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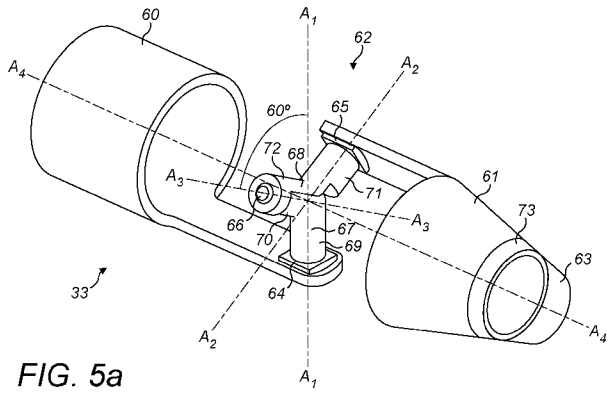

FIG. 5a

(57) Abstract: A surgical robotic component comprising an articulated terminal portion, the terminal portion comprising: a distal segment having an attachment for a surgical tool;a basal segment for attaching the terminal portion to the remainder of the surgical robotic component; and an intermediate compound joint between the distal segment and the basal segment, the intermediate compound joint permitting relative rotation of the distal segment and the basal segment about first, second and third axes;the terminal portion being arranged such that, in at least one configuration of the intermediate compound joint: (i) the axial direction of the basal segment is parallel to the axial direction of the distal segment, and (ii) the first, second and third axes are transverse to the axial directions of the basal and distal segments.

ARTICULATION FOR SURGICAL ROBOTER

This invention relates to surgical articulations, for example for use in surgical robotic components.

BACKGROUND

Figure 1 illustrates a typical surgical robot arm. A patient 1 is lying on a bed 2. The robot arm 3 extends from a base 4 towards the patient. The arm has a series of rigid links 5, 6, 7 which are connected to each other and to the base by articulations 8, 9, 10. The articulations provide a sufficient range of motion that the arm can approach the patient in different ways so as to perform a range of surgical procedures. The links can be made to move about the articulations by motors 11 which are under the control of a surgeon. The final link 7 of the arm terminates in a wrist articulation 12 to which a surgical instrument 13 is attached. The surgical instrument is designed for insertion into the patient and terminates in an end effector for performing or aiding the surgery, for example an endoscope or a cutting tool or pinching tool.

It is desirable for the wrist articulation 12 to be highly mobile, so that the end effector can be placed in a wide range of orientations relative to the final link of the arm. It is also desirable for the wrist joint 12 to be kinematically well-functioning, without there being any attitudes in the core of their range of motion that are difficult to reach or where there could be poor control over the motion of the end effector.

Figure 2 illustrates a typical wrist articulation. This wrist comprises two different types of joints: a "roll" joint which permits rotation about an axis generally along the arm, and a "pitch" joint which permits rotation about an axis generally transverse to the arm. The roll joints are indicated as 21 and 23 and the pitch joint is indicated as 22. With the wrist in the configuration shown in figure 2, the axes of the joints 21, 22 and 23 are indicated as 24, 25 and 26 respectively. This wrist gives an instrument 27 the freedom of movement to occupy a hemisphere whose base is centred on axis 24. However, this wrist is not well suited for use in a surgical robotic component. One reason for this is that when the pitch joint 22 is offset

by just a small angle from the straight position shown in figure 2 a large rotation of joint 21 is needed to produce some relatively small lateral movements of the tip of the instrument. In this condition, when the pitch joint is almost straight, in order to move the end effector smoothly in a reasonable period of time the drive to joint 21 must be capable of very fast operation. This requirement is not readily compatible with making the links small and lightweight because it calls for a relatively large drive motor and sufficiently stiff links and articulations that the motor can react against them without jolting the position of the robotic component.

There is a need for a surgical robot arm and also surgical instruments that can successfully perform a wider range of surgical procedures than existing ones.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a surgical robotic component comprising an articulated terminal portion, the terminal portion comprising: a distal segment having an attachment for a surgical tool; a basal segment for attaching the terminal portion to the remainder of the surgical robotic component; and an intermediate compound joint between the distal segment and the basal segment, the intermediate compound joint permitting relative rotation of the distal segment and the basal segment about first, second and third axes; the terminal portion being arranged such that, in at least one configuration of the intermediate compound joint: (i) the axial direction of the basal segment is parallel to the axial direction of the distal segment, and (ii) the first, second and third axes are transverse to the axial directions of the basal and distal segments.

Suitably, in the at least one configuration of the intermediate compound joint, the first, second and third axes are co-planar with each other. In the at least one configuration of the intermediate compound joint, the first, second and third axes may be perpendicular to the axial directions of the basal and distal segments.

Suitably, in the at least one configuration of the intermediate compound joint, the axial direction of the basal segment is collinear with the axial direction of the distal segment.

Suitably, the first, second and third axes intersect each other. The first, second and third axes may be co-planar with each other and offset from each other in that plane by 60°.

Suitably, the intermediate compound joint comprises: a first revolute joint which enables the distal segment to rotate about the first axis relative to the basal segment; a second revolute joint which enables the distal segment to rotate about the second axis relative to the basal segment; and a third revolute joint which enables the distal segment to rotate about the third axis relative to the basal segment.

The first, second and third revolute joints may be arranged to be independently driven.

Suitably, the surgical robotic component comprises a first drive shaft located in the basal segment for driving the first revolute joint, a second drive shaft located in the distal segment for driving the second revolute joint, and a third drive shaft located in the basal segment for driving the third revolute joint.

Suitably, the terminal portion comprises an additional revolute joint between the distal segment and the attachment, which permits rotation of the attachment about the axial direction of the distal segment.

Suitably, the only means of articulating the attachment relative to the basal segment are the intermediate compound joint and the additional revolute joint.

Suitably, the intermediate compound joint comprises a first intermediate segment and a second intermediate segment, the first intermediate segment coupled to the basal segment and separately coupled to the second intermediate segment, and the second intermediate segment coupled to the distal segment and separately coupled to the first intermediate segment. The first intermediate segment may comprise a basal arm portion coupled to the basal segment such that motion of the basal arm portion is restrained to rotation about the first axis relative to the basal segment. The second intermediate segment may comprise a

distal arm portion coupled to the distal segment such that motion of the distal arm portion is restrained to rotation about the second axis relative to the distal segment.

Suitably, the first intermediate segment comprises a first connecting arm portion and the second intermediate segment comprises a second connecting arm portion, the first connecting arm portion coupled to the second connecting arm portion such that motion of the first connecting arm portion is restrained to rotation about the third axis relative to the second connecting arm portion.

