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(54) **ROBOTIC SYSTEM FOR LAPAROSCOPIC SURGERY**

ROBOTERSYSTEM FÜR DIE LAPAROSKOPISCHE CHIRURGIE

SYSTÈME ROBOTISÉ DESTINÉ À LA CHIRURGIE LAPAROSCOPIQUE

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(73) Proprietor: **Universitat Politècnica De Catalunya  
08034 Barcelona (ES)**

(72) Inventors:  
• **AMAT GIRBAU, Josep  
08034 Barcelona (ES)**  
• **CASALS GELPI, Alicia  
08034 Barcelona (ES)**

• **FRIGOLA BOURLON, Manel  
08034 Barcelona (ES)**

(74) Representative: **ZBM Patents - Zea, Barlocchi &  
Markvardsen  
Plaza Catalunya, 1  
08002 Barcelona (ES)**

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## Description

### Field of the Invention

**[0001]** The present invention relates to a robotic system for holding and handling a surgical tool or instrument for surgery, particularly for minimally invasive laparoscopic surgery. The robotic system of the invention comprises a supporting structure to which one or more arms that can be remotely operated from a tele-operation station are slidably attached.

**[0002]** Each of said arms attached to the supporting structure is configured as an articulated assembly comprising two elements. Both elements are hinged to each other and, in turn, the first member can be rotated relative to the supporting structure.

### Background art

**[0003]** The invention finds general application in the field of robotic surgery and particularly in the field of minimally invasive surgery. In minimally invasive surgery smaller incisions are made as compared to those in conventional surgery that require a very precise operation of the surgical tool. Through these incisions surgical operations are carried out, including introducing of vision cameras (laparoscopy) for obtaining images of internal organs and transmitting them to a television monitor through which the surgeon can be guided to perform such surgical procedures.

**[0004]** These surgical procedures through robotic surgery are performed remotely by using tele-operation stations connected to a robotic system via dedicated communication lines.

**[0005]** Robotic systems include architectures designed to behave like a human arm, allowing a robot arm to be arranged in different positions. These architectures are formed by one or several arms mounted on a supporting structure and formed by hinged members so they can be moved properly in the space to operate a tool, terminal organ or end effector, such as a gripper or other device to perform surgical operations. Movement is driven by commands that are remotely received through the tele-operation station.

**[0006]** Each of said arms is an articulated structure comprising several members hinged to each other and rotatably mounted to the supporting structure. One example of robot arm architecture with articulated members is the robot known as *Scara*, with freedom of movement in the X and Y axes, although they are limited in their movements in the vertical axis Z, where simple and short-distance procedures are usually performed.

**[0007]** The limitations of these architectures are typically overcome through an intensive use of complex electronics and mechanisms in order to provide a robotic system suitable for minimally invasive surgery. This involves an undesirably costly robotic system due to complexity as a whole.

**[0008]** Document US2003208186 describes a robotic mechanism with three degrees of freedom comprising a supporting structure to which an arm is slidably attached vertically. The arm comprises a first member and a second member hinged to each other. The first member is in turn hinged to the supporting structure and by means of it a tool can be positioned. However, such architecture has the disadvantage that it does not allow the tool to be properly positioned in order to insert it by a surgical instrument (trocar).

**[0009]** Document US5762458 refers to a system for performing minimally invasive cardiac surgery procedures. This system comprises articulated arms adapted to handle a tool in space. Said arms have several degrees of freedom and, in one embodiment, they are provided with three motor driven joints (that can be driven in displacement and rotation), two passive joints and one motor driven joint that can be rotated for driving a tool placed at the arm end. This robotic system has the disadvantage that it does not allow for a fully effective positioning of the tool through the incision in the patient.

**[0010]** Document JPH07136173 refers to a remote controlled surgical manipulator intended to be used for working on organs. It comprises a single arm structure that can rotate around a longitudinal axis. It further comprises means for positioning an insertion portion that is free to move.

