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(12) **United States Patent**
Green

(10) **Patent No.: US 7,248,944 B2**
(45) **Date of Patent: *Jul. 24, 2007**

(54) **ROLL-PITCH-ROLL WRIST METHODS FOR MINIMALLY INVASIVE ROBOTIC SURGERY**

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(73) Assignee: **Institute Surgical, Inc**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/360,745**

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Related U.S. Application Data

(63) Continuation of application No. 11/015,212, filed on Dec. 16, 2004, now Pat. No. 7,017,124, which is a continuation of application No. 08/709,930, filed on Sep. 9, 1996, now Pat. No. 6,963,792, which is a continuation of application No. 07/823,932, filed on Jan. 21, 1992, now abandoned.

(51) **Int. Cl.**
G06F 19/00 (2006.01)

(52) **U.S. Cl.** **700/245**; 700/250; 700/251; 700/254; 700/257; 700/264; 901/3; 901/46; 901/47

(58) **Field of Classification Search** 700/245, 700/250, 251, 254, 257, 264, 275; 600/101, 600/102, 103, 104, 118, 424, 429; 606/1, 606/130; 901/1, 8, 9, 30, 33, 34
See application file for complete search history.

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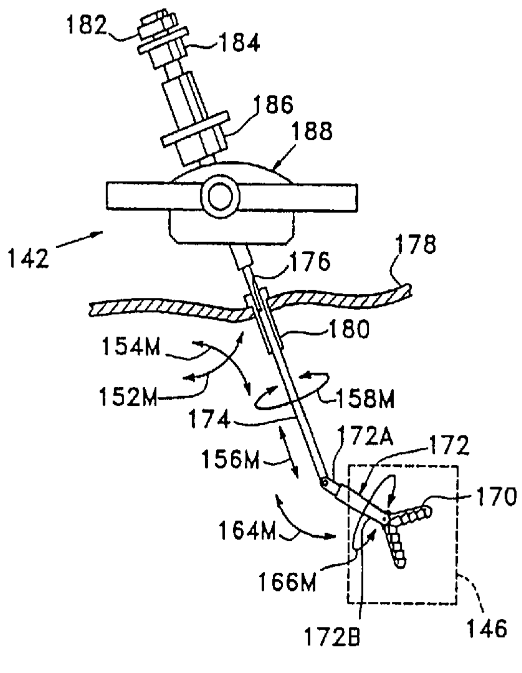
(57) **ABSTRACT**

A teleoperator system with telepresence is shown which includes right and left hand controllers (**72**R and **72**L) for control of right and left manipulators (**24**R and **24**L) through use of a servomechanism that includes computer (**42**). Cameras (**46**R and **46**L) view workspace (**30**) from different angles for production of stereoscopic signal outputs at lines (**48**R and **48**L). In response to the camera outputs a 3-dimensional top-to-bottom inverted image (**30**I) is produced which, is reflected by mirror (**66**) toward the eyes of operator (**18**). A virtual image (**30**V) is produced adjacent control arms (**76**R and **76**L) which is viewed by operator (**18**) looking in the direction of the control arms. Use of the teleoperator system for surgical procedures also is disclosed.

85 Claims, 9 Drawing Sheets



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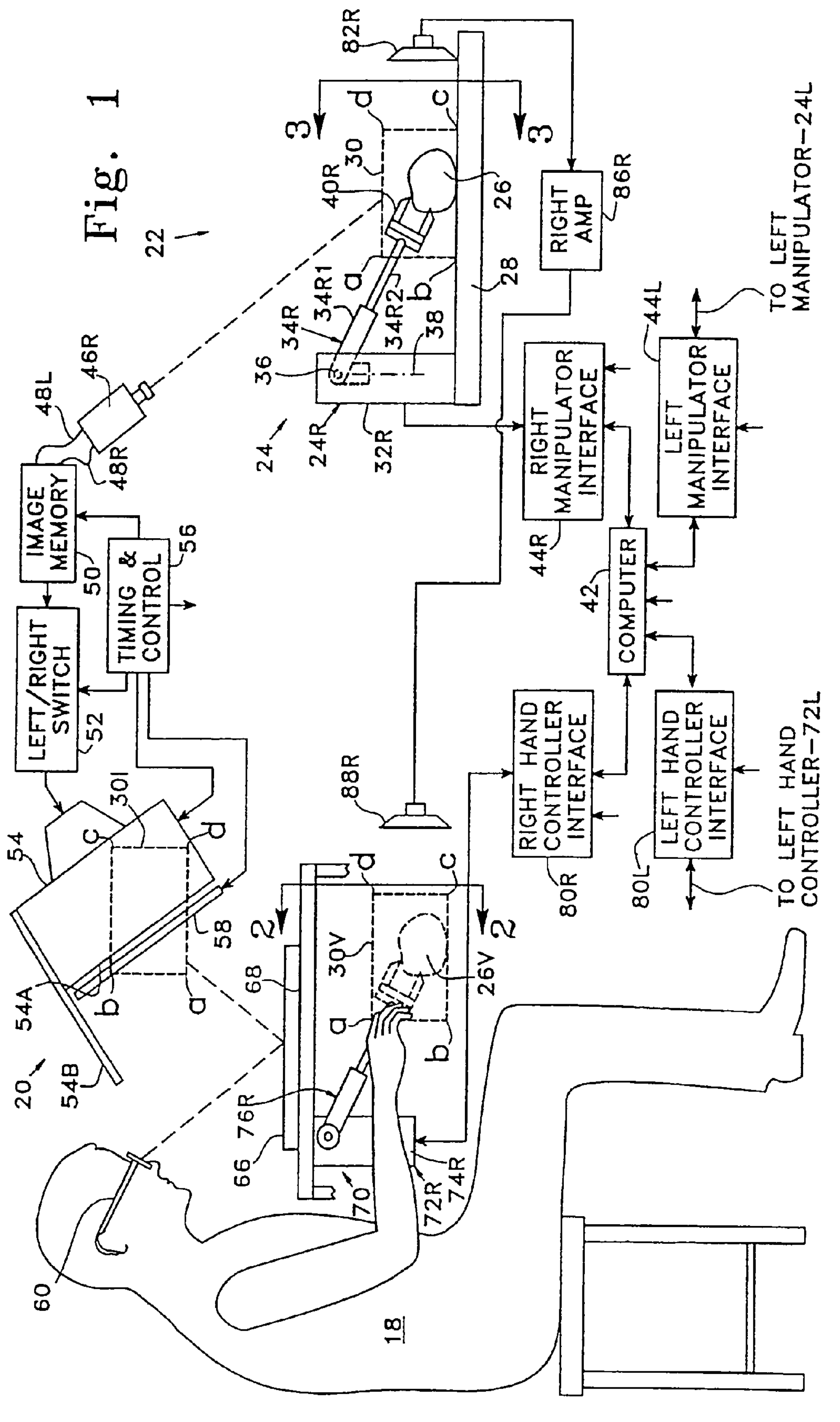


Fig. 1
IMAGE MEMORY
TIMING & CONTROL
LEFT/RIGHT SWITCH
RIGHT AMP
RIGHT MANIPULATOR INTERFACE
LEFT MANIPULATOR INTERFACE
COMPUTER
RIGHT HAND CONTROLLER INTERFACE
LEFT HAND CONTROLLER INTERFACE
TO LEFT MANIPULATOR-24L
TO LEFT HAND CONTROLLER-72L
18
20
22
24
24R
26
26V
28
30
30I
30V
32R
34R
34R1
34R2
36
38
40R
42
44L
44R
46R
48L
48R
50
52
54
54A
54B
56
58
60
66
68
70
72R
74R
76R
80L
80R
82R
86R
88R