The surgical robotic component may be a surgical robot arm. The surgical tool may be a surgical instrument which terminates in a surgical end effector.

The surgical robotic component may be a surgical instrument suitable for being driven by a surgical robot arm. The surgical tool may be a surgical end effector.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of example with reference to the accompanying drawings. In the drawings:

figure 1 shows a surgical robot arm;

figure 2 shows a robotic component wrist;

figure 3 shows a robot arm having a surgical instrument attached thereto;

figure 4 shows a surgical instrument;

figure 5 shows a robotic wrist component. The wrist is illustrated in three different configurations at figure 5a, 5b and 5c; and

figure 6 shows an exemplary configuration in which the robotic wrist component of figure 5 can be driven.

DETAILED DESCRIPTION

Figure 3 shows an exemplary robot arm (indicated generally at 30) having a surgical instrument 31 attached thereto. The robot arm extends from a base 32. The base could be mounted to the floor of an operating theatre, or to a fixed plinth, could be part of a mobile

trolley or cart, could be mounted to a bed or could be mounted to the ceiling of an operating room. The base is fixed in place relative to the patient's bed or chair when an operation is being carried out. The robot arm comprises a wrist portion shown generally at 33 and a main portion shown generally at 34. The main portion makes up the majority of the extent of the arm and terminates at its distal end in its attachment to the wrist portion. The proximal end of the main portion is attached to the base. The wrist portion makes up the distal part of the arm and is attached to the distal end of the main portion.

The main portion of the arm comprises four joints 35, 36, 37, 38 and three shaft sections 39, 40, 41. The joints are revolute joints. The shaft sections are rigid, with the exception of joints 35 and 37 which are set into shaft sections 39 and 40 respectively. Each shaft section may have substantial length, and serve to provide the arm with reach and the ability to offset the wrist laterally and/or vertically from the base. The first shaft section could be truncated relative to the second and third shaft sections if the base is located in a suitable place; particularly if the base is elevated from the floor.

The first shaft section 39 is attached to the base 32. In practice the first shaft section can conveniently extend in a generally upright direction from the base but it could extend at a significant incline to vertical, or even horizontally.

Joint 35 is located in the first shaft section. Joint 35 permits relative rotation of the proximal part of the first shaft section, which is fixed to the base, and the remainder of the arm about an axis 42. Conveniently, axis 42 is parallel with or substantially parallel with the main extent of the first shaft section in forming the arm, which runs from the base towards joint 36. Thus, conveniently the angle of axis 42 to the main extent of the first shaft section in forming the arm could be less than 30°, less than 20° or less than 10°. Axis 42 could be vertical or substantially vertical. Axis 42 could extend between the base and joint 36.

Joint 36 is located at the distal end of the first shaft section 39. Joint 36 permits relative rotation of the first shaft section 39 and the second shaft section 40, which is attached to the distal end of joint 36, about an axis 43 which is transverse to the first shaft section 39 and/or the second shaft section 40. Conveniently axis 43 is perpendicular or substantially

perpendicular to either or both of the first and second shaft sections. Thus, conveniently the angle of axis 43 to the main extents of either or both of the first and second shaft sections could be less than 30°, less than 20° or less than 10°. Conveniently axis 43 is perpendicular or substantially perpendicular to axis 42 and/or to the axis 44 to be described below.

Joint 37 is located in the second shaft section. Joint 37 permits relative rotation of the proximal part of the second shaft section and the remainder of the arm about an axis 44. Conveniently, axis 44 is parallel with or substantially parallel with the main extent of the second shaft section. Thus, conveniently the angle of axis 44 to the main extent of the second shaft section could be less than 30°, less than 20° or less than 10°. Axis 44 could intersect or substantially intersect (e.g. within 50mm of) axis 43 and the axis 45 that will be described below. In figure 3 joint 37 is shown located closer to the distal end of the second shaft section than the proximal end. This is advantageous because it reduces the mass that needs to be rotated at joint 37, but joint 37 could be located at any point on the second shaft section. The second shaft section is conveniently longer than the first shaft section.

Joint 38 is located at the distal end of the second shaft section 40. Joint 38 permits relative rotation of the second shaft section and the third shaft section 41, which is attached to the distal end of joint 38, about an axis 45 which is transverse to the second shaft section 40 and/or the third shaft section 41. Conveniently axis 45 is perpendicular or substantially perpendicular to either or both of the second and third shaft sections. Thus, conveniently the angle of axis 45 to the main extents of either or both of the second and third shaft sections could be less than 30°, less than 20° or less than 10°. Conveniently axis 45 is perpendicular or substantially perpendicular to axis 44.

In summary, then, in one example the main portion of the arm can be composed as follows, in order from the base to the distal end of the main portion:

1. a first shaft section 39 having substantial or insubstantial length and containing a joint 35 that permits rotation e.g. about an axis generally along the extent (if any) of the first shaft section in forming the arm (a “roll joint”);

2. a joint 36 permitting rotation transverse to the first shaft section and/or to the axis of the preceding joint (joint 35) and/or to the axis of the succeeding joint (joint 37) (a “pitch joint”);

3. a second shaft section 40 having substantial length and containing a joint 37 that permits rotation about an axis generally along the extent of the second shaft section and/or to the axis of the preceding joint (joint 36) and/or to the succeeding joint (joint 38) (a roll joint);
4. a joint 38 permitting rotation transverse to the second shaft section and or to the preceding joint (joint 37) and/or to the succeeding joint (joint 38) (a pitch joint); and
5. a third shaft section 41 having substantial length.

The wrist portion 33 is attached to the distal end of the third shaft section. An example of the wrist portion is shown in more detail in figure 5.

Figure 4 illustrates an exemplary surgical instrument, shown generally at 50. The surgical instrument 50 comprises an instrument base 52, an elongate instrument shaft 51, a wrist portion 33, and an end effector 54. The end effector 54 can be made to move about the wrist articulation 33 by motor 53 which is under the control of a surgeon via the robot arm. The end effector could, for example, be a gripper, a pair of shears, a camera, a laser or a knife. An example of the wrist portion 33 is shown in more detail in figure 5.

An exemplary wrist portion 33 is shown in more details in figures 5a, 5b and 5c. The wrist portion 33 may be located at the end of the robot arm as shown in figure 3 and/or at the end of the instrument as shown in figure 4.