**[0011]** WO0030557 describes surgical manipulator for manipulating medical tools with at least one degree of freedom. The manipulator includes a plurality of arms for pivotally supporting the medical tools. The arms can be oriented through joints whose motions can be controlled.

### Summary of the invention

**[0012]** The present invention provides a robotic system for laparoscopic surgery, particularly but not exclusively, for minimally invasive surgery. The robotic system of the invention has a substantially simpler construction than robotic systems used for the same purpose so far. In addition to the structural simplicity of the robotic system provided herein, the invention features a robotic system for laparoscopic surgery with a particular architecture capable of properly positioning a tool, terminal organ or end effector, such as a gripper or device to perform surgical operations, with high mobility for being properly introduced through an incision in the patient.

**[0013]** The robotic system for minimally invasive laparoscopic surgery of the invention comprises a supporting structure comprising a vertical column around which longitudinal axis arms can be rotated. The column may be mounted on a stationary platform that is preferably provided with wheels for ease of movement if necessary. One or more robotic arms are slidably attached vertically to the column. In the event that more than one robotic arm is provided on the supporting structure, said arms are attached such that they can be slidably displaced vertically in order to adjust their height from the ground

and therefore allowing a surgical tool to be effectively positioned in a proper position.

**[0014]** Each of the arms of the robotic system comprises a first member and a second member. Both the first and second members are hinged to each other through a shaft or joint. On the other hand, the first member of the arm is rotatably mounted on the supporting structure and, in turn, said first member is adapted to be rotated about its longitudinal axis. Particularly, the first member of the arm is rotatably mounted on an extension integral with the supporting structure.

**[0015]** The second member of the robotic arm is adapted to receive a joint with at least two passive degrees of freedom at one end thereof for attaching a surgical tool or instrument. In the event that more than one robotic arm is provided, the arms can be rotated independently of each other around the longitudinal axis of the supporting structure. This architecture provides a significantly simplified assembly.

**[0016]** In some embodiments of the invention, said joint having at least two degrees of freedom for attaching a tool may have three degrees of freedom, such as a gimbal-type joint. One-axis stability (usually in the axis of the tool or instrument direction) and spatial movement suitable for operations of the tool through the incision in the patient by introducing two passive degrees of freedom in the system are thus achieved.

**[0017]** Thus, the assembly is provided with a total of five degrees of freedom (four plus the supporting structure vertical displacement for positioning and manoeuvrability of the tool) so the tool can be always positioned in the direction defined by the penetration site into the cavity made in the patient (for example, the abdominal cavity) through the trocar.

**[0018]** In one embodiment, the longitudinal axis of the first member of the robotic arm can be at least substantially perpendicular to the joint axis of the first member and the second member.

**[0019]** The second member of the arm may comprise two rods arranged substantially parallel to each other and separated by a distance suitable for providing therein and hinged thereto one end of the first member of the arm. This allows collision free rotation of the first and the second members of the robotic arm.

**[0020]** Other objects, advantages and features of the robotic system for minimally invasive laparoscopic surgery of the invention will be apparent from the description of a preferred embodiment of the invention. This description is given by way of non-limitative example and it is illustrated in the accompanying drawings.

#### Brief description of the drawings

**[0021]** In the drawings,

Figure 1 is a diagram of a tele-operation system fitted with robotic systems according to the invention;

Figure 2 is a perspective view of one embodiment of the robotic system of the invention comprising a two-arm structure;

Figure 3 is a perspective view of one embodiment of the robotic system of the invention, and

Figure 4 is a diagrammatic view of the kinematic chain of the robotic system where the degrees of freedom are shown.

#### Description of one preferred embodiment

**[0022]** A tele-operation system 100 for performing minimally invasive laparoscopic surgery is shown in the figures. The tele-operation system 100 comprises a workstation 110 having two robotic systems 200 according to the invention and a tele-operation station 120 for operation and control of the robotic system 200. The tele-operation station 120 includes a three-dimensional control system 130 for displaying the workplace scene with a desired magnification factor (zoom) and a perspective that can be controlled through the movements of one of the available arms.