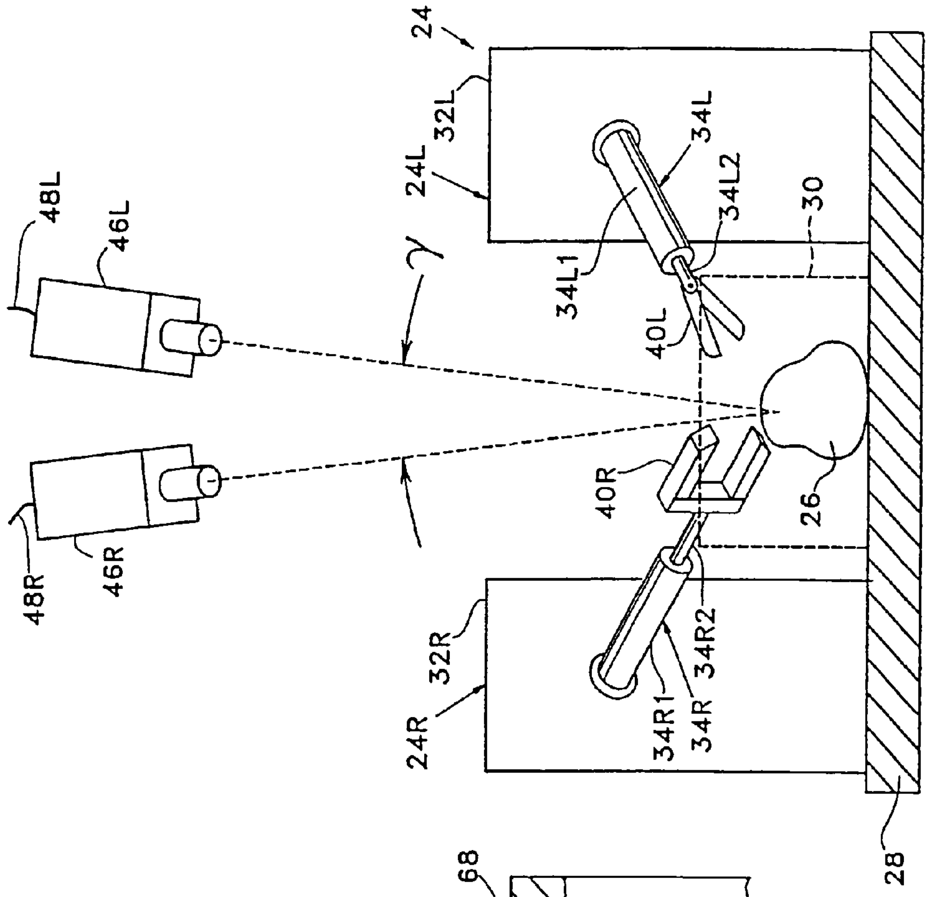

24
24L
32L
34L
34L1
34L2
30
40L
γ
48L
46L
48R
46R
40R
26
24R
32R
34R1
34R
34R2
28

Fig. 3

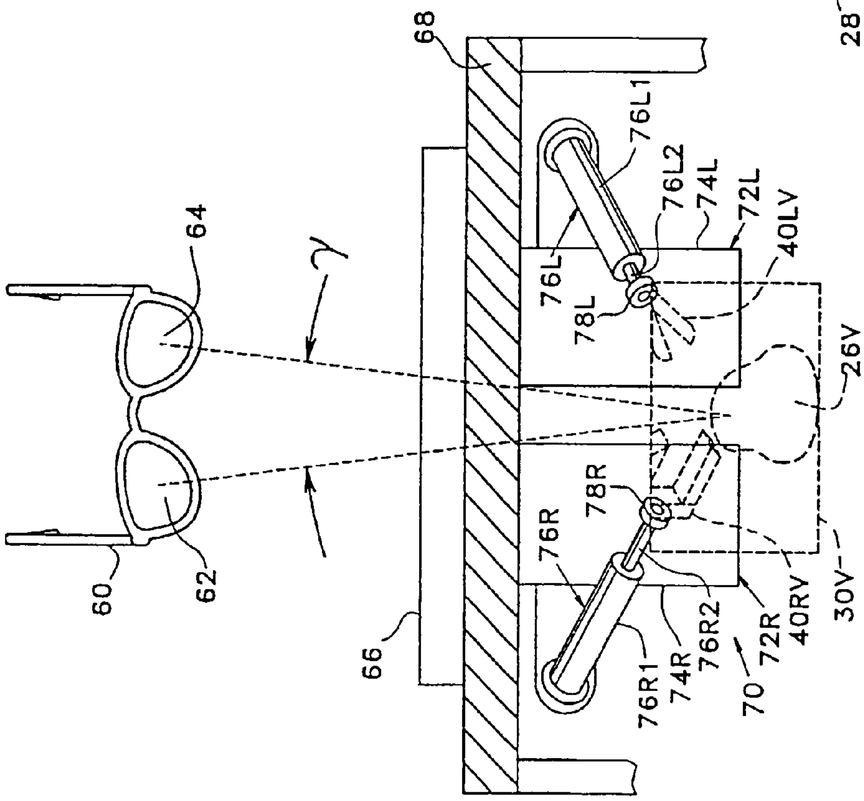

68
64
γ
60
62
66
76L1
76L2
76L
74L
72L
40LV
78L
26V
78R
76R
76R2
74R
76R1
72R
40RV
30V
70

Fig. 2

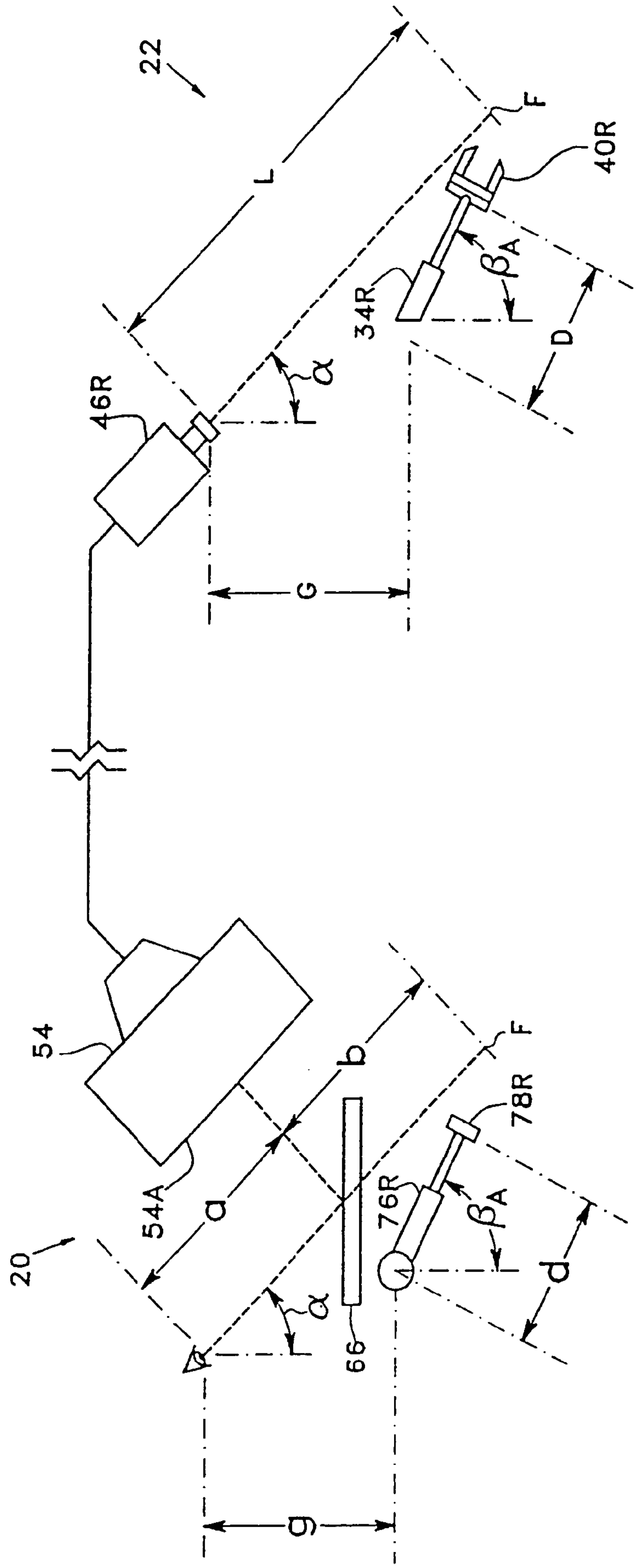


Fig. 4

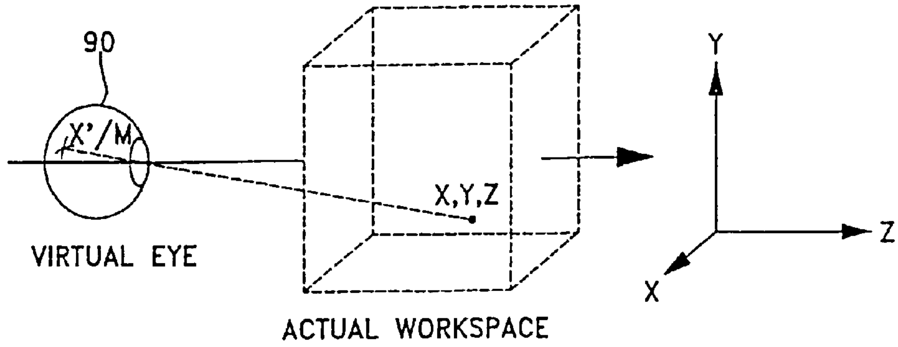

90
X'/M
VIRTUAL EYE
X,Y,Z
ACTUAL WORKSPACE
Y
Z
X

Fig. 5

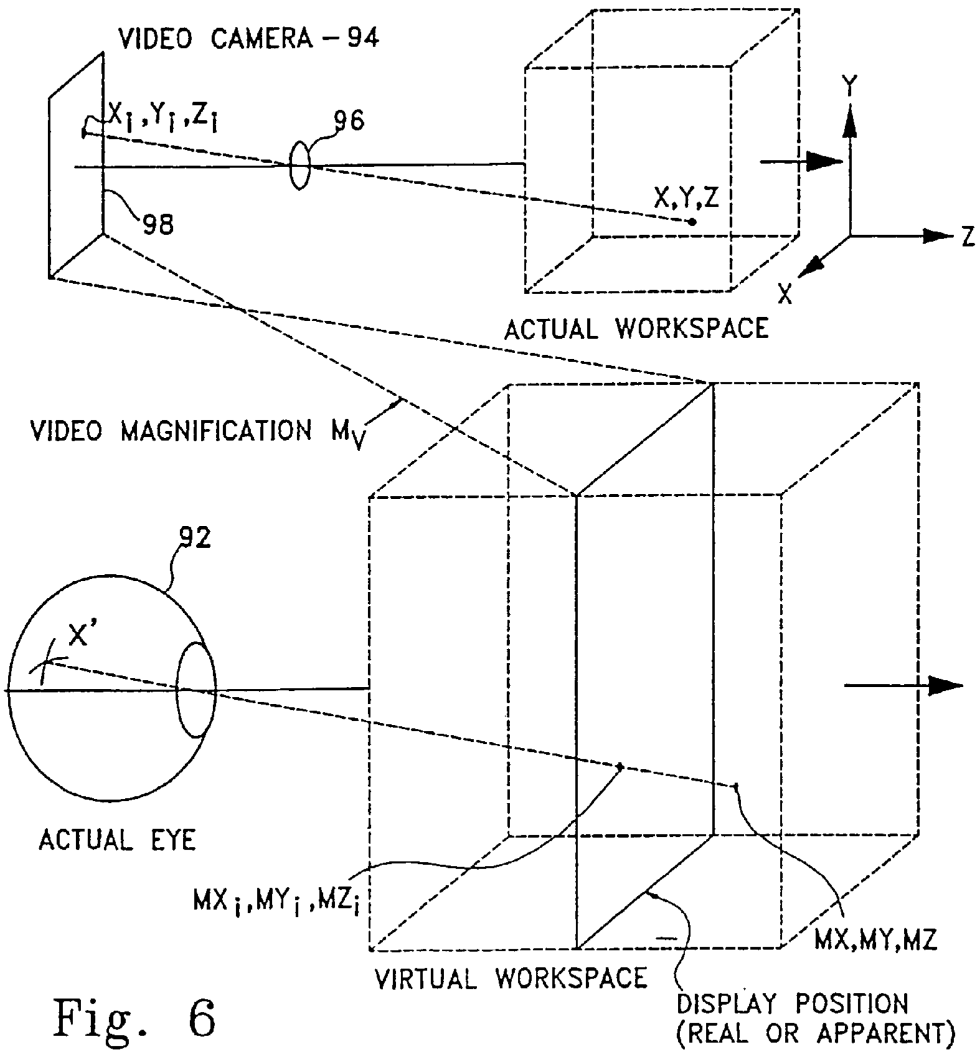

VIDEO CAMERA – 94
X_i, Y_i, Z_i
96
98
X,Y,Z
ACTUAL WORKSPACE
Y
Z
X
VIDEO MAGNIFICATION M_V
92
X'
ACTUAL EYE
MX_i, MY_i, MZ_i
MX,MY,MZ
VIRTUAL WORKSPACE
DISPLAY POSITION
(REAL OR APPARENT)

Fig. 6

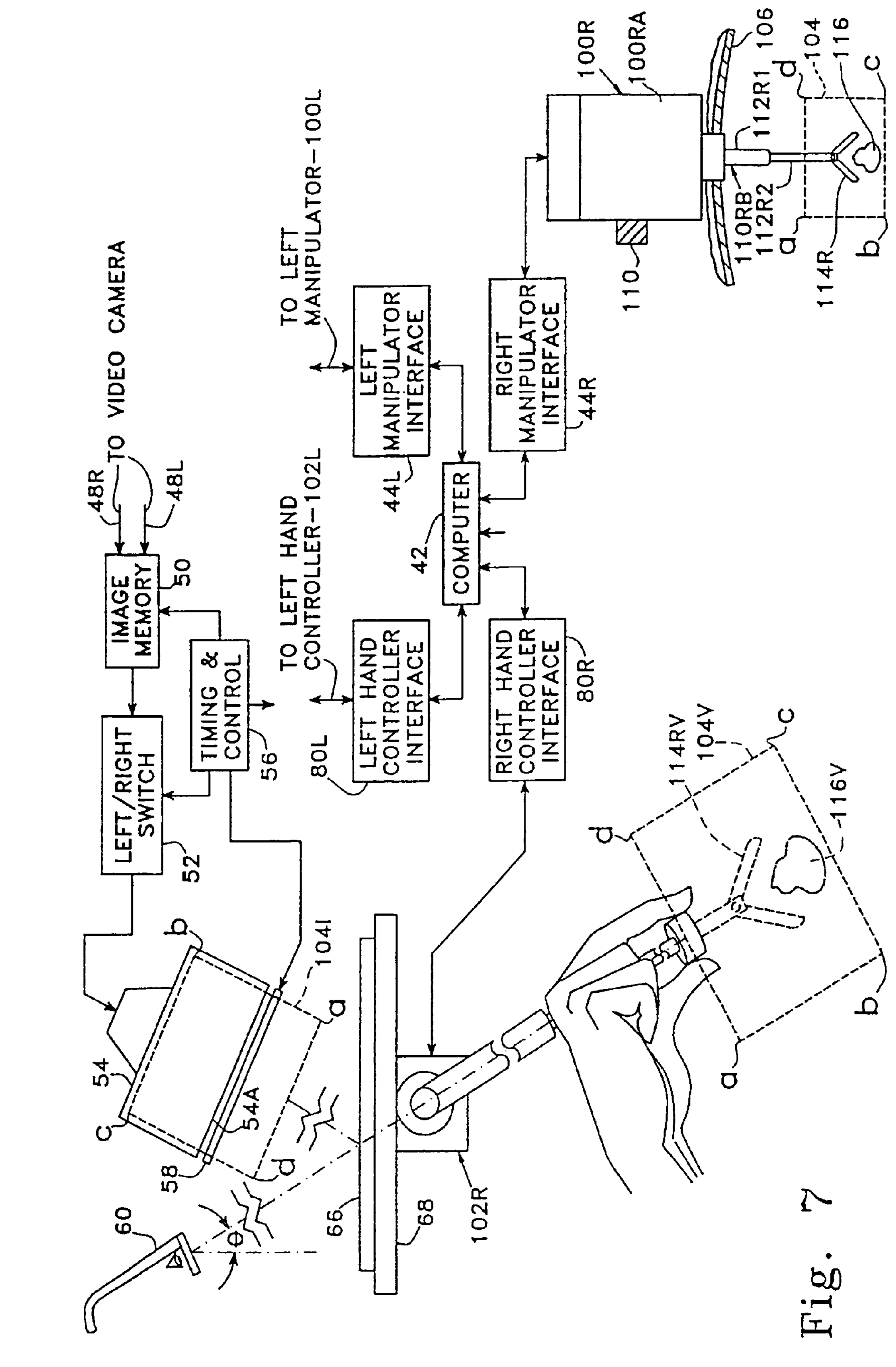
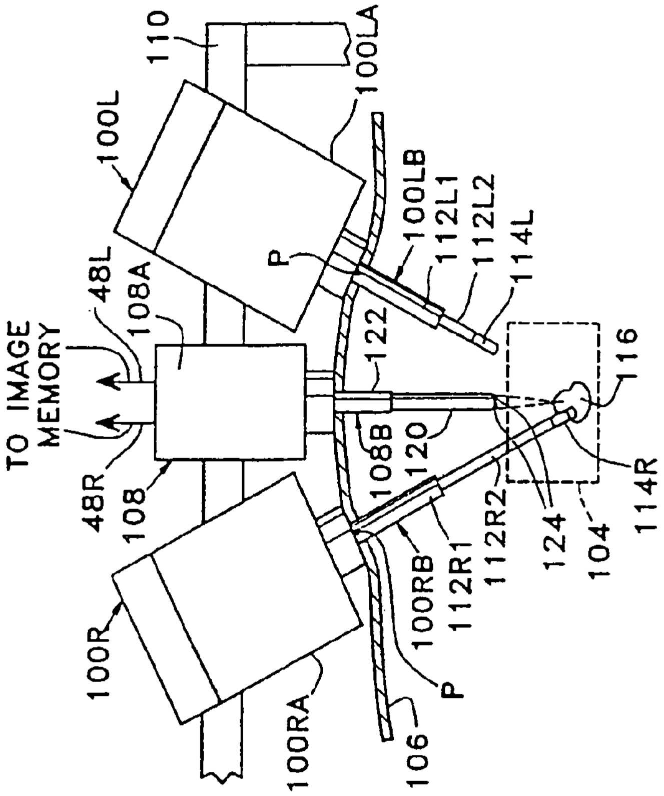