Figure 5a shows the wrist 33 in a straight configuration. The wrist 33 comprises a basal segment 60, a distal segment 61 and an intermediate compound joint 62 between the basal segment and the distal segment. Suitably, when the wrist is located at the end of a robot arm as shown in figure 3, the distal segment has an attachment 63 for connecting to a surgical tool, and the basal segment attaches to the remainder of the robot arm. Suitably, when the wrist is located at the end of a surgical instrument as shown in figure 4, the distal segment has an attachment 63 for connecting to an end effector, and the basal segment attaches to the instrument shaft 51. The basal and distal segments are rigid.

The compound joint 62 is arranged so as to permit relative rotation of the distal segment 61 and basal segment 60 about three axes: A1, A2 and A3. The compound joint comprises three

revolute joints 64, 65 and 66. Revolute joint 64 enables distal segment 61 to rotate about axis A1 relative to the basal segment 60. Revolute joint 65 enables distal segment 61 to rotate about axis A2 relative to the basal segment 60. Revolute joint 66 enables distal segment 61 to rotate about axis A3 relative to the basal segment 60.

Compound joint 62 comprises two intermediate segments 67 and 68. Intermediate segment 67 is coupled to basal segment 60 and intermediate segment 68. Intermediate segment 67 is moveably attached to basal segment 60 and to intermediate segment 68. The relative movement of intermediate segment 67 and basal segment 60 is restricted to a rotation about axis A1. The relative motion of intermediate segment 67 and basal segment 60 is restricted to a revolute motion about axis A1. Suitably, the only way of articulating intermediate segment 67 relative to basal segment 60 is rotation about A1 by means of joint 64.

Intermediate segment 68 is coupled to distal segment 61 and intermediate segment 67. Intermediate segment 68 is moveably attached to distal segment 61 and to intermediate segment 67. The relative movement of intermediate segment 68 and distal segment 61 is restricted to a rotation about axis A2. The relative movement of intermediate segment 68 and distal segment 61 is restricted to a revolute motion about axis A2. Suitably, the only way of articulating intermediate segment 68 relative to distal segment 61 is rotation about A2 by means of joint 65.

Intermediate segment 67 and intermediate segment 68 are moveably attached together. The relative movement of intermediate segment 67 and intermediate segment 68 is restricted to a rotation about axis A3. The relative movement of intermediate segment 67 and intermediate segment 68 is restricted to a revolute motion about axis A3. Suitably, the only way of articulating intermediate segment 68 relative to intermediate segment 67 is rotation about A3 by means of joint 66.

Each intermediate segment 67 and 68 is a rigid link. Intermediate segment 67 comprises two arms 69, 70. The two arms 69 and 70 are held fast together at a relative angle which corresponds to the angle between the axes A1 and A3 when the wrist is in the straight configuration depicted in figure 5a. In other words, when the axial directions of the basal

segment 60 and the distal segment 61 are aligned, or in the same attitude, the angle between axial directions of arm 69 and arm 70 of intermediate segment 67 is the same as the angle between axes A1 and A3.

Similarly, intermediate segment 68 comprises two arms 71 and 72. The two arms 71 and 72 are held fast together at a relative angle which corresponds to the angle between the axes A2 and A3 when the wrist is in the straight configuration depicted in figure 5a. In other words, when the axial directions of the basal segment 60 and the distal segment 61 are aligned, or in the same attitude, the angle between axial directions of arm 71 and arm 72 of intermediate segment 68 is the same as the angle between axes A2 and A3.

Arm 70 of intermediate segment 67 is coupled to arm 72 of intermediate segment 68 such that the motion of arm 72 is constrained to rotation about axis A3 relative to arm 70. In the particular example of figure 5, arm 72 embraces arm 70. Arms 70 and 72 are co-axial, and that axis is A3.

Suitably, the only way of articulating the distal segment 61 relative to the basal segment 60 is by motion of the compound joint 62 as described above.

The following describes an exemplary arrangement of the axes A1, A2 and A3. In the arrangement shown in figure 5a in which the axial direction of the basal segment 60 is collinear with the axial direction of the distal segment 61, the axes A1, A2 and A3 are transverse to the axial directions of the basal and distal segments. Suitably, the three axes A1, A2 and A3 are coplanar when the wrist 33 is in the configuration of figure 5a. That plane is perpendicular to the axial directions of the basal and distal segments. Suitably, the axes A1, A2 and A3 intersect each other at a single point on that plane, or substantially intersect at a single point (e.g. by all intersecting a sphere of radius 50mm). Suitably, the axes A1, A2 and A3, and hence the arms of the intermediate segments which are aligned along those axes, are equally spaced in that plane. In other words, for three axes A1, A2 and A3, each axis is offset from each of the other axes by 60°, as shown in figure 5a.

Figures 5b and 5c illustrate the wrist 33 in two different bent configurations, resulting from articulation of compound joint 62 from the straight configuration shown in figure 5a. Like parts are indicated by the same references. Figures 5b and 5c show examples of posing the wrist relative to the configuration in figure 5a by rotation around all three of the joints 64, 65 and 66 about axes A1, A2 and A3 respectively.

The compound joint 62 enables the attachment (which is either (i) the surgical instrument in the case that the wrist 33 is located at the end of the robot arm, or (ii) the end effector in the case that the wrist 33 is located at the end of the surgical instrument) to face any direction in a hemisphere whose base is perpendicular to the axial direction of the basal segment 60.

Each joint of the compound joint 62 may be driven independently of the other joints by one or more motive devices such as electric motors or hydraulic pistons. The motive device(s) may be located locally at the respective joint, or they may be located closer to the base of the robot and coupled to the joints by couplings such as cables or linkages. The motive devices are controllable by a user of the robot.

Figure 6 illustrates an exemplary configuration in which joints 64 and 66 are driven from drive shafts extending through the basal segment 60 of the wrist, and joint 65 is driven from a drive shaft extending through the distal segment 61 of the wrist. In the example of figure 6, hypoid gears are used to drive the joints. In figure 6, like parts to figure 5 are indicated by the same references. Joint 64 is driven by drive shaft 81. Drive shaft 81 terminates in worm 82 which engages gear 83. Gear 83 is held fast to intermediate segment 67. Worm 82 holds gear 83 (and hence intermediate segment 67) fast to basal segment 60 unless driven by drive shaft 81. When drive shaft 81 is driven by a motor, it causes worm 82 to rotate, which causes gear 83 to rotate, which causes intermediate segment 67 to rotate about axis A1 relative to the basal segment 60.

Joint 65 is driven by drive shaft 84. Drive shaft 84 terminates in worm 85 which engages with gear 86. Gear 86 is held fast to intermediate segment 68. Worm 85 holds gear 86 (and hence intermediate segment 68) fast to distal segment 61 unless driven by drive shaft 84. When drive shaft 84 is driven by a motor, it causes worm 85 to rotate, which causes gear 86 to

rotate, which causes intermediate segment 68 to rotate about axis A2 relative to distal segment 61.