**[0023]** The operator's control commands can be converted by the tele-operation station 120 into the operation of the robotic system 200 enhancing the manual operator's capabilities and operations can be controlled for more reliability. This allows the articulated robotic arms 210, 220 of the robotic system 200 to be gesturally operated and controlled through the movements of the operator's arms. The movements that the operator is capable to perform with his/her two hands can be applied to any of the arms 210, 220, at will, with the help of auxiliary actuating pedals (not shown). The robotic arms 210, 220 of the robotic system 200 (shown in figure 3) can be electrically actuated for locating and positioning each of the tools, terminal organs or end effectors 900 (such as grippers or surgical devices suitable for performing operations).

**[0024]** The link between tele-operation station 120 and the robotic system 200 is performed through a control unit 140. The control unit 140 is configured by a computer network that allow for real time control of the path of the robotic arms 210, 220 and positioning of surgical tools 900 controlled by the arms 210, 220, so that they all times conform with the movements of the operator's commands. The control unit 140 also performs movement coordination in order to avoid collisions between the arms 210, 220, and monitoring and correcting of the paths thereof according to operator's predefined criteria. The control unit 140 allows the operation with floating reference axes, which are reset in position and orientation at the operator's will in order to facilitate operation of the task in the vertical field position, although the operation is performed within the abdominal capacity of the patient 600 in other positions. It also allows the scale factor to be changed in order to adjust centimetre movements in

the actuation station into millimetre movements as necessary. Such unit 140 further allows restraints on the workload of each of the arms 210, 220 to be defined in order to increase safety of patient 600. Through the unit 140 it is also possible to display the usable working space of the arms 210, 220 in order to facilitate initial proper positioning thereof over the operating table 700 and over the patient 600.

[0025] The signal 150 received from the tele-operation station 120 through magnetic position sensors 450 provides information 460 about the paths of the tools 900. Other position detection means, such as potentiometric or inertial sensors are also possible. This allows operator's movement capability to be facilitated as well as the mechanical constraints of most common 6D actuators to be avoided. A control 600 of the robotic system 200 and a control 650 of the tools 900 as well as a control 660 to avoid collisions are thus made possible.

[0026] The workstation 110 comprises one or more robotic system 200 according to the invention. Figure 3 shows one of said robotic systems 200 in detail. As it can be seen, each robotic system 200 comprises two arms 210, 220 mounted on a common supporting structure 230. Each arm 210, 220 has a load capacity such that forces up to 2.5 Kg can be applied and it is adapted to operate alongside the operating table 700, on either side thereof, or simultaneously using both of them, one on each side of the operating table 700. The arms 210, 220 of the robotic system 200 can be moved in space to cover an appropriate minimum working volume. The working volume is defined by a set of points where the tool 900 of each arm 210, 220 can be positioned, and corresponds to the volume enclosed by the surfaces determined by the points accessed by the tool 900 with its structure fully extended and fully retracted. In the structure of the embodiment, the minimum working volume corresponds to a hemisphere of radius 50 cm arranged centred on the same fixed centre but adjustable in height, and with accuracies of better than 1 mm.

[0027] In the embodiment shown in figures 2 and 3, the supporting structure 230 comprises a vertical column 235 fixed on a platform 240 having lockable wheels 245 for ease of movement. The platform 240 comprises a lower section 250 and **first and second** upper sections 260, 270, rotatably mounted to each other and to the lower section 250. The lower portion 250 of the supporting structure 230 is secured to the platform 240 for holding the robotic system 200 during operation. The **first and second** upper sections 260, 270 of column 235 are mounted so that they can slide vertically according to the vertical direction indicated at D, that is, substantially perpendicular to the platform 240 of the supporting structure 230. The vertical linear displacement D of the **first and second** upper sections 260, 270 allows the height of the robotic arms 210, 220 to the ground to be adjusted independently and thus the proper positioning of the tool 900.

[0028] For simplicity in the description the structure of one of the arms 210 of the robotic system 200 will be

described below, although it will be understood that each of said arms 210, 220 has the same or a technically equivalent configuration.

