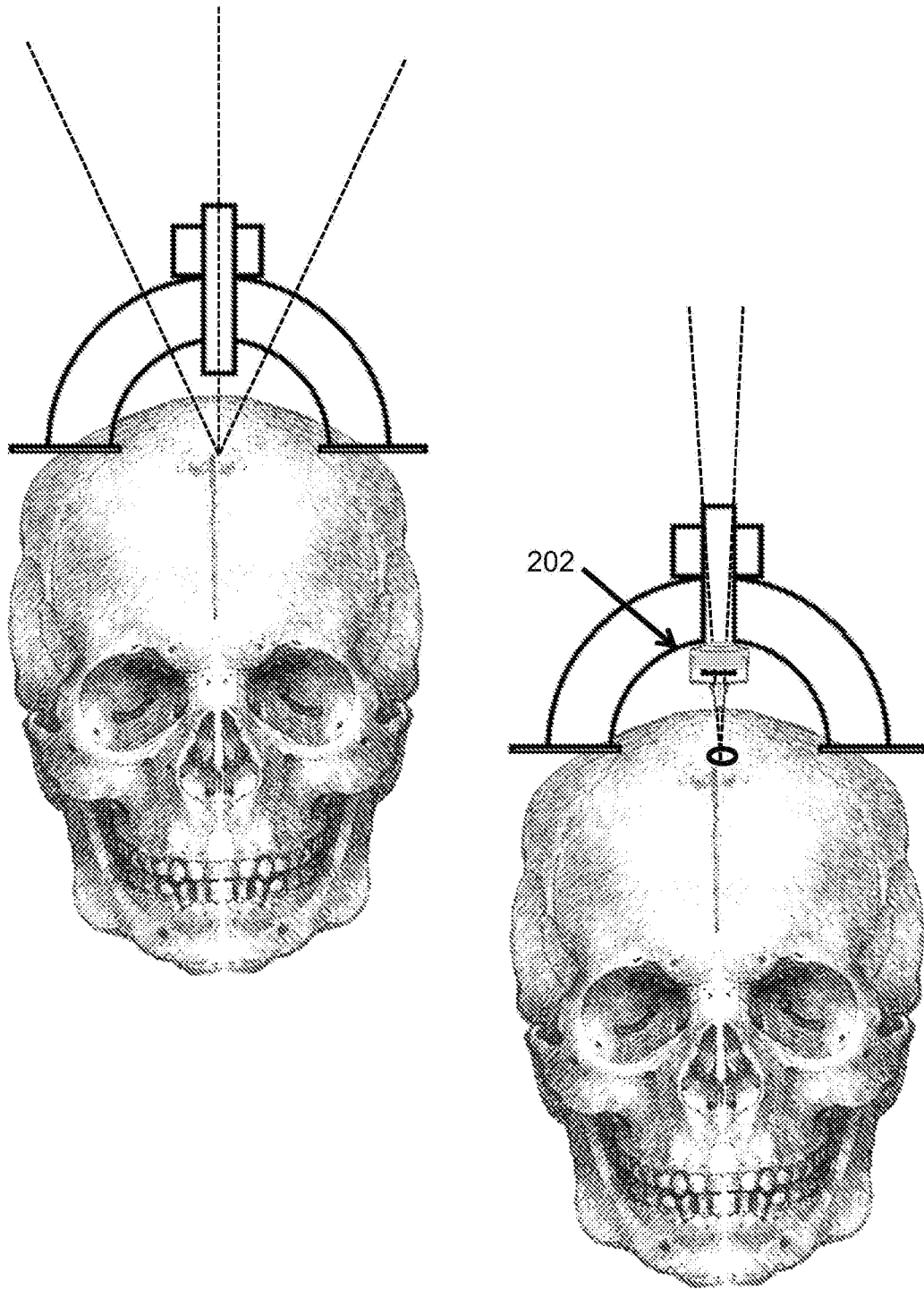


Fig. 21

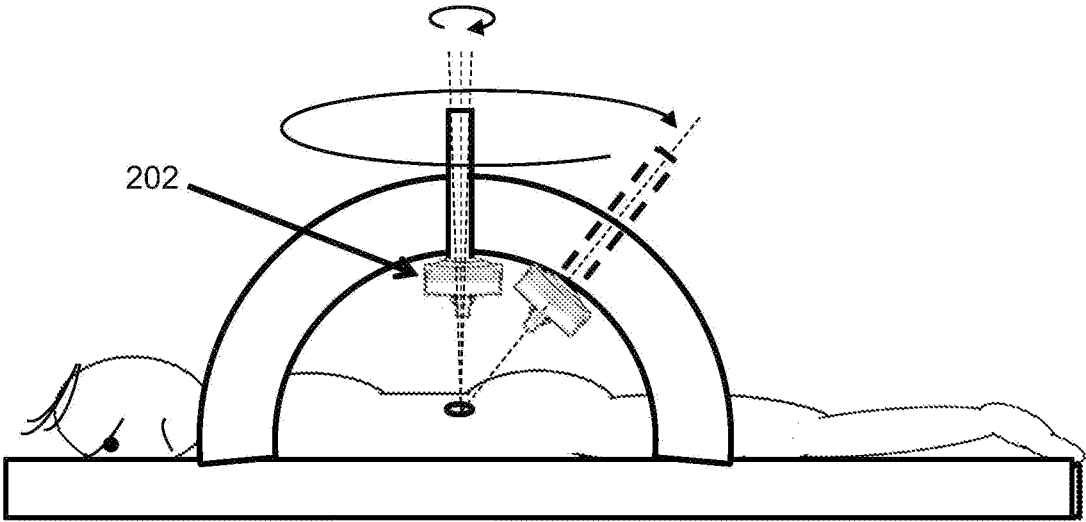


Fig. 22

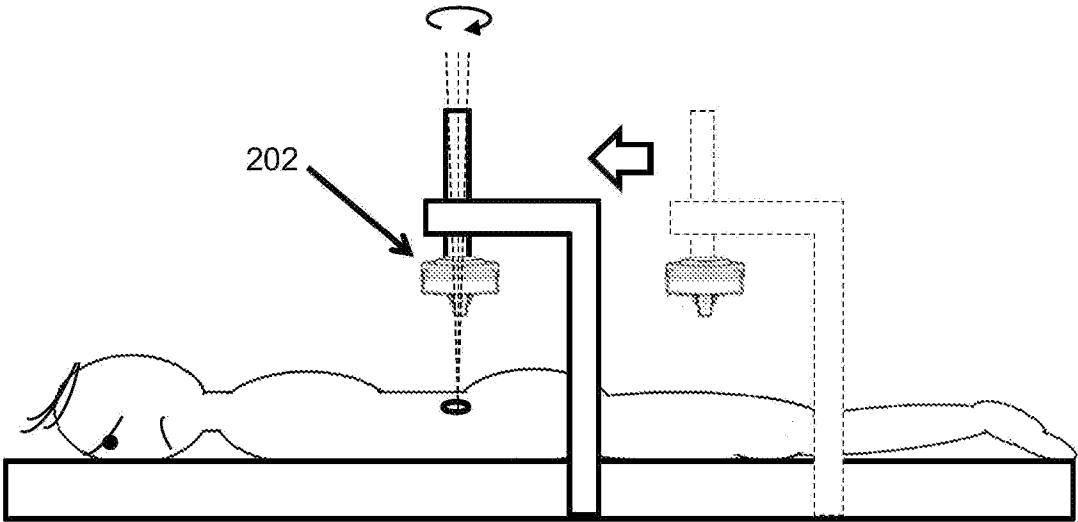


Fig. 23

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/088147

A. CLASSIFICATION OF SUBJECT MATTER A61B34/20(2016.01)i; A61B17/06(2006.01)i 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) IPC: A61B34/-; A61B17/- 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) CNKI, CNTXT, ENTXT, DWPI, IEEE: THE UNIVERSITY OF HONG KONG, KWOKKa Wai, HEZhuoliang, DAJing, HOJustin Di-Lang, TONGHon-Sing, positioner, needle, holder, robot, nest, alignment, centre, remain, auto, structure, frame, bellow, hypotube, tube, fluid, driver, motor, arm		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016367331 A1 (MEDTRONIC, INC.) 22 December 2016 (2016-12-22) description, paragraphs [0007]-[0058], figures 1-12	1-16
Y	WO 2022017384 A1 (THE UNIVERSITY OF HONG KONG) 27 January 2022 (2022-01-27) description, page 4, line 9 to page 15, line 30 and figures 1-9	1-16
Y	CN 111712211 A (THE UNIVERSITY OF HONG KONG) 25 September 2020 (2020-09-25) paragraphs [0011]-[0140], figures 1-13	2, 6-10
A	US 2014025088 A1 (TECHNION RESEARCH & DEVELOPMENT FOUNDATION LTD.) 23 January 2014 (2014-01-23) the whole document	1-16