Joint 66 is driven by drive shaft 87. Drive shaft 87 terminates in worm 88 which engages with gear 89. Gear 89 is held fast to intermediate segment 68. Worm 88 holds gear 89 (and hence intermediate segment 68) fast to intermediate segment 67 unless driven by drive shaft 87. When drive shaft 87 is driven by a motor, it causes intermediate segment 68 to rotate about axis A3 relative to intermediate segment 67. In the example shown on figure 6, in order to reach gear 89, drive shaft 87 passes through an opening 90 in intermediate segment 67. Drive shaft 87 is articulated using double universal joint 91 so as to cause drive shaft 87 to cooperate with motion of the joints 64 and 65 of the compound joint 62. The double universal joint 91 (also known as a DV joint) counteracts motion caused to drive shaft 87 when joint 64 and/or joint 66 is articulated so as to enable worm 88 to remain engaged with gear 89. A helical universal joint may be used instead of a double universal joint. In an alternative arrangement, drive shaft 87 may reach gear 89 by articulating around intermediate segment 67. Alternatively, an offset hypoid gear may be used for driving joint 66 so as to avoid passing drive shaft 87 through intermediate segment 67. In an alternative example to that shown in figure 6, gear 89 may be held fast to intermediate segment 67 and not to intermediate segment 68, and hence, when driven, cause intermediate segment 67 to rotate about axis A3 relative to intermediate segment 68.

The wrist 33 of figures 5 and 6 has a kinematic redundancy. Compound joint 62 could consist of only two joints which are transverse both to each other and the basal and distal segments. However, it has been found that when the compound joint consists of only two joints which permit motion transverse to each other and the axial direction of the basal segment, the bend angle of the distal segment relative to the basal segment is limited to about 60°. However, by using an additional joint in compound joint 62 such that basal and distal segments are rotatable about the three axes A1, A2 and A3, it has been found that a wider range of motion results, with a bend angle of up to 120°. In practice, when motion about one axis reaches the end of its travel, motion about another axis can continue the motion. Additionally, the kinematic singularity described above is eliminated. Additionally, there is often more than one way in which the joints can be articulated to get from a first orientation of wrist 33 to a

second orientation of wrist 33. Conveniently, the path taken is the one that minimises the total joint motion. Thus, the robotic component that the wrist is located in does not need as much space around it to be able to articulate to its possible positions. In the case of a robot arm as shown in figure 3, this can make it easier to position the bases of multiple robots around an operating site because surgical staff have more freedom over where to locate the robot bases. It can also help to avoid the need to redesign existing operating room workflows to accommodate a robot. It can also improve the accessibility of multiple such arms to an operation site, especially a site for a procedure such as an ENT (ear, nose and throat) procedure where typically multiple instruments must access the operation site through a small opening. In the case of a surgical instrument, this may allow space for a further surgical instrument to be used in the operation, for example in an ENT procedure where space for the instruments inside the body is very limited.

The wrist 33 is capable of a large bend angle, but is still slim and lightweight. The compact arrangement of joints in compound joint 62 are much lighter weight than alternative joint configurations which achieve a comparable bend angle. For example, a double universal joint can be used to achieve a comparable bend angle, but is significantly more complex in structure and heavier. The more lightweight the compound joint 62, the less stiff the shafts of the robot arm and instrument need to be to support the compound joint, and hence the lighter weight the whole robot can be. This makes the robot easier to move around the operating theatre and set up for use. Further joints could be used in the compound joint to further increase the redundancy and hence the range of motion of the compound joint. However, further joints add weight and complexity. Additional drive shafts may be required to drive the additional joints.

Although figure 6 shows the constituent joints of the compound joint 62 being driven using hypoid gears, other gearing may be used, for example spiroid gears, bevel gears, conventional robotic drives etc. Suitably, each joint of the compound joint 62 is driven using the same gearing.

Suitably, the wrist 33 of figure 5 comprises a further revolute joint 73 attached to the distal end of the distal segment. Joint 73 permits the attachment to rotate about axis A4 relative

to the remainder of the wrist 33. Axis A4 is the axial direction of distal segment 61. In the configuration of figure 5a, the axis A4 conveniently intersects or substantially intersects (e.g. within 50mm) axes A1, A2 and A3 at a single point. Suitably, the only means of articulating the attachment relative to the basal segment are the compound joint 62 and the joint 73.

For the case that the wrist 33 is at the terminal end of the robot arm, as shown in figure 3, the instrument base 52 is designed cooperatively with the end of the robot arm so that the instrument base can be releasably attached to the robot arm with the shaft 51 extending away from the instrument base. Conveniently the shaft 51 extends away from the instrument base in a direction that is parallel or substantially parallel and/or coaxial or substantially coaxial with axis A4 of the distal segment 61. This means that the end effector 54 has substantial range of movement by virtue of the joints of the wrist 33 of the robot arm, and that the joints of the wrist 33 can be used conveniently to position the end effector. This arrangement can permit the end effector to be readily rotated to a desired orientation through motion of the wrist without excessively disrupting a wound channel in the patient. The fact that the elongation of the instrument shaft extends away from the wrist as described above means that the wrist has a degree of articulation that is similar to the wrist of a human surgeon. One result of that is that many surgical techniques practised by humans can readily be translated to motions of this robot arm. This can help reduce the need to devise robot-specific versions of known surgical procedures.

The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems disclosed herein, and without limitation to the scope of the claims. The applicant indicates that aspects of the present invention may consist of any such individual feature or combination of features. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. A surgical robotic component comprising an articulated terminal portion, the terminal portion comprising:

a distal segment having an attachment for a surgical tool;

a basal segment for attaching the terminal portion to the remainder of the surgical robotic component; and

an intermediate compound joint between the distal segment and the basal segment, the intermediate compound joint permitting relative rotation of the distal segment and the basal segment about first, second and third axes;

the terminal portion being arranged such that, in at least one configuration of the intermediate compound joint: (i) the axial direction of the basal segment is parallel to the axial direction of the distal segment, and (ii) the first, second and third axes are transverse to the axial directions of the basal and distal segments.

2. A surgical robotic component as claimed in claim 1, wherein in the at least one configuration of the intermediate compound joint, the first, second and third axes are co-planar with each other.

3. A surgical robotic component as claimed in claim 1 or 2, wherein in the at least one configuration of the intermediate compound joint, the first, second and third axes are perpendicular to the axial directions of the basal and distal segments.