[0029] The robotic arm 210 of the system described according to the invention comprises two members 300, 400 hinged to each other.

[0030] The first member 300 is an elongated body that is mounted on the supporting structure 230 so that it can be rotated about a longitudinal axis L1 of the first member 300. More specifically, this first member 300 is rotatably mounted on an extension 265 integral with the **first** upper section 260 (the other robot arm 220 is rotatably mounted on the extension 275 corresponding to the **second** upper section 270). The first member 300 can be thus rotated relative to the extension 265 of the **first** upper section 260 of the robotic arm 210 around the longitudinal axis L1 and both arms 210, 220 can be rotated independently around the longitudinal axis L3 of the supporting structure 230, that is, the column 235.

[0031] The second member 400 of the robotic arm 210 is hinged to the first member 300 of the robotic arm 210 via a joint 280 so that they can be rotated about an axis L2, as it can be seen in figure 3. The longitudinal axis L1 of the first member 300 is substantially perpendicular to the axis L2 of the joint 280 of the first member 300 and the second member 400.

[0032] As it can be seen, the second articulated member 400 is formed with two rods 410, 420, which in the embodiment of the figures has an elliptical cross section. It will be understood, however, that the two rods 410, 420 may have each other spaced at a given distance in order to allow the second member 400 to be joined to one end of the first member 300 while preventing both members 300, 400, of the arm 210 from colliding with each other when rotating around axis L2 of the joint 280 arranged on a common end of both rods 410, 420 of the arm 210.

[0033] The opposite end 500 of both rods 410, 420 of the arm 210 is adapted for attaching of a surgical tool or instrument 900 through a pivot axis L4. The pivot axis L4 avoids collisions between the tool 900 and the rods 410, 420 of the second member 400 of the arm 210, 220. A mechanical joint 550 is provided at end 500 which allows the positioning of the tool 900 within the working space to be controlled in an appropriate manner for the operations through the incision in the patient 600. This mechanical joint 550 is a joint having two or more degrees of freedom adapted for attaching of the surgical tool or instrument 900. In the embodiment of the figures, the mechanical joint 550 is a joint having three degree of freedom, such as a gimbal-type joint. This allows two additional passive degrees of freedom to be introduced as well as one-axis stability (usually the positioning axis of tool 900) to be provided. The tool 900 can be therefore positioned always in a direction defined by the penetration site 950 into the cavity performed in the patient 600 (e.g. abdominal cavity), as shown in figure 4.

[0034] A manual adjustment fastening member for the trocars may be provided. This fastening member com-

prises a suspension member that may be manually attached to the supporting structure 230. At one end thereof two elements secured to this suspension member are supported through two manually lockable ball joints that allow the respective trocars to be fastened through a gimbal-type joint for reducing efforts performed with the surgical instrument or tool 900 on the patient's abdomen 600.

**[0035]** Figure 4 schematically shows the kinematic chain of the mechanical structure of one embodiment of the robotic system 200 of the invention. As shown, each arm 210, 220 of the system 200 is an open kinematic chain of the D-G-G-G-G+gimbal type with five degrees of freedom allowing for relative movement of the different elements 235, 300, 400, 900 between each two consecutive links of the structure.

**[0036]** Apart from the prismatic joint (vertical translational movement D), the four joints according to axes L1, L2, L3 and L4 are motor driven with the displacement D being shared by the two arms 210, 220.

**[0037]** Although the present invention has been described in the specification and illustrated in the accompanying drawings with reference to a preferred embodiment thereof, the robotic system of the invention is susceptible of several changes without departing from the scope of protection defined in the following claims.