A	US 2020246099 A1 (ADVANCED NEUROMODULATION SYSTEMS, INC.) 06 August 2020 (2020-08-06) the whole document	1-16
A	EP 1854591 A1 (CHENU, Jean-Maire) 14 November 2007 (2007-11-14) the whole document	1-16
☒ Further documents are listed in the continuation of Box C. ☒ 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 “D” document cited by the applicant in the international application “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 19 July 2024		Date of mailing of the international search report 24 July 2024
Name and mailing address of the ISA/CN CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China		Authorized officer HUANG,Xi Telephone No. (+86) 010-53962487

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/088147

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2017128139 A1 (INNEROPTIC TECHNOLOGY, INC.) 11 May 2017 (2017-05-11) the whole document	1-16

INTERNATIONAL SEARCH REPORT
Information on patent family members

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Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2016367331	A1	22 December 2016	US	10076387	B2	18 September 2018
				WO	2016205066	A1	22 December 2016
WO	2022017384	A1	27 January 2022	None			
CN	111712211	A	25 September 2020	WO	2019144904	A1	01 August 2019
				US	2021015558	A1	21 January 2021
				US	11779398	B2	10 October 2023
				EP	3745983	A1	09 December 2020
US	2014025088	A1	23 January 2014	US	9956041	B2	01 May 2018
				WO	2012095845	A1	19 July 2012
				US	2018014885	A1	18 January 2018
				US	10548670	B2	04 February 2020
				US	2022096161	A1	31 March 2022
				US	11974815	B2	07 May 2024
				US	2020237442	A1	30 July 2020
				US	11197720	B2	14 December 2021
US	2020246099	A1	06 August 2020	US	11406470	B2	09 August 2022
				EP	3917435	A1	08 December 2021
				WO	2020160127	A1	06 August 2020
				US	2022331045	A1	20 October 2022
EP	1854591	A1	14 November 2007	ATE	475516	T1	15 August 2010
				DK	1854591	T3	22 November 2010
				FR	2900857	A1	16 November 2007
				FR	2900857	B1	17 October 2008
				EP	1854591	B1	28 July 2010
				DE	602007008008	D1	09 September 2010
US	2017128139	A1	11 May 2017	WO	2010096419	A2	26 August 2010
				US	2010268067	A1	21 October 2010
				US	8690776	B2	08 April 2014
				US	2012101370	A1	26 April 2012
				US	8585598	B2	19 November 2013
				US	10136951	B2	27 November 2018
				US	2019167354	A1	06 June 2019
				US	11464575	B2	11 October 2022
				US	2014142425	A1	22 May 2014
				US	9398936	B2	26 July 2016