4. A surgical robotic component as claimed in any preceding claim, wherein in the at least one configuration of the intermediate compound joint, the axial direction of the basal segment is collinear with the axial direction of the distal segment.

5. A surgical robotic component as claimed in any preceding claim, wherein the first, second and third axes intersect each other.

6. A surgical robotic component as claimed in any preceding claim, wherein the first, second and third axes are co-planar with each other and offset from each other in that plane by 60°.

7. A surgical robotic component as claimed in any preceding claim, wherein the intermediate compound joint comprises:

a first revolute joint which enables the distal segment to rotate about the first axis relative to the basal segment;

a second revolute joint which enables the distal segment to rotate about the second axis relative to the basal segment; and

a third revolute joint which enables the distal segment to rotate about the third axis relative to the basal segment.

8. A surgical robotic component as claimed in claim 7, wherein the first, second and third revolute joints are arranged to be independently driven.

9. A surgical robotic component as claimed in claim 8, comprising a first drive shaft located in the basal segment for driving the first revolute joint, a second drive shaft located in the distal segment for driving the second revolute joint, and a third drive shaft located in the basal segment for driving the third revolute joint.

10. A surgical robotic component as claimed in claims 7, 8 or 9, wherein the terminal portion comprises an additional revolute joint between the distal segment and the attachment, which permits rotation of the attachment about the axial direction of the distal segment.

11. A surgical robotic component as claimed in claim 10, wherein the only means of articulating the attachment relative to the basal segment are the intermediate compound joint and the additional revolute joint.

12. A surgical robotic component as claimed in any preceding claim, wherein the intermediate compound joint comprises a first intermediate segment and a second

intermediate segment, the first intermediate segment coupled to the basal segment and separately coupled to the second intermediate segment, and the second intermediate segment coupled to the distal segment and separately coupled to the first intermediate segment.

13. A surgical robotic component as claimed in claim 12, wherein the first intermediate segment comprises a basal arm portion coupled to the basal segment such that motion of the basal arm portion is restrained to rotation about the first axis relative to the basal segment.

14. A surgical robotic component as claimed in claim 12 or 13, wherein the second intermediate segment comprises a distal arm portion coupled to the distal segment such that motion of the distal arm portion is restrained to rotation about the second axis relative to the distal segment.

15. A surgical robotic component as claimed in claims 12, 13 or 14, wherein the first intermediate segment comprises a first connecting arm portion and the second intermediate segment comprises a second connecting arm portion, the first connecting arm portion coupled to the second connecting arm portion such that motion of the first connecting arm portion is restrained to rotation about the third axis relative to the second connecting arm portion.

16. A surgical robotic component as claimed in any preceding claim, wherein the surgical robotic component is a surgical robot arm.

17. A surgical robotic component as claimed in claim 16, wherein the surgical tool is a surgical instrument which terminates in a surgical end effector.

18. A surgical robotic component as claimed in any preceding claim, wherein the surgical robotic component is a surgical instrument suitable for being driven by a surgical robot arm.

19. A surgical robotic component as claimed in claim 18, wherein the surgical tool is a surgical end effector.

20. A surgical robotic component substantially as herein described with reference to figures 3, 4, 5 and 6 of the accompanying drawings.