## Claims

1. Robotic system (200) for laparoscopic surgery comprising a supporting structure (230) that includes at least two arms (210, 220) slidably attached to and hinged on said supporting structure (230) each one of said arms (210; 220) comprising a first member (300) and a second member (400) hinged to each other and a joint (550) having at least two degrees of freedom for attaching a tool (900), the first member (300) being rotatably hinged on the supporting structure (230), and adapted to be rotated around its longitudinal axis (L1), and the second member (400) being adapted to receive the joint (550) **characterized in that:**

the arms (210, 220) are respectively associated with corresponding first and second upper sections (260, 270), wherein

said first and second upper sections (260, 270) are rotatably mounted to each other and to the supporting structure (230) and capable of sliding vertically for independently adjusting the height of the arms (210, 220),

whereby the arms (210, 220) are capable of being rotated independently of each other around a longitudinal axis (L3) of the supporting struc-

ture (230).

2. Robotic system (200) as claimed in claim 1, wherein said longitudinal axis (L1) of the first member (300) of each one of said arms (210; 220) is at least substantially perpendicular to a joint axis (L2) for joining the first member (300) and the second member (400) to each other.
3. Robotic system (200) as claimed in claim 1 or 2, wherein the supporting structure (230) comprises a vertical column around which longitudinal axis (L3) the arms (210, 220) can be rotated.
4. Robotic system (200) as claimed in claim 1, wherein the joint (550) of each one of said arms (210; 220) having at least two degrees of freedom (500) for attaching a tool (900) is a gimbal-type joint.
5. Robotic system (200) as claimed in any of the preceding claims, wherein the second member (400) of each one of said arms (210; 220) consists of two parts (410, 420) on which the first member of the arm (300) is hinged.
6. Robotic system (200) as claimed in any of the preceding claims, wherein the first member (300) of each one of said arms (210; 220) is rotatably mounted on an extension (265; 275) integral with the supporting structure (230).

## Patentansprüche

1. Robotersystem (200) für laparoskopische Chirurgie umfassend eine Tragstruktur, (230) welche mindestens zwei Arme (210, 220) umfasst, welche an der Tragstruktur (230) verschieblich befestigt und angelenkt sind, wobei jeder Arm (210; 220) ein erstes Element (300) und ein zweites Element (400) umfasst, welche aneinander angelenkt sind, und ein Gelenk (550) umfasst, das mindestens zwei Freiheitsgrade zur Befestigung von einem Werkzeug (900) hat, wobei das erste Element (300) drehbar an der Tragstruktur (230) angelenkt ist, und angepasst ist, um um seine Längsachse (L1) herum gedreht zu werden, und das zweite Element (400) angepasst ist, um das Gelenk (550) zu empfangen **dadurch gekennzeichnet, dass:**

die Arme (210, 220) jeweils mit entsprechenden ersten und zweiten Oberteilen (260, 270) verknüpft sind, wobei

der erste und der zweite Oberteil (260, 270) drehbar aneinander und an der Tragstruktur (230) montiert sind und vertikal geschoben werden können, um die Höhe der Arme

- (210, 220) unabhängig einzustellen,  
wobei die Arme (210, 220) unabhängig voneinander um eine Längsachse (L3) der Tragstruktur (230) gedreht werden können. 5
2. Robotersystem (200) wie in Anspruch 1 beansprucht, wobei die Längsachse (L1) des ersten Elements (300) von jedem Arm (210; 220) mindestens im Wesentlichen senkrecht zu einer Gelenkachse (L2) zur Verbindung des ersten Elements (300) und des zweiten Elements (400) miteinander ist. 10
3. Robotersystem (200) wie in Anspruch 1 oder 2 beansprucht, wobei die Tragstruktur (230) eine vertikale Säule umfasst, um deren Längsachse (L3) die Arme (210, 220) gedreht werden können. 15
4. Robotersystem (200) wie in Anspruch 1 beansprucht, wobei das Gelenk (550) von jedem Arm (210; 220) aufweisend mindestens zwei Freiheitsgrade (500) zur Befestigung von einem Werkzeug (900) ein Kardangelenk ist. 20
5. Robotersystem (200) wie in einem der vorhergehenden Ansprüche beansprucht, wobei das zweite Element (400) von jedem Arm (210; 220) aus zwei Teilen (410, 420) besteht, an denen das erste Element des Arms (300) angelenkt ist. 25
6. Robotersystem (200) wie in einem der vorhergehenden Ansprüche beansprucht, wobei das erste Element (300) von jedem Arm (210; 220) an einem einstückig mit der Tragstruktur (230) angeordneten Verlängerungsstück (265, 275) drehbar montiert ist. 30
- 35