TO VIDEO CAMERA
48R
48L
IMAGE MEMORY
50
LEFT/RIGHT SWITCH
52
TIMING & CONTROL
56
TO LEFT HAND CONTROLLER-102L
LEFT HAND CONTROLLER INTERFACE
80L
TO LEFT MANIPULATOR-100L
LEFT MANIPULATOR INTERFACE
44L
COMPUTER
42
RIGHT HAND CONTROLLER INTERFACE
80R
RIGHT MANIPULATOR INTERFACE
44R
100R
100RA
110
110RB
112R1
112R2
106
104
116
114R
a
b
c
d
60
θ
54
54A
58
104I
66
68
102R
114RV
104V
116V

Fig. 7


TO IMAGE MEMORY
48R
48L
108
108A
108B
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100L
100LA
100LB
112L1
112L2
114L
116
100R
100RA
100RB
112R1
112R2
114R
120
122
124
104
106
P
P

Fig. 9

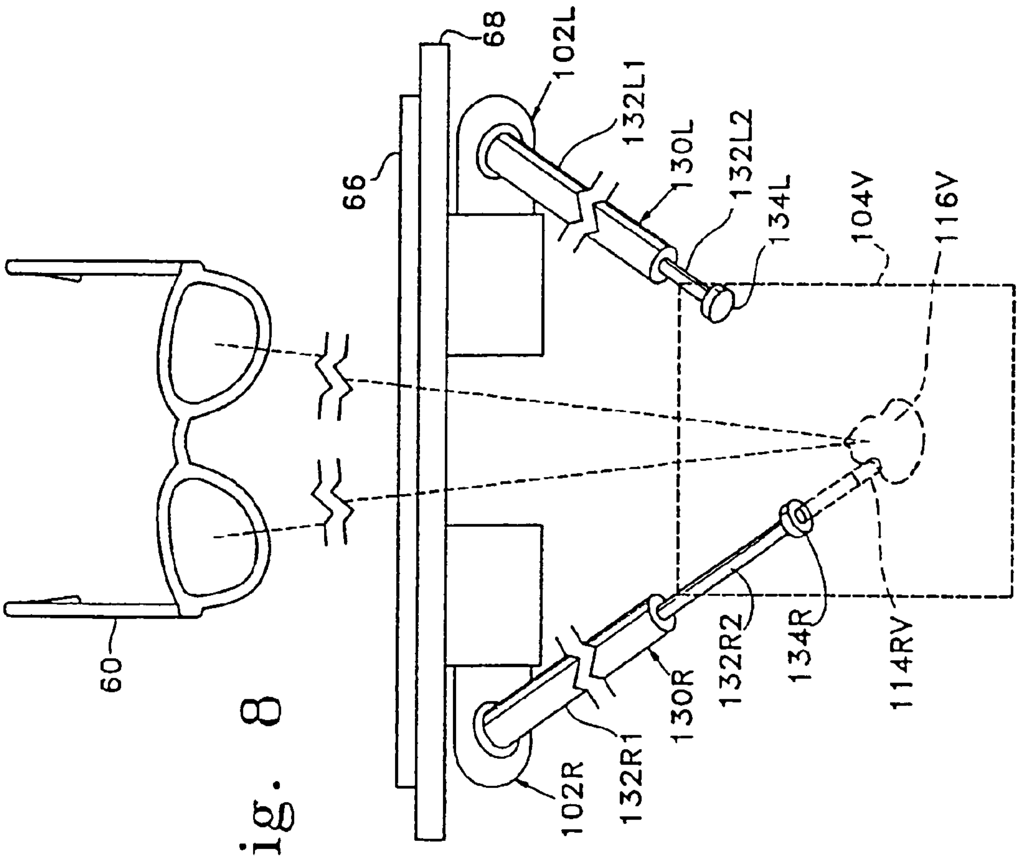
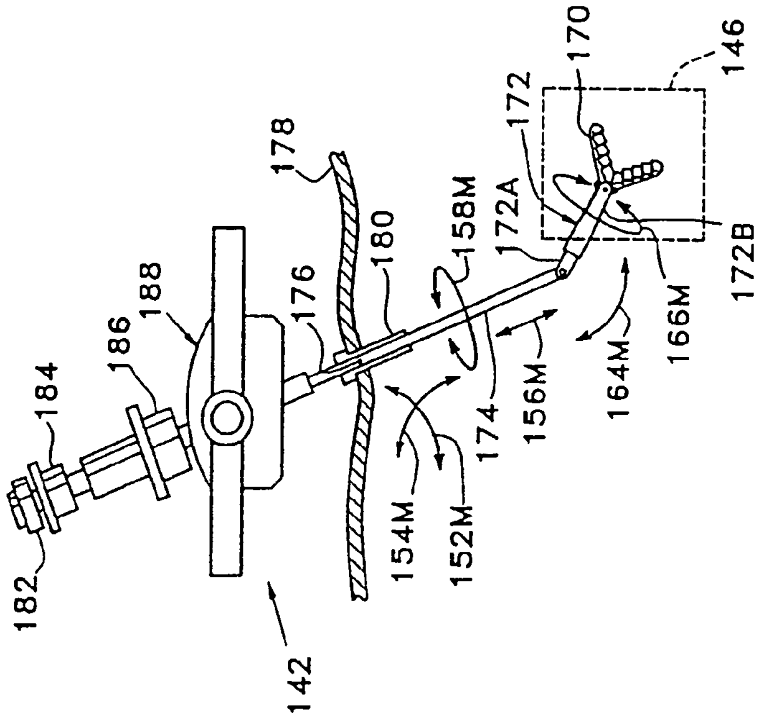

60
66
68
102L
102R
132L1
132L2
130L
134L
104V
116V
114RV
134R
132R2
130R
132R1

Fig. 8

Fig. 11


142
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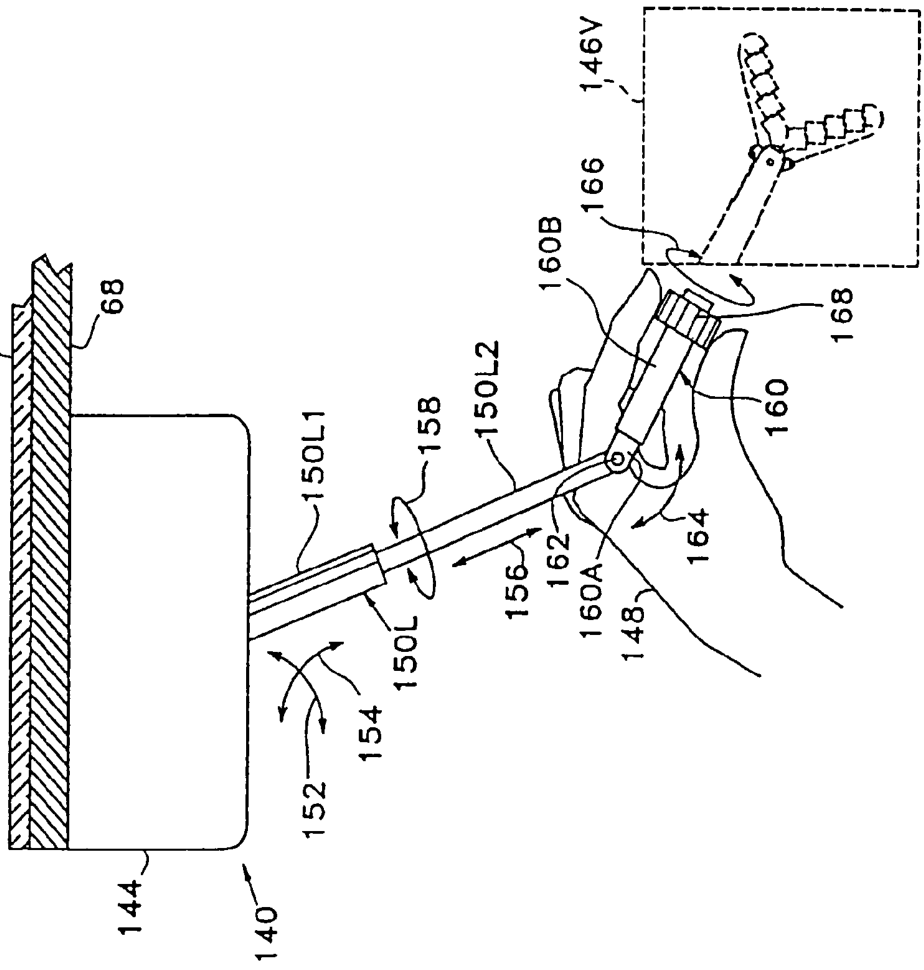
184
186
188
176
178
180
174
154M
152M
156M
158M
172A
172
170
146
172B
166M
164M