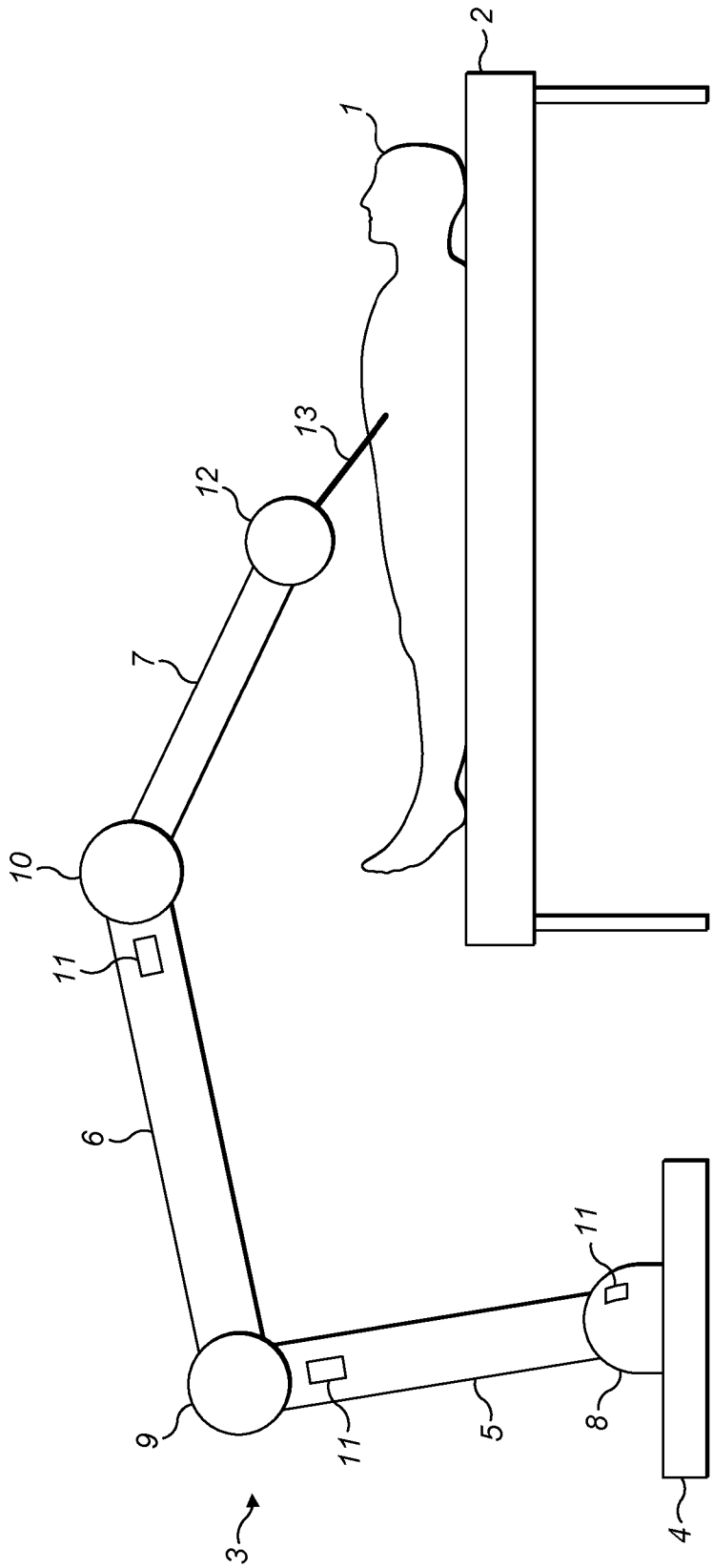

FIG. 1

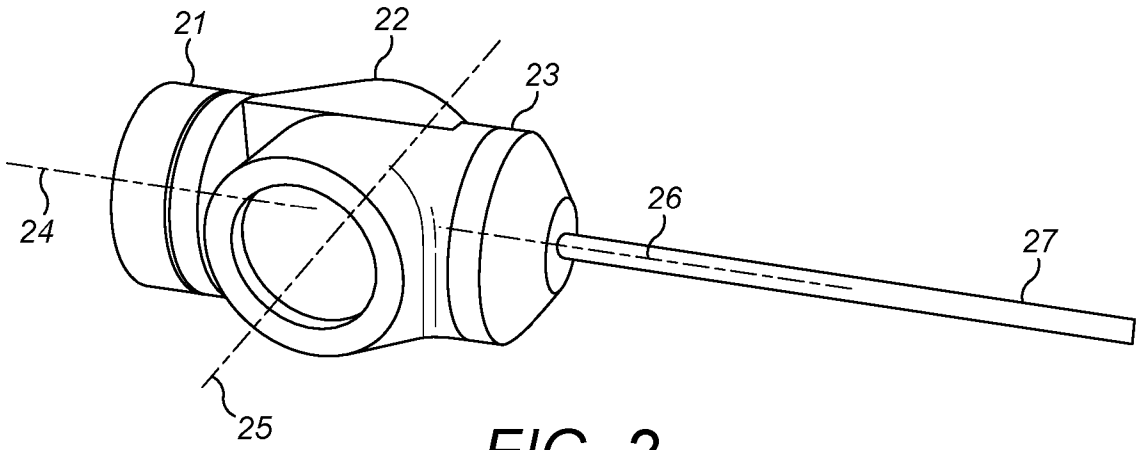

FIG. 2

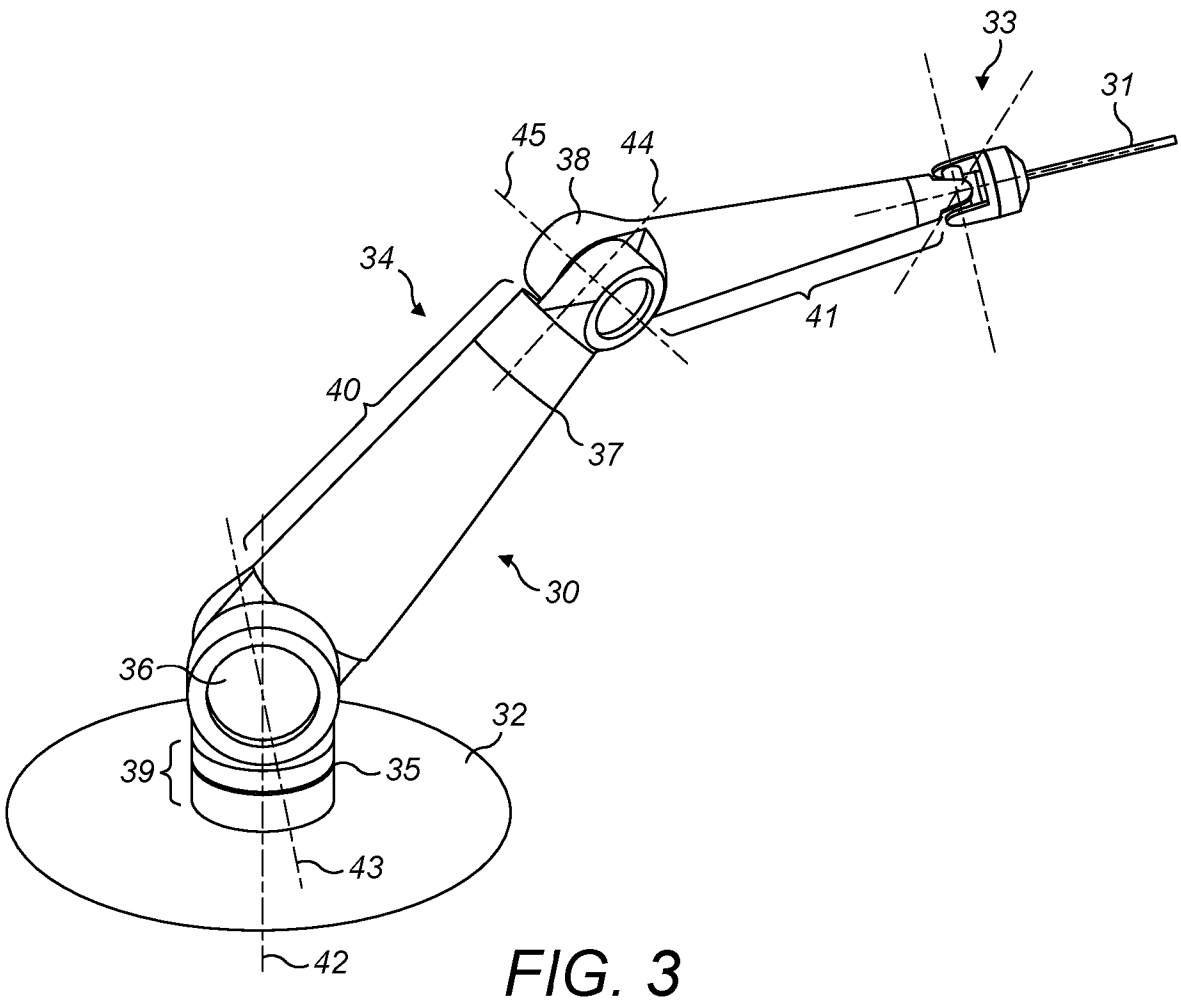