## Revendications

1. Système robotisé (200) destiné à la chirurgie laparoscopique comprenant une structure de support (230) qui inclut au moins deux bras (210, 220) attachés de façon coulissante à et montés à charnière sur ladite structure de support (230), chacun desdits bras (210 ; 220) comprenant un premier élément (300) et un deuxième élément (400) montés à charnière l'un par rapport à l'autre et une articulation (550) ayant au moins deux degrés de liberté pour attacher un outil (900), le premier élément (300) étant monté à charnière de façon pivotante sur la structure de support (230), et adapté pour être pivoté autour de son axe longitudinal (L1), et le deuxième élément (400) étant adapté pour recevoir la rotule (550) 40
- 45
- caractérisé en ce que : 50
- 55
- les bras (210, 220) sont associés respectivement avec des correspondantes sections supérieures (260, 270) première et deuxième, dans lequel
- lesdites sections supérieures (260, 270) première et deuxième sont montées à rotation l'une par rapport à l'autre et sur la structure de support (230) et elles peuvent être glissées verticalement pour ajuster de façon indépendante la hauteur des bras (210, 220),
- dans lequel les bras (210, 220) sont capables d'être pivotés de façon indépendante l'un de l'autre autour d'un axe longitudinal (L3) de la structure de support (230).
2. Système robotisé (200) tel que revendiqué dans la revendication 1, dans lequel ledit axe longitudinal (L1) du premier élément (300) de chacun desdits bras (210 ; 220) est au moins essentiellement perpendiculaire à un axe de rotule (L2) pour joindre le premier élément (300) et le deuxième élément (400) l'un à l'autre.
3. Système robotisé (200) tel que revendiqué dans la revendication 1 ou 2, dans lequel la structure de support (230) comprend une colonne verticale autour de l'axe longitudinal (L3) de laquelle les bras (210, 220) peuvent pivoter.
4. Système robotisé (200) tel que revendiqué dans la revendication 1, dans lequel la rotule (550) de chacun desdits bras (210 ; 220) ayant au moins deux degrés de liberté (500) pour attacher un outil (900) est un joint Cardan.
5. Système robotisé (200) tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel le deuxième élément (400) de chacun desdits bras (210 ; 220) est constitué de deux parties (410, 420) sur lesquelles le premier élément du bras (300) est articulé.
6. Système robotisé (200) tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel le premier élément (300) de chacun desdits bras (210 ; 220) est monté à rotation sur une extension (265 ; 275) intégrée dans la structure de support (230).