Fig. 10


66
68
144
140
152
154
150L
150L1
158
150L2
156
162
160A
148
164
160
160B
168
166
146V

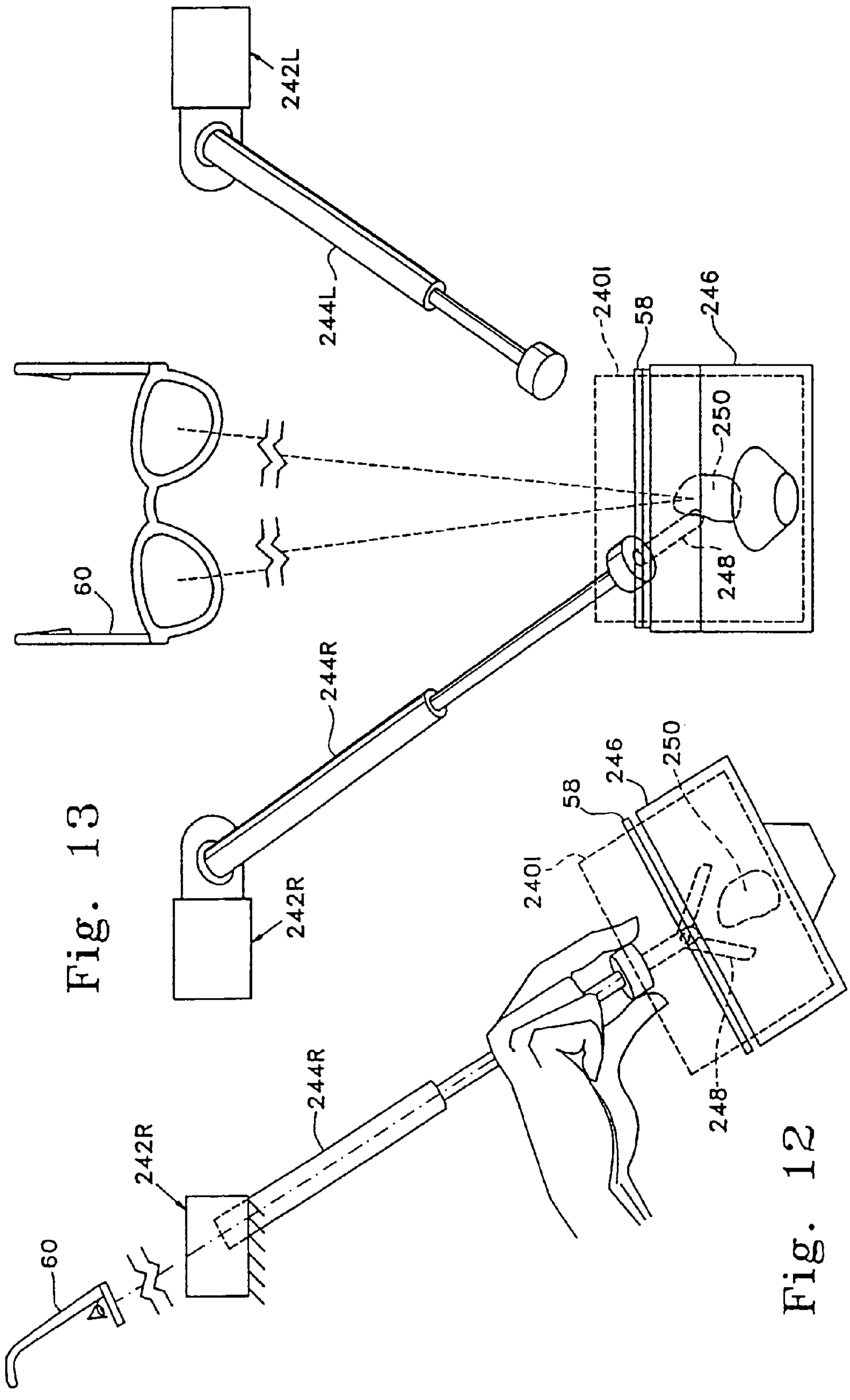


Fig. 13
242L
244L
240I
58
246
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248
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244R
242R
Fig. 12
242R
244R
60
58
246
250
240I
248

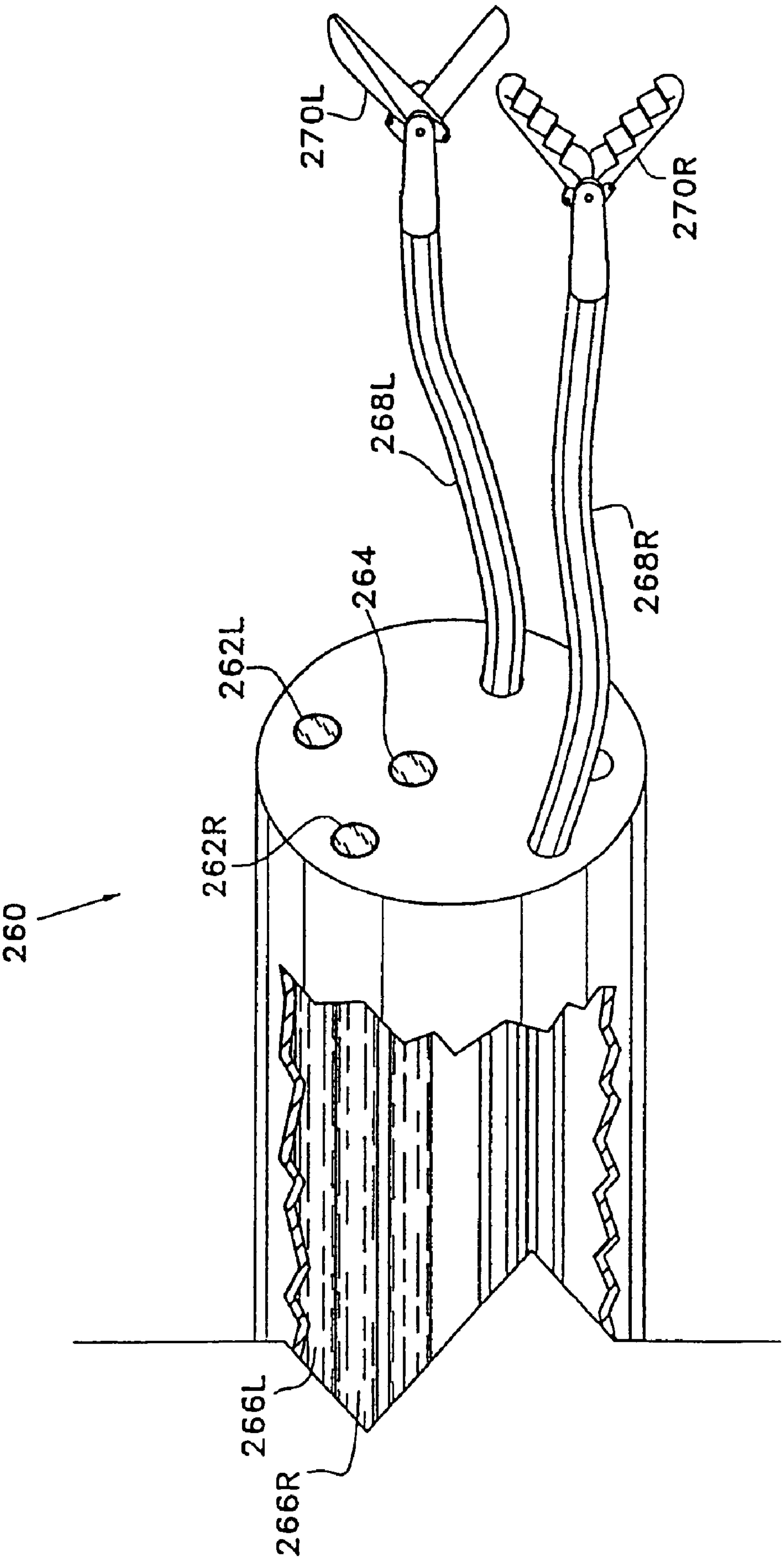

Fig. 14

ROLL-PITCH-ROLL WRIST METHODS FOR MINIMALLY INVASIVE ROBOTIC SURGERY

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/015,212 filed Dec. 16, 2004; now U.S. Pat. No. 7,107,124 which is a continuation of U.S. patent application Ser. No. 08/709,930 filed Sep. 9, 1996 (now U.S. Pat. No. 6,963,792), which is a continuation of U.S. patent application Ser. No. 07/823,932 filed Jan. 21, 1992 (now abandoned), the full disclosures of which are incorporated herein by reference.

STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

REFERENCE TO A "SEQUENCE LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX SUBMITTED ON A COMPACT DISK

Not Applicable

FIELD OF THE INVENTION

This invention relates generally to teleoperator method and apparatus, and particularly to those which include means for providing the operator of remote apparatus with the same sense as working directly with his hands at the worksite.

BACKGROUND OF THE INVENTION

Teleoperating, which is well known, includes the human performance of tasks at a remote location using manipulators. Telepresense includes providing the teleoperator with the same feedback and control that he would have were he actually at the worksite carrying out the operation with his own hands. Telepresence operation generally includes use of a stationary visual display, particularly a stereographic visual display of the remote workspace. Stereoscopic television systems are well known as shown, for example, in U.S. Pat. Nos. 4,562,463 and 4,583,117 and in U.K. Patent Application GB 2,040,134.

Remote manipulators employing stereoscopic TV viewing together with force feedback also are well known as shown, for example, in an article entitled, "Controlling Remote Manipulators Through Kinesthetic Coupling," Bejczy et al, Computers in Mechanical Engineering, July 1983, pps. 48–60, and in an article entitled, "Stereo Advantage for a Peg-In-Hole Task Using a Force-Feedback Manipulator" by E. H. Spain, SPIE Vol. 1256 Stereoscopic Displays and Applications, 1990, pps. 244–254. In the Bejczy et al. article, force-torque feedback is disclosed. Also, in U.S. Pat. No. 3,921,445, a manipulator which includes force, torque and slip sensors of a type which may be employed with the present invention is shown.

Even though the operator of prior art manipulators is provided with a stationary three-dimensional image of the workspace, and manual controllers for control of the manipulators are provided with feedback, the operator is not provided with a sense of actually being present at the worksite. The present invention is directed to a viewing arrangement for use in a remote manipulation system which substantially adds to the operator's sense of presence at the remote manipulator site.

BRIEF SUMMARY OF THE INVENTION

An object of this invention is the provision of an improved teleoperator system and method which include an improved viewing system to enhance the operator's sense of presence at remote manipulators controlled by the operator from a remote location.

An object of this invention is the provision of an improved teleoperator system and method of the above-mentioned type wherein an image of manipulator end effectors for viewing by the operator are sensed by the operator as comprising an integral part of hand-controllers used by the operator to control the end effectors, thereby giving the operator a strong sense of presence at the worksite.

An object of this invention is the provision of an improved teleoperator system and method of the above-mentioned type which is well adapted for use in a wide variety of applications including military, industrial, biomedical, and the like.

The present invention includes manipulators located at a worksite and which are controlled by hand-operated means at a remote operator control station. End effectors at the manipulators are used for manipulating objects located in a workspace at the worksite, and force-torque feedback is employed for transmitting back to the operator mechanical resistance encountered by the end effectors. Stereographic visual display means provide the operator with an image of the workspace. In accordance with the present invention, the image is located adjacent the hand-operated means so that the operator looks in the direction of the hand-operated means for viewing the image adjacent the hand-operated means. Either a real or virtual image of the workspace may be provided adjacent the hand-operated means. Display means for display of a real image may be located adjacent the hand-operated means for direct viewing of the real image by the operator. For display of a virtual image of the workspace, a mirror is located between the operator's eyes and the hand-operated means. In this case, display means provide a real image which is inverted from top to bottom, which inverted image is viewed via the mirror, which mirror inverts the image and provides the operator with a virtual image of the workspace, which appears to be located adjacent the hand-operated means. By locating the image of the workspace adjacent the hand-operated means the operator is provided with a sense that the end effectors and hand-operated means are substantially integral despite the fact the end effectors are located at the worksite and the hand-operated means are located at the remote operator's station. A stereophonic sound system may be included to provide the operator with stereophonic sound from the worksite. Video camera means are provided for viewing the workspace from which an image of the workspace is obtained. Various other sensors and associated responders may be located at the worksite and operator's station, respectively, for transmission of pressure, tactile, heat, vibration and similar information for enhanced telepresence operation.