FIG. 3


52
51
50
33
53
54

FIG. 4

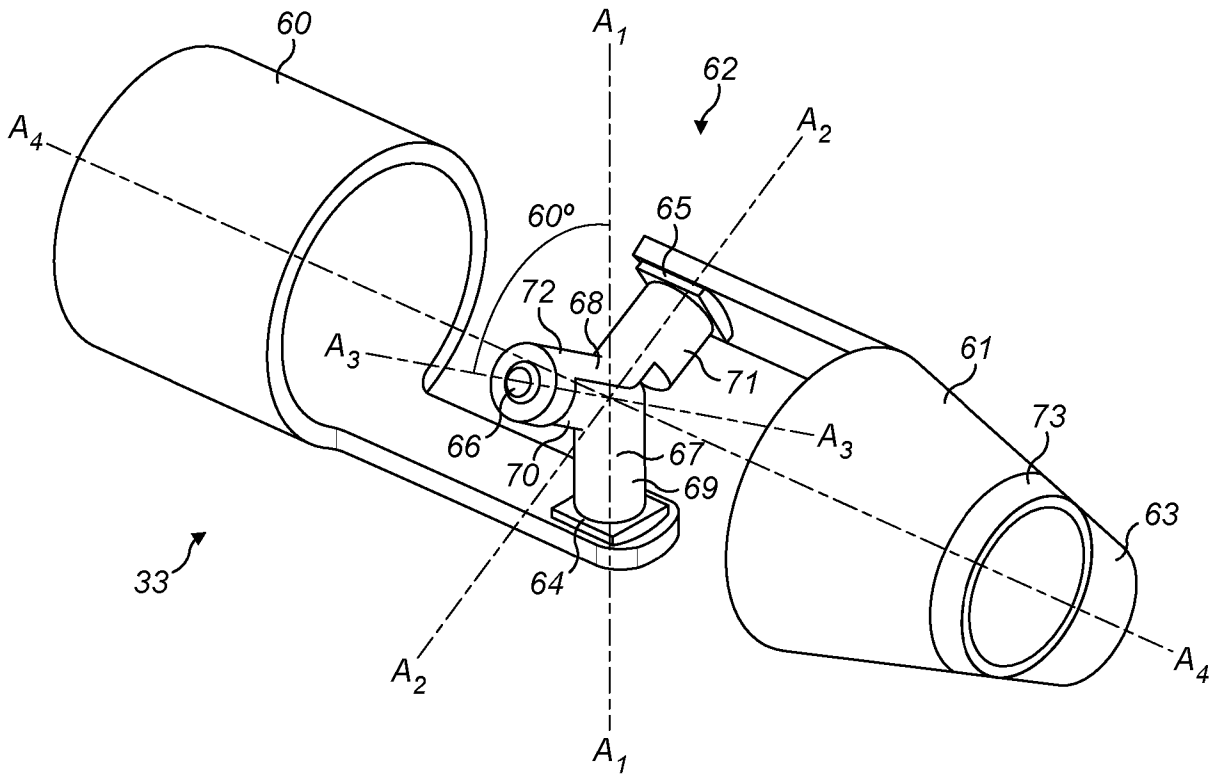
60
A1
62
A2
A4
60°
65
72
68
A3
71
61
73
A3
66
70
67
69
63
33
64
A2
A4
A1