FIG.1

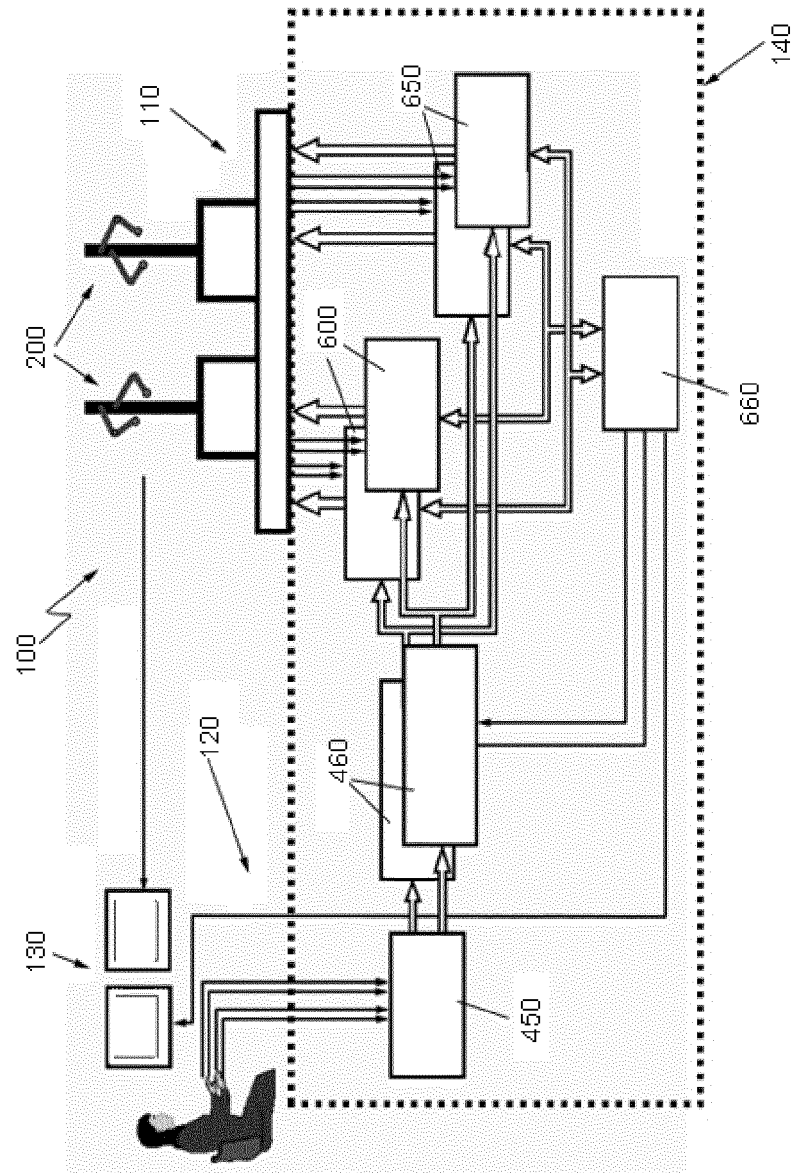


FIG. 2

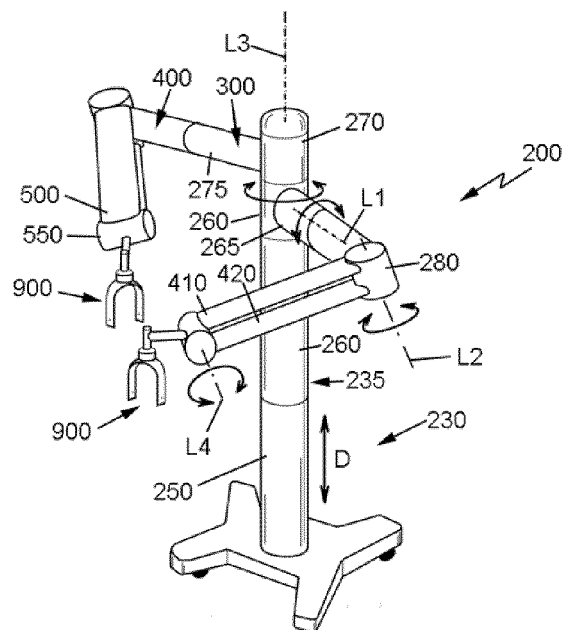
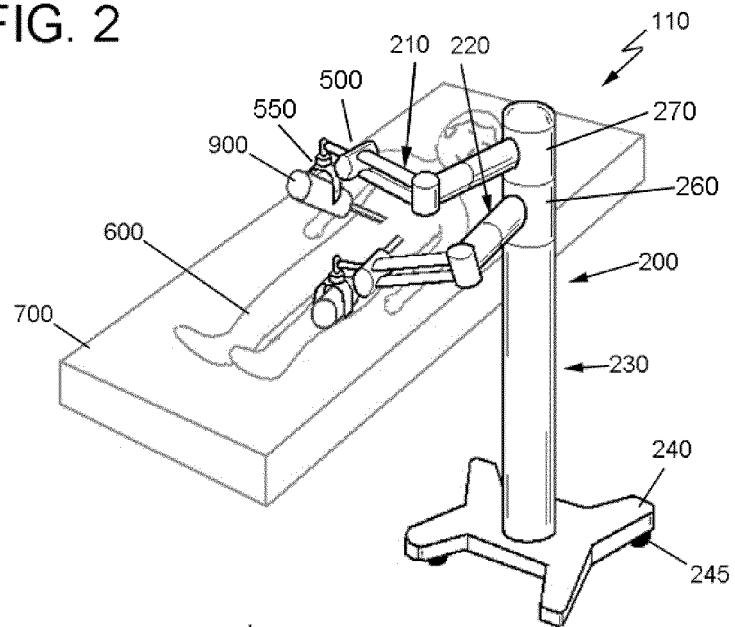
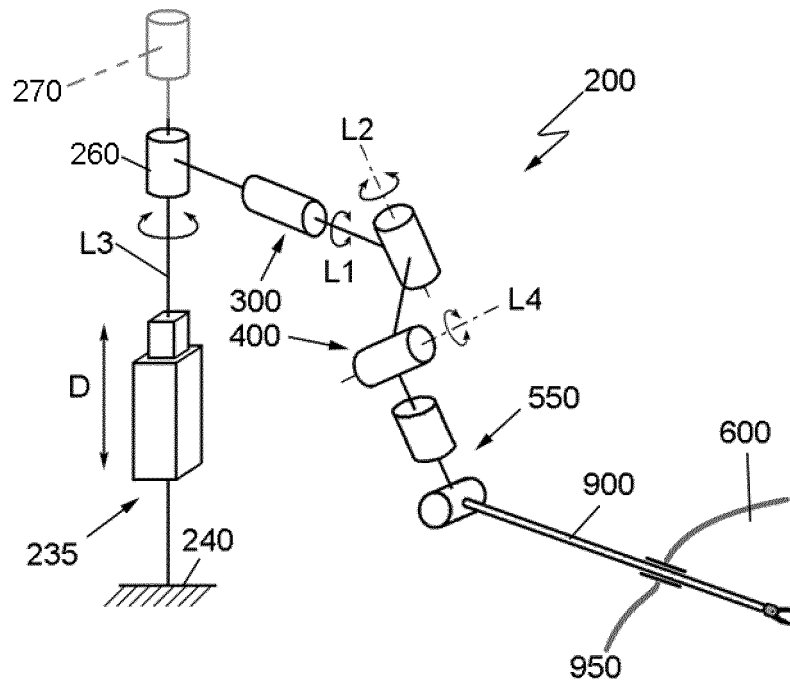


FIG.3



FIG. 4



**REFERENCES CITED IN THE DESCRIPTION**

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[标]申请(专利权)人(译)	加泰罗尼亚理工大学		
申请(专利权)人(译)	Universitat 大学POLITÈCNICA DE CATALUNYA		
当前申请(专利权)人(译)	Universitat 大学POLITÈCNICA DE CATALUNYA		
[标]发明人	AMAT GIRBAU JOSEP CASALS GELPI ALICIA FRIGOLA BOURLON MANEL		
发明人	AMAT GIRBAU, JOSEP CASALS GELPI, ALICIA FRIGOLA BOURLON, MANEL		
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#### 摘要(译)

它包括支撑结构 ( 230 ) , 其中至少一个臂 ( 210; 220 ) 可滑动地连接。每个臂 ( 210; 220 ) 包括彼此铰接的第一和第二构件 ( 300, 400 ) 。第一构件 ( 300 ) 可旋转地铰接到支撑结构 ( 230 ) 并且它可以围绕纵向轴线 ( L1 ) 旋转, 并且第二构件 ( 400 ) 可以接收具有至少两个自由度 ( 550 ) 的接头。附加工具 ( 900 ) 。第一构件 ( 300 ) 的纵向轴线 ( L1 ) 基本垂直于将第一构件 ( 300 ) 和第二构件 ( 400 ) 彼此连接的轴线 ( L2 ) 。获得了简化的结构, 允许工具保持臂 ( 210; 220 ) 的精确和有效的空间运动。