Depending upon the application, different scaling may be provided in the transmission of information between the operator's station and worksite. For example, for microassembly, microsurgery and like operations involving small part manipulation, optical and/or video magnification may be employed to provide an enlarged 3-dimensional image for viewing by the operator. With similar scaling between the hand operated means and manipulators, the perception of the operator is substantially that which a miniature operator would have were he at the worksite.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with other objects and advantages thereof, will be better understood from the following description considered with the accompanying drawings. It will be understood that the drawings are for purposes of illustration and example only, and that the invention is not limited thereto. In the drawings, wherein like reference characters refer to the same parts in the several views,

FIG. **1** is a diagrammatic showing of a teleoperator system embodying the present invention including side elevational views of a worksite and remote control operator's station;

FIG. **2** is an enlarged rear elevational view of the operator's station taken substantially along line **2**—**2** of FIG. **1**;

FIG. **3** is an enlarged rear elevational view of the worksite taken substantially along line **3**—**3** of FIG. **1**;

FIG. **4** is a simplified side elevational view which is similar to FIG. **1** and showing dimensional relationships between elements at the worksite and elements at the operator's station;

FIG. **5** is a diagrammatic view to illustrate visual perception by a miniature virtual eye, and

FIG. **6** is a diagrammatic view to illustrate visual perception by the operator when image magnification is employed;

FIG. **7** is a diagrammatic view which is similar to that of FIG. **1** but showing the teleoperator system used for telepresence surgery;

FIG. **8** is a rear elevational view of the operator's station shown in FIG. **7**;

FIG. **9** is a rear elevational view of the worksite shown in FIG. **7**;

FIGS. **10** and **11** are fragmentary side elevational views of modified forms of operator's station and manipulator, respectively, having increased degrees of freedom;

FIG. **12** is a side elevational view of a modified form of operator's station wherein display means are positioned for direct viewing by the operator;

FIG. **13** is a rear elevational view of the modified form of operator's station shown in FIG. **12**; and

FIG. **14** shows a fragmentary portion of the insertion portion of an endoscope for use with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference now is made to FIGS. **1**–**3** wherein the teleoperator system is shown to include an operator's station **20** (FIGS. **1** and **2**) and worksite **22** (FIGS. **1** and **3**). An operator **18** at the operator's station controls manipulator means **24** at the remote worksite. Manipulator means **24**, comprising right and left manipulators **24**R and **24**L, respectively, are used for manipulating objects, such as object **26** which is shown located on a platform, or base, **28** within a workspace **30** shown in broken lines. For purposes of illustration only, and not by way of limitation, the right manipulator **24**R is shown to comprise a housing **32**R affixed to base **28** and from which housing a telescopic arm **34**R extends. The inner end **34**R**1** of arm **34**R is mounted for pivotal movement in any pivotal direction using conventional mounting means. For example, the inner end of arm **34**R may be mounted for pivotal movement about a horizontal pivot axis **36** which pivot axis, in turn, is adapted for pivotal movement about vertical axis **38**.

Arm **34**R includes telescopic inner section **34**R**1** and outer section **34**R**2**, which outer section is adapted both for axial movement into and out of inner section **34**R**1** and for rotation about its longitudinal axis. An end effector **40**R is carried at the outer end of the arm which, for purposes of illustration, is shown to comprise a gripper. Motor means, not shown, control pivotal movement of arm **34**R about pivot axes **36** and **38**, axial and rotary movement of outer arm section **34**R**2** along and about the longitudinal axis of the arm, and opening and closing of gripper **40**R. The motor means, together with motor control circuits for control of the motors, may be included in housing **32**R. The motors are under control of a computer **42** connected thereto through right manipulator interface **44**R and the above-mentioned motor control circuits.

The left manipulator **24**L is of substantially the same design as the right manipulator **24**R and the same reference numerals, but with the suffix L instead of R, are used to identify similar parts. For purposes of illustration, the left end effector **40**L, shown in FIG. **3**, is seen to comprise cutting blades which operate to cut in the manner of a pair of scissor blades.

The worksite is provided with a pair of video cameras **46**R and **46**L for viewing workspace **30** from different angles for production of stereoscopic signal outputs therefrom at lines **48**R and **48**L. The angle γ between the optical axes of the cameras shown in FIG. **3** is substantially equal to the operator's interocular viewing angle γ of an image of the workspace as shown in FIG. **2**.

The video camera outputs at lines **48**R and **48**L are supplied to an image memory **50** for momentary storage of video fields of right and left images from the cameras. Fields of right and left images from image memory **50** are alternately supplied through left/right switch means **52** to visual display means **54**, such as a television monitor, for alternate display of the two images at the face **54**A of the monitor. Timing and control means **56** provide timing and control signals to various elements of the system, including elements included in the stereographic display system, for signal timing and control of the system. If digital storage means **50** are employed, then conversion of the camera signal outputs to digital signal form by analog to digital converter means prior to storage, and conversion of the digital signal output from left/right switch means to analog signal form in preparation for display at monitor **54** may be employed.

An electrooptical device **58** at the face of the display means **54** controls polarization of light received from display means **54** under control of a left/right synchronizing signal from timing and control unit **56**. The left and right image fields are viewed by operator **18** wearing a pair of passive polarized glasses **60** having right and left polarizing elements **62** and **64** polarized in orthogonal directions. The polarization of light from display **54** through electrooptical device **58** is synchronized field by field such that the right field is occluded from the left eye and the left field is occluded from the right eye for stereographic viewing by the operator. Other means for stereographic viewing of left and right image fields are well known, including, for example, those using active stereographic glasses, which may be used in the practice of this invention to provide the operator with a stereoscopic view of the remote workspace.

The vertical deflection coil connections for monitor **54** are reversed, causing the monitor to scan from bottom to top thereby creating a top-to-bottom inverted image **301** of workspace **30**. Letters a, b, c and d are used to identify corresponding corners of the workspace **30** and inverted workspace image **301**. The inverted workspace image **301** is viewed by the operator via a mirror **66** at the top of a table **68**, which mirror inverts image **301** to return the image as viewed by the operator to an upright position. Looking downwardly in the direction of the mirror, the operator views a virtual image **30**V of workspace **30**. In accordance with one aspect of the present invention, the image viewed by the operator, which in the FIG. **1**–**3** embodiment comprises a virtual image, is located adjacent controller means **70** used by the operator for control of manipulator means **24** at the worksite.

Controller means **70** are shown located beneath the table top **68** and include right and left controllers **72**R and **72**L for control of the respective right and left manipulators **24**R and **24**L. The right and left controllers are of substantially the same design so that a description of one applies to both. As with the manipulators, the suffixes R and L are used to distinguish elements of the right controller from those of the left controller. For purposes of illustration, and not by way of limitation, the right controller **72**R is shown to comprise a housing **74**R affixed to the bottom of table top **68** and from which hand-operated means **76**R in the form of a telescopic control arm, or stick, extends.

The right and left control arms **76**R and **76**L are provided with the same degrees of freedom as the associated manipulator arms **34**R and **34**L, respectively. For example, the inner end of control arm **76**R is mounted for pivotal movement about a horizontal pivot axis, corresponding to manipulator pivot axis **36**, which axis, in turn, is adapted for pivotal movement about an intersecting vertical axis, corresponding to manipulator axis **38**. Control arm **76**R also includes inner section **76**R**1** and outer section **76**R**2**, which outer section is adapted both for axial movement into and out of inner section **76**R**1** and for rotation about its longitudinal axis. It will be apparent that the control arm **76**R is provided with the same four degrees of freedom as the associated manipulator arm **34**R. Additionally, sensor means **78**R are located adjacent the outer end of outer arm section **76**R**2** for use in controlling gripping action of gripper **40**R. Similar sensor means **78**L adjacent the outer end of control arm **76**L are adapted for use in controlling operation of scissor blades **40**L.

Right and left controllers **72**R and **72**L are included in a servomechanism system wherein mechanical motion of control arms **76**R and **76**L controls the position of manipulator arms **34**R and **34**L, and pressure on sensor means **78**R and **78**L controls opening and closing of end effectors **40**R and **40**L, respectively. In FIG. **1**, right and left hand controller interfaces **80**R and **80**L, respectively, are shown for connection of the controllers to computer **42**. Servomechanisms for control of mechanical motion at a remote location are well known, including those which provide force and torque feedback from the manipulator to the hand-operated controller means. Any suitable prior art servomechanism may be used in the practice of the present invention, with those incorporating force and torque feedback being particularly preferred for telepresence operation of the system. In the illustrated system, right and left microphones are included at the worksite, outputs from which microphones are amplified by right and left amplifiers and supplied to right and left speakers at the operators' station for providing a stereophonic sound output to provide the operator with an audio perspective present at the workspace. In FIG. **1**, only the right channel of the stereophonic system is shown including right microphone **82**R, right amplifier **86**R and right speaker **88**R. The left microphone and speaker are located directly behind the respective right microphone and speaker at the worksite and operator's control station as viewed in FIG. **1**. Obviously, earphones may be provided for use by the operator in place of the speakers which would help to block out external noises at the operator's control station. Also, in FIG. **1** a light shield **54**B at the monitor is shown for blocking direct viewing of the monitor face by the operator.

Reference now is made to FIG. **4** wherein a simplified diagrammatic view of the system illustrated in FIGS. **1**–**3** is shown and wherein various lengths and angular positions are identified by reference characters. In FIG. **4**, the optical path length between the cameras and a point F at the workspace is identified by reference character L. A corresponding path length between the operator's eyes and point F at the virtual image of the workspace is identified by the distance a+b, where a is the distance from the eyes of the operator to mirror **66**, and b is the distance from the mirror to point F at the virtual image. Other dimensions shown include the height G of the cameras above the pivot point of manipulator arm **34**R and corresponding height g of the operator's eyes above the pivot point of control arm **76**R. With the control arm **76**R at length d, the manipulator arm **34**R adjusts to length D. Similarly, with the control arm **76**R at an angle β_A, with the vertical, the manipulator arm **34**R is positioned at the same angle from vertical. The angle from vertical at which the cameras view the workspace and the eyes view the virtual image of the workspace is identified by α.

Between elements of the worksite and operator station, the following relationships pertain:

$$a+b=kL, \tag{1}$$

$$d=kD, \text{ and} \tag{2}$$

$$g=kG \tag{3}$$

where k is a scale factor constant.

When k equals 1 such that a+b=L, d=D and g=G, no scaling of worksite dimensions is required.

Any scale factor may be employed, the invention not being limited to full-scale manipulation. For example, the worksite can be small, including microscopic in size, in which case the optical parameters, including distance to object, interocular distance and focal length, and mechanical and dimensional parameters are appropriately scaled.

By using appropriate scaling and image magnification and force and torque feedback, and by locating the image **30**V of the workspace **30** adjacent hand-operated control means **76**R and **76**L, the operator is provided with a strong sense of directly controlling the end effectors **40**R and **40**L. The operator is provided with a sense that the end effectors **40**R and **40**L and respective control arms **76**R and **76**L are substantially integral. This same sense of togetherness of the hand-operated control means and end effectors is not provided in prior art arrangements wherein the image viewed by the operator is not located adjacent the hand-operated control means. Even where the prior art includes stereoscopic viewing and force and torque feedback, there is a feeling of disconnectedness of the hand notions from the visual image object being worked upon. The present invention overcomes this sense of disconnectedness by locating the workspace image where the operator's hands appear to exercise direct control over the end effectors.

For small-scale manipulation, such as required for surgical applications, it is desired to replicate the visual experience that a miniature observer would have were he closely adjacent the actual worksite. In FIG. **5**, the virtual eye **90** of a hypothetical miniature observer is shown viewing an actual workspace. Light from a source at a point X, Y, Z in the actual workspace produces a stimulus on the miniature observer's eye **90** at a point identified as X'/M. In FIG. **6**, an eye **92** of an actual operator is shown viewing an enlarged image of the virtual workspace produced by means of a video camera **94** used to view the actual workspace. The illustrated camera includes a light-receiving lens **96** and solid state imaging device such as a charge-coupled-device (CCD) array **98** where the point light source at X, Y, Z is shown imaged at point X_i, Y_i, Z_i. With correct scaling, a corresponding light source is produced at point MX_i, MY_i, MZ_i at either the real or apparent position of the face of the visual display which, due to stereoscopic operation of the system appears to the operator to originate from point MX, MY, MZ corresponding to point X, Y, Z at the actual workspace. At the retina of the actual eye **92**, a stimulus is produced at point X' at proportionately the same position as point X'/M at eye **90** of the hypothetical observer. This relationship is ensured by selecting a correctly scaled camera distance and lens focal length such that the optical magnification $M_o=M/M_v$ where M is the desired overall magnification and M_v is the video magnification. A typical video magnification, M_v, which equals the ratio of the CCD-array **98** width to the display width, is about 40.

Reference now is made to FIGS. **7** through **9** wherein a modified form of this invention is shown for medical use. Here, right and left manipulators **100**R and **100**L are shown which are under control of right and left controllers **102**R and **102**L, respectively. Elements of the imaging system are substantially the same as those employed in the imaging system illustrated in FIGS. **1**–**3** described above except that an enlarged virtual image **104**V of actual workspace **104** is provided for viewing by the operator. Also, servomechanism elements for connection of the right and left controllers **102**R and **102**L to the respective manipulators **100**R and **100**L are substantially the same as those described above with reference to FIGS. **1**–**3**. In the illustrated arrangement, the right and left manipulators are of substantially the same construction as are the right and left controllers, such that a description of one manipulator and one controller applies to both. Again, suffixes R and L are used to distinguish between right and left elements thereof.