FIG. 5a

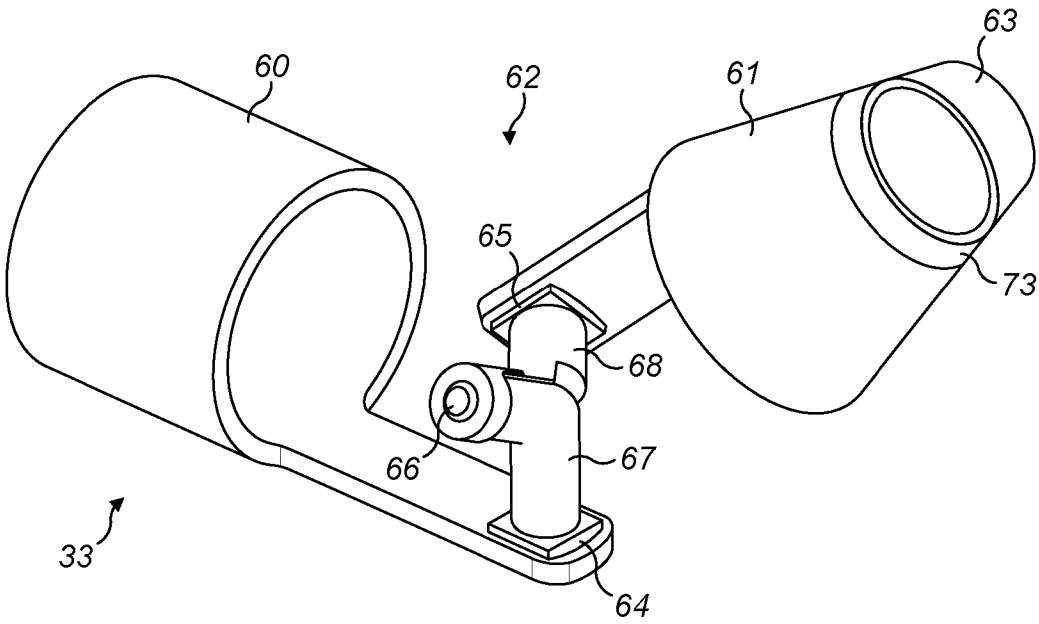

FIG. 5b

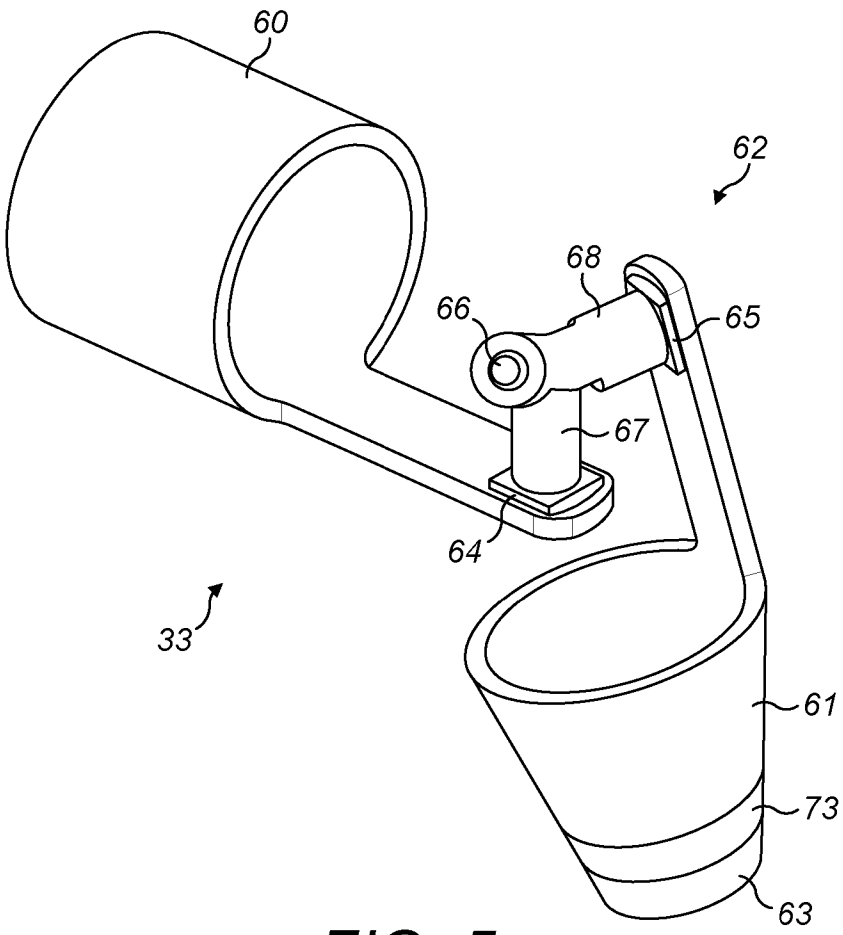

FIG. 5c

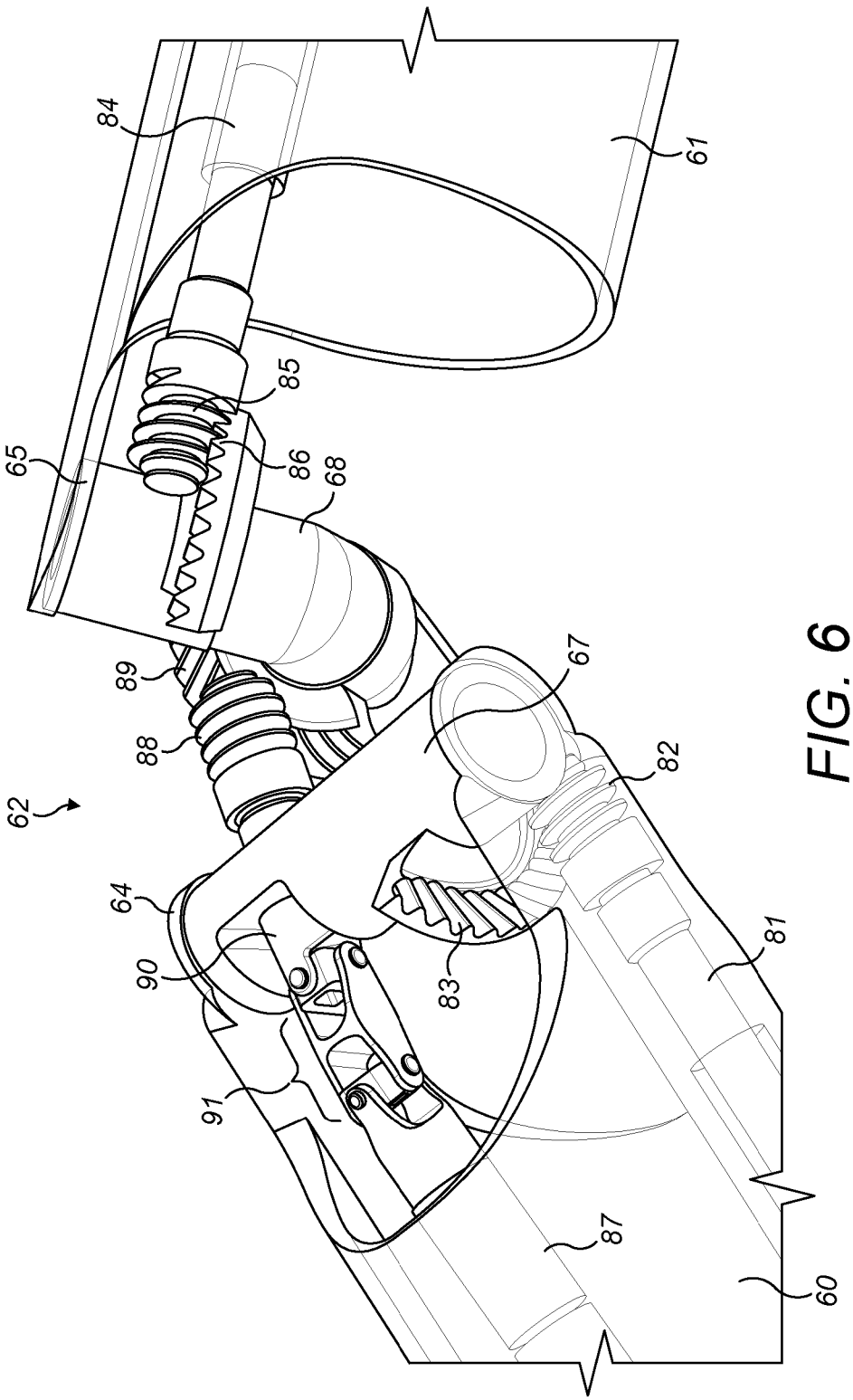

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/052828

A. CLASSIFICATION OF SUBJECT MATTER
INV. B25J17/00 B25J17/02 A61B43/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B B25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 699 177 B1 (WANG YULUN [US] ET AL) 2 March 2004 (2004-03-02) column 10, lines 9-16; figures 15,16 -----	1-6, 16-19
X,P	WO 2015/107326 A1 (CAMBRIDGE MEDICAL ROBOTICS LTD [GB]) 23 July 2015 (2015-07-23) pages 2-5 page 6, lines 10-16 figures 2,4 -----	1,16-19
X,P	WO 2015/132549 A1 (CAMBRIDGE MEDICAL ROBOTICS LTD [GB]) 11 September 2015 (2015-09-11) figures 4,7 -----	1,16-19

☐ 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

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 January 2016	30/03/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schmidt, Matthias

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2015/052828

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

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

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

2. ☒ Claims Nos.: 20
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

see FURTHER INFORMATION sheet PCT/ISA/210

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

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

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

see additional sheet

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

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

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

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

2-6, 16-19(completely); 1(partially)

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 20

Rule 6.2(a) PCT, unclear what to search.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 2-6, 16-19(completely); 1(partially)

   compound joint

   ---

2. claims: 7-11(completely); 1(partially)

   three revolute joint

   ---

3. claims: 12-15(completely); 1(partially)

   coupled intermediate segments

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2015/052828

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6699177 B1	02-03-2004	NONE	
WO 2015107326 A1	23-07-2015	GB 2522950 A	12-08-2015
		GB 2522951 A	12-08-2015
		WO 2015107326 A1	23-07-2015
		WO 2015107327 A1	23-07-2015
WO 2015132549 A1	11-09-2015	GB 2523224 A	19-08-2015
		GB 2523831 A	09-09-2015
		WO 2015132549 A1	11-09-2015