The manipulators include outer control sections **100**RA and **100**LA and insertion sections **100**RB and **100**LB, which insertion sections are adapted for insertion into a body cavity through cylindrical tubes, or cannulas, not shown. For purposes of illustration, the manipulators are shown inserted through the abdomen wall **106** of a subject. As is well understood, for laparoscopic surgical procedures, wall **106** is separated from internal organs by insufflation wherein a gas is introduced into the abdomen by any suitable means not shown. Manipulator motors and associated motor control circuits are contained in the outer control sections **100**RA and **100**LA of the manipulators for control of the insertion section. The manipulators, together with a laparoscope **108** for viewing organs within the cavity, are carried by a fixed rail **110** forming part of a surgical table upon which the subject is supported.

The insertion sections **100**RB and **100**LB of the manipulators may be of substantially the same design as manipulator arms **34**R and **34**L described above with reference to the FIGS. **1**–**3** embodiment. The insertion sections are of relatively small size for use inside the body. Insertion section **100**RB includes telescopic inner section **112**R**1** and outer section **112**R**2**, which outer section is adapted for both axial movement into and out of inner section **112**R**1** and for rotation about its longitudinal axis. End effectors **114**R and **114**L are carried at the outer ends of the respective right and left sections **112**R**2** and **112**L**2** for manipulation of organ **116**. The inner section **112**R**1** is adapted for pivotal movement about intersecting perpendicular axes located substantially at point P where the insertion section intersects wall **106**. Exclusive of operation of end effectors **114**R and **114**L the manipulator arms each are provided with four degrees of freedom, the same as in the embodiment shown in FIGS. **1**–**3**. End effectors **114**R and **114**L simply may comprise, essentially, microsurgical instruments with their handles removed including, for example, retractors, electrosurgical cutters and coagulators, micro-forceps, microneedle holders, dissecting scissors, blades, irrigators, and sutures.

Laparoscope **108** for viewing the workspace **104** is shown comprising an outer operating section **108**A and insertion section **108**B. The outer end section **120** of insertion section **108**B is axially and rotatably movable within the inner end **122** thereof, and is provided with a pair of image transmission windows **124**, **124** for stereoscopic viewing of workspace **104**. The laparoscope also is provided with illuminating means, not shown, for illuminating the workspace, and with liquid inlet and outlet means, not shown, for flow of liquid past the windows. Video camera means within section **108**A are responsive to light received through the viewing windows for generation of left and right electronic images at output lines **48**R and **48**L for connection to image memory **50**. A magnified 3-dimensional image **1041** is produced at display means **54** for viewing by the operator wearing cross-polarized classes **60** via mirror **66**. As with the embodiment shown in FIGS. **1**–**3**, a virtual image **104**V of the workspace **104** is produced adjacent control arms **130**R and **130**L of controllers **102**R and **102**L. Control arms **130**R and **130**L are of the same type as control arms **76**R and **76**L included in the FIGS. **1**–**3** embodiment described above. They include telescopic inner and outer sections **132**R**1** and **132**R, and **132**L**1** and **132**L**2**. Sensor means **134**R and **134**L located adjacent the outer ends of the control arms control operation of end effectors **114**R and **114**L, respectively, in the manner described above with reference to FIGS. **1**–**3**. It here will be noted that the angle from vertical at which the image is viewed by the operator need not equal the angle from vertical at which the object is viewed by the cameras. In the arrangement illustrated in FIGS. **7**–**9**, the operator is shown to view the image **104**V at an angle θ from vertical (FIG. **7**) whereas the object **116** is shown as viewed directly downwardly. With no external reference, the sense of vertical within a body is not particularly great, and no confusion is produced in the mind of the operator as a result of the different observer and camera viewing angles relative to vertical.

With the FIGS. **7**–**9** embodiment, not only is a magnified virtual image **104**V of the workspace provided for viewing by the operator, but control arms **130**R and **130**L of greater length than the length of the manipulator insertion sections **100**RB and **100**LB are employed. Servomechanism scaling of axial movement of the telescopic control arms is provided such that axial extension or retraction thereof results in a smaller extension or retraction of the telescopic insertion sections. Angular pivotal motion of the control arms **130**R and **130**L produces the same angular pivotal motion of insertion sections **100**RB and **100**LB, and rotational movement of the end sections **132**R**2** and **132**L**2** of the control arms produces the same rotational motion of end sections **112**R**2** and **112**L**2** of the insertion sections of the right and left manipulators, without scaling. This embodiment of the invention, with its magnified image, is of particular use in the area of microsurgery, and especially in those cases where the surgeon cannot reach an area by hand because of size constraints.

The present invention is not limited to use with manipulators having any particular number of degrees of freedom. Manipulators with different degrees of freedom which are well known in the art may be used in the practice of this invention. In FIGS. **10** and **11**, to which reference now is made a controller **140** and manipulator **142**, respectively, are shown which include a wrist joint to provide the same with additional freedom of movement. The illustrated controller **140** includes a housing **144** affixed to the bottom of table top **68** upon which table mirror **66** is located. An enlarged virtual image **146**V of actual workspace **146** is provided adjacent the operator's hand **148** viewable by the operator when looking downwardly onto the mirror **66** in a manner described above.

A control arm **150**L comprising inner and outer sections **150**L**1** and **150**L**2**, respectively, is mounted within housing **144** for pivotal movement in any pivotal direction as indicated by intersecting double-headed arrows **152** and **154**. The outer section **150**L**2** is adapted for axial movement into and out of inner section **150**L**1** in the direction of double-headed arrow **156**. It also is adapted for rotation about its longitudinal axis in the direction of double-headed arrow **158**. In this embodiment, the control arm includes an end section **160** pivotally attached to outer section **150**L**2** by wrist joint **162** for pivotal movement in the direction of double-headed arrow **164**. End section **160** comprises axially aligned inner and outer sections **160**A and **160**B, the outer section **160**B of which is rotatable about its longitudinal axis in the direction of double-headed arrow **166**. As with the above-described arrangements, sensor means **168** are located adjacent the free end of the control arm for operation of an end effector **170** at manipulator **142** shown in FIG. **11**.

Referring to FIG. **11**, end effector **170** is shown to comprise a pair of movable jaws attached to a wrist **172** comprising axially aligned links **172**A and **172**B. Outer link **172**B is rotatable about its longitudinal axis relative to inner link **172**A by motor means, not shown, in the direction of double-headed arrow **166**M in response to rotation of section **160**B of the hand-operated control unit in the direction of arrow **166**. Wrist link **172**A is pivotally attached to manipulator forearm **174** for pivotal movement in the direction of double-headed arrow **164**M in response to pivotal movement of end section **160** of the hand-operated control means about pivot axis **162**. Forearm **174** is longitudinally axially movable in the direction of double-headed arrow **156**M in response to axial movement of outer section **150**L**2** of control arm **150**L in the direction of double-headed arrow **156**. It also is rotatable about its longitudinal axis in the direction of double-headed arrow **158**M in response to rotation of outer section **150**L**2** of control arm **150**L in the direction of double-headed arrow **158**. Additionally, it is pivotally movable about point **176** in the directions of double-headed arrows **152**M and **154**M in response to pivotal movement of control arm **150**L in the directions of double-headed arrows **152** and **154**, respectively. For biomedical use, such as remote laparoscopic surgery, pivot point **176** is substantially located at the level of abdominal wall **178** through which the manipulator extends. In FIG. **11**, manipulator arm **174** is shown extending through a cannula **180** which penetrates the abdominal wall.

The outer operating end of the manipulator is adapted for attachment to a supporting rail, not shown, of the surgery table upon which the subject is supported. It includes an end effector drive motor **182** for opening and closing of gripper **170**. Wrist drive motor **184** controls pivotal movement of wrist **172** in the direction of double-headed arrow **164**M, and extension drive motor **186** controls axial movement of manipulator arm **174** in the direction of double-headed arrow **156**M. Forearm pivotal control motors and linkages, identified generally by reference numeral **188**, provide for pivotal movement of arm **174** about pivot point **176** in the directions of arrows **152**M and **154**M. Pivotal motion about point **176** is provided by simultaneous lateral movement of the outer operating end of the manipulator and pivotal movement of arm **174**. Movements are coordinated such that the center of rotation of forearm **174** is fixed in space at point **176** at the level of the abdominal wall.

Controller **140** and manipulator **142** are included in a system such as shown in FIGS. **7**, **8** and **9** which includes a second controller and manipulator for use by the operator's right hand, and associated servomechanism means of any suitable type, not shown, for remote control of the manipulators by the hand-operated controllers. Video camera means at the worksite, such as shown in FIG. **9**, together with display means, such as shown in FIG. **7**, are employed for providing the operator with an image of the workspace at a location adjacent the left and right hand-operated control means. By using manipulators with a wrist joint, an added degree of freedom is provided for increased maneuverability and usefulness thereof. However, as noted above, the present invention is not limited to use with manipulators with any particular degree of freedom.

Reference now is made to FIGS. **12** and **13** wherein a modified form of this invention is shown which provides for direct viewing of a 3-dimensional image **2401** of a workspace, not shown. In FIGS. **12** and **13**, only the operator's station is shown, which includes right and left controllers **242**R and **242**L and associated right and left hand-operated means **244**R and **244**L which may be of the same type as controllers and control arms described above. The operator's station is adapted for remote control of manipulators which also may be of the above-described type. The 3-dimensional image **2401** of the workspace is provided by visual display means **246** in conjunction with electrooptical device **58** at the face of the display means and cross-polarized glasses **60** worn by the operator, to which display means left and right video fields from left and right video cameras that view the workspace are alternately supplied, all in the manner described in detail above. End effector and object images **248** and **250**, respectively, are shown within the workspace image as viewed by video cameras at the worksite. The display means **246** is located adjacent the left and right hand-operated means **244**R and **244**L for direct viewing by the operator. With this arrangement, the end effector and object images together with the hand-operated means **244**R and **244**L are simultaneously viewable by the operator. Since the hand-operated means also are visible, the operator is provided with a visual sense of connection between the end effector means and hand-operated means whereby they appear substantially as being integral.

Reference now is made to FIG. **14** wherein the distal end portion, or tip, **260** of the insertion section of an endoscope is shown which is of substantially the same type as shown in the above-mentioned publication entitled "Introduction to a New Project for National Research and Development Program (Large-Scale Project) in FY 1991" which endoscope may be used in the practice of the present invention. The insertion end of the endoscope includes a pair of spaced viewing windows **262**R and **262**L and an illumination source **264** for viewing and illuminating a workspace to be observed. Light received at the windows is focused by objective lens means, not shown, and transmitted through right and left fiber-optic bundles **266**R and **266**L to a pair of cameras at the operating end of the endoscope, not shown. The camera outputs are converted to a 3-dimensional image of the workspace which image is located adjacent hand-operated means at the operator's station, not shown. Right and left steerable catheters **268**R and **268**L pass through accessory channels in the endoscope body, which catheters are adapted for extension from the distal end portion, as illustrated. End effectors **270**R and **270**L are provided at the ends of the catheters which may comprise conventional endoscopic instruments. Force sensors, rot shown, also are inserted through the endoscope channels. Steerable catheters which include control wires for controlling bending of the catheters and operation of an end effector suitable for use with this invention are well known. Control motors for operation of the control wires are provided at the operating end of the endoscope, which motors are included in a servomechanism of a type described above for operation of the steerable catheters and associated end effectors from a remote operator's station. As with the other embodiments, the interfacing computer in the servomechanism system remaps the operator's hand motion into the coordinate system of the end effectors, and images of the end effectors are viewable adjacent the hand-operated controllers in a manner described above. With this embodiment, the operator has the sensation of reaching through the endoscope to put his hands directly on the end effectors for control thereof. Endoscopes of different types may be employed in this embodiment of the invention so long as they include one or more accessory channels for use in control of end effector means, and suitable viewing means for use in providing a visual display of the workspace. For example, gastric, colonscopic, and like type, endoscopes may be employed.

The invention having been described in detail in accordance with requirements of the Patent Statutes, various other charges and modifications will suggest themselves to those skilled in this art. For example, as noted above, the invention may include the use of tactile feedback to provide the subtle sensations for palpation and for manipulating tissues and instruments. To provide this feedback, tactile sensor arrays may be included on the end effectors which are coupled to tactile sensor stimulator arrays on the hand-operated control means, which reproduce the tactile sensation on the operator's hands. A variety of transduction technologies for teleoperator tactile sensing are known including resistive/conductive, semiconductor, piezoelectric capacitive and photoelectric. Hand-operated control means and manipulators of different types may be employed using a wide variety of well-known mechanisms and electromechanical elements including, for example, gimbals, linkages, pulleys, cables, drive belts and bands, gears, optical or electromagnetic position encoders, and angular and linear motors. Force feedback to the operator requires use of body contact with hand-operated control means. Both hand grip type hand controllers such as those illustrated, and control brace type hand controllers are well adapted for use with the present invention for force feedback to the operator. Control brace hand controllers include use of structures with positive sensors mounted on the operator at joints for measuring joint angles. Force feedback then can be applied to each joint. Similarly, light fabric gloves with variable-resistance or fiber-optic flex sensors mounted on the joints for measuring bending of individual fingers may be used. Gloves of this type also may be provided with force feedback to provide for telepresence interaction with real objects. Regardless of the type of hand-operated control means employed, an image of the workspace is produced adjacent thereto to provide the operator with a sense that the end effector means and hand-operated control means are substantially integral. Also, as noted above, servomechanisms of many different types are well known in the robotic and teleoperator system arts, and the invention is not limited to any particular type. Those that include force and torque feedback to the operator are preferred to contribute to a telepresence sense of operation. In addition, many different means for producing a stereoscopic image of the workspace are known. For example, instead of using two cameras, a single camera may be employed together with switched cross-polarizing elements in the image receiving path. In this case, a pair of spaced stereoscopic lenses are used for viewing the workspace from different angles and providing first and second images thereof to the camera. In the FIG. **9** arrangement, wherein a laparoscope is shown, other types of endoscopes may be used for viewing the workspace. As noted above, the invention is not limited to any particular application or use. In the biomedical field, uses include, for example, open surgery, including surgery from a remote location, microsurgery, and minimum invasive surgery such as laparoscopic and endoscopic surgery. Laboratory use including microscopic manipulation also is contemplated. Industrial use of the invention include, for example, hazardous materials handling, remote operations, microassembly, and the like. Military and undersea use of the teleoperator system of this system are apparent. It is intended that the above and other such changes and modifications shall fall within the spirit and scope of the invention defined in the appended claims.

What is claimed is:

1. A surgical apparatus for performing a procedure on a tissue in a body of a patient through a minimally invasive aperture, the minimally invasive surgical manipulator comprising:

- a minimally invasive surgical end effector configured for manipulating the tissue within the patient body;
- an elongate shaft having a distal end insertable into the body of the patient through the aperture, the elongate shaft having a longitudinal axis;
- a wrist member coupling the end effector to the distal end of the shaft, the wrist member having a longitudinal axis;
- the wrist member and end effector rotatable about the longitudinal axis of the shaft;
- the wrist member and end effector pivotable about a wrist axis crossing the shaft; and
- the end effector rotatable about a longitudinal axis of the wrist member.

2. The minimally invasive surgical apparatus of claim **1**, wherein the wrist member pivots at a wrist joint coupling the wrist member to the shaft, the wrist joint defining the wrist axis, and the wrist axis being perpendicular to the longitudinal axis of the shaft and to the longitudinal axis of the wrist member.

3. The minimally invasive surgical apparatus of claim **1**, wherein the end effector comprises first and second jaw members, the first jaw member pivotable about a jaw pivot axis crossing the longitudinal axis of the wrist member so as to open and close the jaws.

4. The minimally invasive surgical apparatus of claim **3**, wherein the jaw pivot axis is perpendicular to the longitudinal axis of the wrist member.

5. The minimally invasive surgical apparatus of claim **1**, wherein rotating of the wrist member about the longitudinal axis of the wrist member changes an orientation of the end effector when the wrist member is roughly perpendicular to the shaft.

6. The minimally invasive surgical apparatus of claim **1**, further comprising a robotic linkage supporting a proximal end of the shaft, the robotic linkage having a plurality of robotic motors coupled to the end effector so as to effect said rotations and pivoting.

7. The minimally invasive surgical apparatus of claim **6**, wherein the motors are actuated in response to manual movement of an input device according to a master-slave by robotic controller.

8. A minimally invasive robotic surgical apparatus comprising:

an elongate shaft having a proximal end, a distal end configured for insertion through a minimally invasive surgical aperture, and a longitudinal axis therebetween;

a robotic linkage supporting the proximal end of the shaft;

a minimally invasive surgical end effector configured for insertion through the aperture;

a wrist member coupling the end effector to the distal end of the shaft, the wrist member having a longitudinal axis; and

the end effector movable, when inserted into the body of a patient through the aperture so as to manipulate the tissue, by:

rotation of the shaft relative to the linkage about a longitudinal axis of the shaft;

rotation of the end effector about the axis of a wrist member; and

pivoting of the wrist member so as to vary an angle between the longitudinal axis of the wrist member and the longitudinal axis of the shaft.

9. A surgical apparatus comprising:

an elongate shaft comprising a distal end and a shaft longitudinal axis;

a wrist member comprising:

a first portion attached to the distal end of the shaft;

a second portion;

a wrist roll axis extending from the first portion to the second portion, and

a wrist pivot axis perpendicular to the wrist roll axis; said surgical apparatus further comprising an end effector attached to the second portion of the wrist member;

wherein:

the wrist member is rotatable about the shaft longitudinal axis; and

the wrist member is pivotable about the wrist pivot axis.

10. The apparatus of claim **9**, wherein the wrist pivot axis runs through the first portion of the wrist member.

11. The apparatus of claim **10**, wherein the wrist member is sized for insertion into a human body cavity through a minimally invasive aperture.

12. The apparatus of claim **10**, wherein the end effector is rotatable about the wrist roll axis.

13. The apparatus of claim **10**, wherein the end effector comprises:

first and second jaw members; and

a jaw pivot axis running through the second portion of the wrist, the jaw pivot axis being perpendicular to the wrist roll axis; wherein the first jaw member is pivotable about the jaw pivot axis.

14. The apparatus of claim **13**, wherein the end effector is rotatable about the wrist roll axis.

15. The apparatus of claim **13**, wherein the jaw pivot axis is perpendicular to the wrist pivot axis.

16. The apparatus of claim **13**, wherein the first and second jaw members are pivotable in opposing directions about the jaw pivot axis to open and close the jaw members.

17. The apparatus of claim **16**, wherein the first and second jaw members are further pivotable in the same direction about the jaw pivot axis.

18. The apparatus of claim **10**, wherein the shaft is axially movable along the shaft longitudinal axis.

19. The apparatus of claim **10**, further comprising a robotic linkage supporting a proximal end of the shaft, the robotic linkage having a plurality of robotic motors coupled to the end effector so as to effect said rotations and pivoting.

20. The apparatus of claim **19**, further comprising hand-operated means at a remote operator control station.

21. A surgical manipulator comprising:

an elongate shaft comprising a distal end and a shaft longitudinal axis;

a wrist member comprising:

a first portion attached to the distal end of the shaft;

a second portion;

a wrist roll axis extending from the first portion to the second portion, and

a wrist pivot axis perpendicular to the wrist roll axis;

the surgical manipulator further comprising an end effector attached to the second portion of the wrist member; wherein;

the shaft is rotatable about the shaft longitudinal axis; and

the wrist member is pivotable about the wrist pivot axis.

22. The manipulator of claim **21**, wherein the wrist pivot axis runs through the first portion of the wrist member.

23. The manipulator of claim **22**, wherein the wrist member is sized for insertion into a human body cavity through a minimally invasive aperture.

24. The manipulator of claim **23**, wherein the end effector is rotatable about the wrist roll axis.

25. The manipulator of claim **23**, wherein the end effector comprises:

first and second jaw members; and

a jaw pivot axis running through the second portion of the wrist, the jaw pivot axis being perpendicular to the wrist roll axis; wherein the first jaw member is pivotable about the jaw pivot axis.

26. The manipulator of claim **25**, wherein the jaw pivot axis is perpendicular to the wrist pivot axis.

27. A surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion;

wherein:

said shaft is, in response to movement of said shaft proximal end, pivotally movable in at least two degrees of freedom about a pivot point, said pivot point disposed on said shaft between said shaft proximal end and said shaft distal end;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and said wrist member is pivotable relative to said shaft about said wrist pitch axis; and

said end effector is rotatable about said wrist longitudinal axis.

28. The manipulator of claim 27, wherein said wrist member and said end effector are sized for insertion through an insertion point during minimally invasive surgery.

29. The manipulator of claim 28, wherein said pivot point is located at said insertion point.

30. The manipulator of claim 27, wherein said end effector comprises a pair of jaws.

31. The manipulator of claim 27, wherein said shaft is axially movable along said shaft longitudinal axis.

32. The manipulator of claim 27, wherein said shaft is rotatable about said shaft longitudinal axis.

33. The manipulator of claim 32, wherein said shaft is axially movable along said shaft longitudinal axis.

34. A robotic system comprising:

a first surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion; wherein:

said shaft is, in response to movement of said shaft proximal end, pivotally movable in at least two degrees of freedom about a pivot point, said pivot point disposed on said shaft between said shaft proximal end and said shaft distal end;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and said wrist member is pivotable relative to said shaft about said wrist pitch axis; and

said end effector is rotatable about said wrist longitudinal axis; and

said robotic system further comprising a first input controller, wherein said first surgical manipulator is movable in response to movement of said first input controller.

35. The system of claim 34, further comprising servomechanisms for providing force and torque feedback from said surgical manipulator to said first input controller.

36. The system of claim 34, wherein movement of said surgical manipulator is related to movement of said first input controller by a scale factor.

37. The system of claim 36, wherein the first input controller comprises master grippers, and wherein said end effector comprises grippers that can open or close in response to said master grippers being opened or closed.

38. The system of claim 37, wherein said grippers can apply a force related by a scale factor to a force applied to said master grippers.

39. The system of claim 37, further comprising servomechanisms for providing force feedback from said grippers to said master grippers.

40. The system of claim 39, further comprising servomechanisms for providing torque feedback from said grippers to said master grippers.

41. The system of claim 37, further comprising a second surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion; wherein;

said shaft is, in response to movement of said shaft proximal end, pivotally movable in at least two degrees of freedom about a pivot point, said pivot point disposed on said shaft between said shaft proximal end and said shaft distal end;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and said wrist member is pivotable relative to said shaft about said wrist pitch axis; and

said end effector is rotatable about said wrist longitudinal axis; and

said robotic system further comprising a second input controller, wherein said second surgical manipulator is movable in response to movement of said second input controller.

42. The surgical robotic system of claim 41, wherein a surgeon can control the first input controller through the surgeon's left hand; and the surgeon can control the second input controller through the surgeon's right hand.

43. The system of claim 34, further comprising a laparoscope for viewing organs within a human body cavity.

44. A robotic system comprising:

a first surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion; wherein:

said shaft is, in response to movement of said shaft proximal end, pivotally movable in at least two degrees of freedom about a pivot point, said pivot point disposed on said shaft between said shaft proximal end and said shaft distal end;

said shaft is axially movable along said shaft longitudinal axis;

said shaft is rotatable about said shaft longitudinal axis;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and said wrist member is pivotable relative to said shaft about said wrist pitch axis;

said end effector is rotatable about said wrist longitudinal axis; and

said robotic system comprising a first input controller, wherein said first surgical manipulator is movable in response to movement of said first input controller.

45. The system of claim 44, wherein movement of said surgical manipulator is related to movement of said input controller by a scale factor.

46. The system of claim 45, further comprising servomechanisms for providing force and torque feedback from said surgical manipulator to said first input controller.

47. The system of claim 45, wherein said input controller comprises master grippers, end said end effector comprises

grippers that can open or close in response to said master grippers being opened or closed.

48. The system of claim **47**, wherein said grippers can apply a force related by a scale factor to a force applied to said master grippers.

49. The system of claim **47**, further comprising servo-mechanisms for providing force feedback from said grippers to said master grippers.

50. The system of claim **49**, further comprising servo-mechanisms for providing torque feedback from said grippers to said master grippers.

51. The system of claim **44**, further comprising a laparoscope for viewing organs within a human body cavity.

52. The robotic system of claim **44**, further comprising a second surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion; wherein:

said shaft is, in response to movement of said shaft proximal end, pivotally movable in at least two degrees of freedom about a pivot point, said pivot point disposed on said shaft between said shaft proximal end and said shaft distal end;

said shaft is axially movable along said shaft longitudinal axis;

said shaft is rotatable about said shaft longitudinal axis;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and

said wrist member is pivotable relative to said shaft about said wrist pitch axis; and

said end effector is rotatable about said wrist longitudinal axis; and

said robotic system further comprising a second input controller, wherein said second surgical manipulator is movable in response to movement of said second input controller.

53. The surgical robotic system of claim **52**, further comprising a laparoscope for viewing organs within a human body cavity.

54. The surgical robotic system of claim **52**, wherein a surgeon can control said first input controller through the surgeon's left hand, and the surgeon can control said second input controller through the surgeon's right hand.

55. A surgical manipulator comprising:

an elongate shaft comprising a shaft proximal end, a shaft distal end, and a shaft longitudinal axis extending between said shaft proximal end and said shaft distal end;

a wrist member comprising a wrist proximal portion, a wrist distal portion, and a wrist longitudinal axis extending between said wrist proximal portion and said wrist distal portion, said wrist proximal portion being coupled to said shaft distal end; and

an end effector coupled to said wrist distal portion;

wherein:

said shaft is, in response to movement of said shaft proximal end, pivotally rotatable about a pivot point, said pivot point lying on said shaft between said shaft proximal end and said shaft distal end;

said wrist member has a wrist pitch axis perpendicular to said shaft longitudinal axis, and

said wrist member is pivotable relative to said shaft about said wrist pitch axis; and

said end effector is rotatable about said wrist longitudinal axis.

56. A method for minimally invasive surgery comprising:

forming a minimally invasive incision in the body of a patient;

inserting an end effector and a distal end of an elongate shaft into said minimally invasive incision, a wrist member coupling the end effector to the distal end of the shaft;

pivoting said shaft about said minimally invasive incision with at least two degrees of freedom by moving a proximal end of said shaft;

pivoting the wrist member about a wrist pitch axis perpendicular to a longitudinal axis of the shaft;

rotating the end effector about a wrist longitudinal axis perpendicular to said wrist pitch axis.

57. The method of claim **56**, further comprising rotating said shaft about said longitudinal axis of the shaft.

58. The method of claim **57**, further comprising moving said shaft along said longitudinal axis of the shaft.

59. The method of claim **57** further comprising:

moving said shaft, wrist member, and end effector in response to moving an input controller.

60. The method of claim **59**, wherein moving said input controller moves said shaft by a scale factor.

61. The method of claim **60**, further comprising providing force and torque feedback from said shaft to said input controller.

62. The method of claim **61**, further comprising providing force and torque feedback from said wrist member to said input controller.

63. The method of claim **59**, wherein moving said input controller moves said wrist member by a scale factor.

64. The method of claim **59**, further comprising opening or closing grippers on said end effector in response to opening and closing master grippers on said input controller.

65. The method of claim **64**, further comprising applying a force to said grippers related by a scale factor to a force applied to said master grippers.

66. The method of claim **64**, further comprising providing force feedback from said grippers to said master grippers.

67. The method of claim **64**, further comprising providing torque feedback from said grippers to said master grippers.

68. The method of claim **56**, further comprising viewing organs within a human body cavity using a laparoscope.

69. The method of claim **56**, further comprising manipulating tissue with said end effector.

70. The method of claim **69**, wherein the end effector comprises two jaw elements, and wherein said manipulating tissue with said end effector comprises gripping a tissue with said jaw elements.

71. A method for minimally invasive surgery comprising:

forming a first minimally invasive incision in the body of a patient;

inserting a first end effector and a distal end of a first elongate shaft into said first minimally invasive incision, a first wrist member coupling the first end effector to the distal end of the first shaft;

pivoting said first shaft about said first minimally invasive incision with at least two degrees of freedom by moving a proximal end of said first shaft;

pivoting the first wrist member about a first wrist pitch axis perpendicular to a longitudinal axis of the first shaft;

rotating the first end effector about a first wrist longitudinal axis perpendicular to said first wrist pitch axis;

forming a second minimally invasive incision in the body of a patient;

inserting a second end effector and a distal end of a second elongate shaft into said second minimally invasive incision, a second wrist member coupling the second end effector to the distal end of the second shaft;

pivoting said second shaft about said second minimally invasive incision with at least two degrees of freedom by moving a proximal end of said second shaft;

pivoting the second wrist member about a second wrist pitch axis perpendicular to a longitudinal axis of the second shaft;

rotating the second end effector about a second wrist longitudinal axis perpendicular to said second wrist pitch axis.

72. The method of claim **71**, further comprising moving said first shaft in response to moving a first input controller using a left hand, and moving said second shaft in response to moving a second input controller using a right hand.

73. The method of claim **72**, further comprising moving said first end effector in response to moving master grippers on said first input controller.

74. A surgical manipulator comprising:

an input device provided with an end section movement unit and an end effector control unit;

a control arm having one end operatively coupled to the input device;

a wrist connected to the other end of the control arm, wherein said wrist is connected to an end effector, and supports said end effector in at least two degrees of freedom of motion; and

a computer that operatively couples the input device to the control arm, the computer configured to transmit a movement by the end section movement unit to the wrist to pivot the wrist, and to transmit a command provided by the end effector control unit to operate the end effector;

wherein the wrist includes a wrist link capable of pivoting about a first axis perpendicular to a longitudinal axis of the control arm, and an outer link capable of turning about a second axis perpendicular to the first axis;

the end effector has a longitudinal axis substantially parallel to the second axis;

the end section movement unit includes a joint capable of pivoting about a pitch axis perpendicular tote longitudinal axis of the control arm and a joint capable of rotating about a roll axis perpendicular to the pitch axis; and

the end effector control unit is provided for gripping by fingers.

75. The manipulator of claim **74**, wherein movement of said wrist is related to movement of said end section movement unit by a scale factor.

76. The manipulator of claim **74**, wherein movement of said end effector is related to movement of said end effector control unit by a scale factor.

77. The manipulator of claim **76**, further comprising servomechanisms for providing force and torque feedback from said wrist to said end section movement unit.

78. The manipulator of claim **74**, further comprising master grippers coupled to said en section movement unit, wherein the end effector comprises grippers that can open or close in response to said master grippers being opened or closed.

79. The manipulator of claim **78**, wherein said grippers can apply a force related by a scale factor to a force applied to said master grippers.

80. The manipulator of claim **78**, further comprising servomechanisms for providing force feedback from said grippers to said master grippers.

81. The manipulator of claim **80**, further comprising servomechanisms for providing torque feedback from said grippers to said master grippers.

82. The manipulator of claim **74**, further comprising a laparoscope for viewing organs within a human body cavity, said laparascope and said surgical manipulator being carried by a fixed rail forming part of a surgical table.

83. A surgical robotic system comprising:

a first surgical manipulator comprising:

an input device provided with an end section movement unit and an end effector control unit;

a control arm having one end operatively coupled to the input device;

a wrist connected to the other end of the control arm, wherein said wrist is connected to an end effector, and supports said end effector in at least two degrees of freedom of motion; and

a computer that operatively couples the input device to the control arm, the computer configured to transmit a movement by the end section movement unit to the wrist to pivot the wrist, and to transmit a command provided by the end effector control unit to operate the end effector;

wherein the wrist includes a wrist link capable of pivoting about a first axis perpendicular to a longitudinal axis of the control arm, and an outer link capable of turning about a second axis perpendicular to the first axis;

the end effector has a longitudinal axis substantially parallel to the second axis;

the end section movement unit includes a joint capable of pivoting about a pitch axis perpendicular to the longitudinal axis of tire control arm and a joint capable of rotating about a roll axis perpendicular to the pitch axis; and

the end effector control unit is provided for gripping by fingers extending substantially in parallel to the roll axis; and

said surgical robotic system comprising a second surgical manipulator comprising:

an input device provide with an end section movement unit and an end effector control unit;

a control arm having one end operatively coupled to the input device;

a wrist connected to the other end of the control arm, wherein said wrist is connected to an end effector, and supports said end effector in at least two degrees of freedom of motion; and

a computer that operatively couples the input device to the control arm, the computer configured to transmit a movement by the end section movement unit to the wrist to pivot the wrist, and to transmit a command provided by the end effector control unit to operate the end effector;

wherein the wrist include s a wrist link capable of pivoting about a first axis perpendicular to a longitudinal axis of the control arm, and an outer link capable of turning about a second axis perpendicular to the first axis;

the end effector has a longitudinal axis substantially parallel to the second axis;

the end section movement unit includes a joint capable of pivoting about a pitch axis perpendicular to the longitudinal axis of the control arm and a joint capable of rotating about a roll axis perpendicular to the pitch axis; and

the end effector control unit is provided for gripping by fingers.

84. The surgical robotic system of claim **83**, further comprising a laparoscope for viewing a axis within a human body cavity.

85. The surgical robotic system of claim **83**, wherein a surgeon can control the input device of the first manipulator through the surgeon's left hand; and

the surgeon can control the input device of the second manipulator through the surgeon's right hand.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,248,944 B2
APPLICATION NO. : 11/360745
DATED : July 24, 2007
INVENTOR(S) : Philip S. Green

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [73] should read.

(73) Assignee: SRI International, Menlo Park, CA (US) as recorded on January 21, 1992

Signed and Sealed this

Twenty-seventh Day of January, 2009

JOHN DOLL
Acting Director of the United States Patent and Trademark Office

专利名称(译)	用于微创机器人手术的滚动 - 俯仰 - 滚动腕部方法		
公开(公告)号	US7248944	公开(公告)日	2007-07-24
申请号	US11/360745	申请日	2006-02-22
[标]申请(专利权)人(译)	斯坦福研究院		
申请(专利权)人(译)	SRI国际公司		
当前申请(专利权)人(译)	学院外科，INC		
[标]发明人	GREEN PHILIP S		
发明人	GREEN, PHILIP S.		
IPC分类号	G06F19/00 A61B17/00 A61B19/00 B25J3/04 B25J19/02 H04N13/00		
CPC分类号	A61B1/00193 A61B17/00234 A61B19/22 A61B19/52 B25J3/04 B25J19/023 H04N13/0239 H04N13 /0246 H04N13/0296 H04N13/0434 H04N13/0438 H04N13/0497 A61B19/5212 A61B19/5225 A61B2019 /2211 A61B2019/2223 A61B2019/223 A61B2019/2234 A61B2019/2249 A61B2019/2292 A61B2019 /2296 A61B2019/464 A61B2019/5227 H04N13/0055 H04N13/0059 A61B34/35 A61B34/37 A61B34/70 A61B34/72 A61B34/76 A61B34/77 A61B90/36 A61B90/361 A61B90/37 A61B2034/301 A61B2034/305 A61B2090/064 A61B2090/371 B25J13/025 H04N13/189 H04N13/194 H04N13/239 H04N13/246 H04N13/296 H04N13/337 H04N13/341 H04N13/398		
审查员(译)	BLACK，THOMAS		
其他公开文献	US20060142897A1		
外部链接	Espacenet USPTO		

摘要(译)

示出了具有远程呈现的遥控操作系统，其包括右手和左手控制器（72R和72L），用于通过使用包括计算机（42）的伺服机构来控制左右操纵器（24R和24L）。摄像机（46R和46L）从不同角度观察工作空间（30），以在线（48R和48L）处产生立体信号输出。响应于摄像机输出，产生三维的从上到下的倒置图像（30I），其由镜子（66）朝向操作者（18）的眼睛反射。在控制臂（76R和76L）附近产生虚像（30V），操作者（18）观察控制臂的方向。还公开了远程操作系统用于外科手术的用途。