US008142447B2

(12) **United States Patent**
Cooper et al.

(10) **Patent No.: US 8,142,447 B2**
(45) **Date of Patent: Mar. 27, 2012**

(54) **MECHANICAL ACTUATOR INTERFACE SYSTEM FOR ROBOTIC SURGICAL TOOLS**

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(73) Assignee: **Intuitive Surgical Operations 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 382 days.

(21) Appl. No.: **12/407,150**

(22) Filed: **Mar. 19, 2009**

(65) **Prior Publication Data**

US 2009/0248043 A1 Oct. 1, 2009

Related U.S. Application Data

(60) Division of application No. 10/316,666, filed on Dec. 10, 2002, now Pat. No. 7,524,320, which is a continuation of application No. 09/929,453, filed on Aug. 13, 2001, now Pat. No. 7,048,745, which is a division of application No. 09/759,542, filed on Jan. 12, 2001, now Pat. No. 6,491,701, which is a continuation of application No. 09/418,726, filed on Oct. 15, 1999, now Pat. No. 6,331,181.

(60) Provisional application No. 60/116,844, filed on Jan. 22, 1999, provisional application No. 60/111,713, filed on Dec. 8, 1998.

(51) **Int. Cl.**
A61B 19/00 (2006.01)

(52) **U.S. Cl.** **606/130**; 606/1; 901/25

(58) **Field of Classification Search** 606/1, 130; 700/257, 245; 901/25; 74/490.01–490.06
See application file for complete search history.

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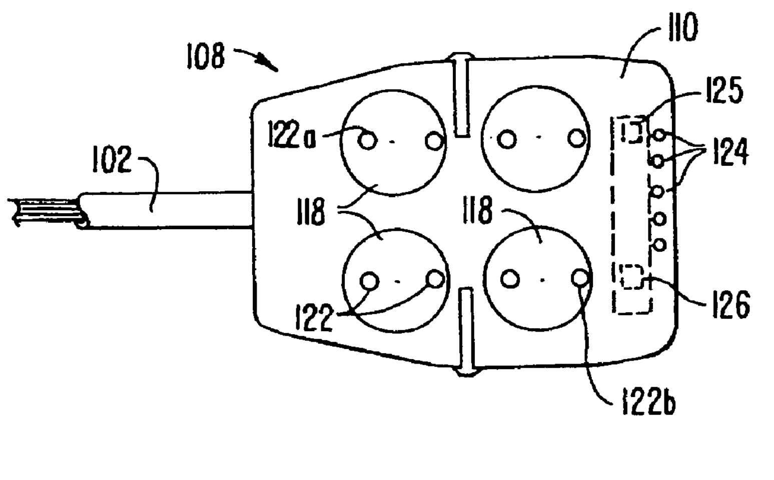
Primary Examiner — Thomas J Sweet
Assistant Examiner — Cheryl Miller

(57) **ABSTRACT**

Robotic surgical tools, systems, and methods for preparing for and performing robotic surgery include a memory mounted on the tool. The memory can perform a number of functions when the tool is loaded on the tool manipulator: first, the memory can provide a signal verifying that the tool is compatible with that particular robotic system. Secondly, the tool memory may identify the tool-type to the robotic system so that the robotic system can reconfigure its programming. Thirdly, the memory of the tool may indicate tool-specific information, including measured calibration offsets indicating misalignment of the tool drive system, tool life data, or the like. This information may be stored in a read only memory (ROM), or in a nonvolatile memory which can be written to only a single time. The invention further provides improved engagement structures for coupling robotic surgical tools with manipulator structures.

5 Claims, 22 Drawing Sheets



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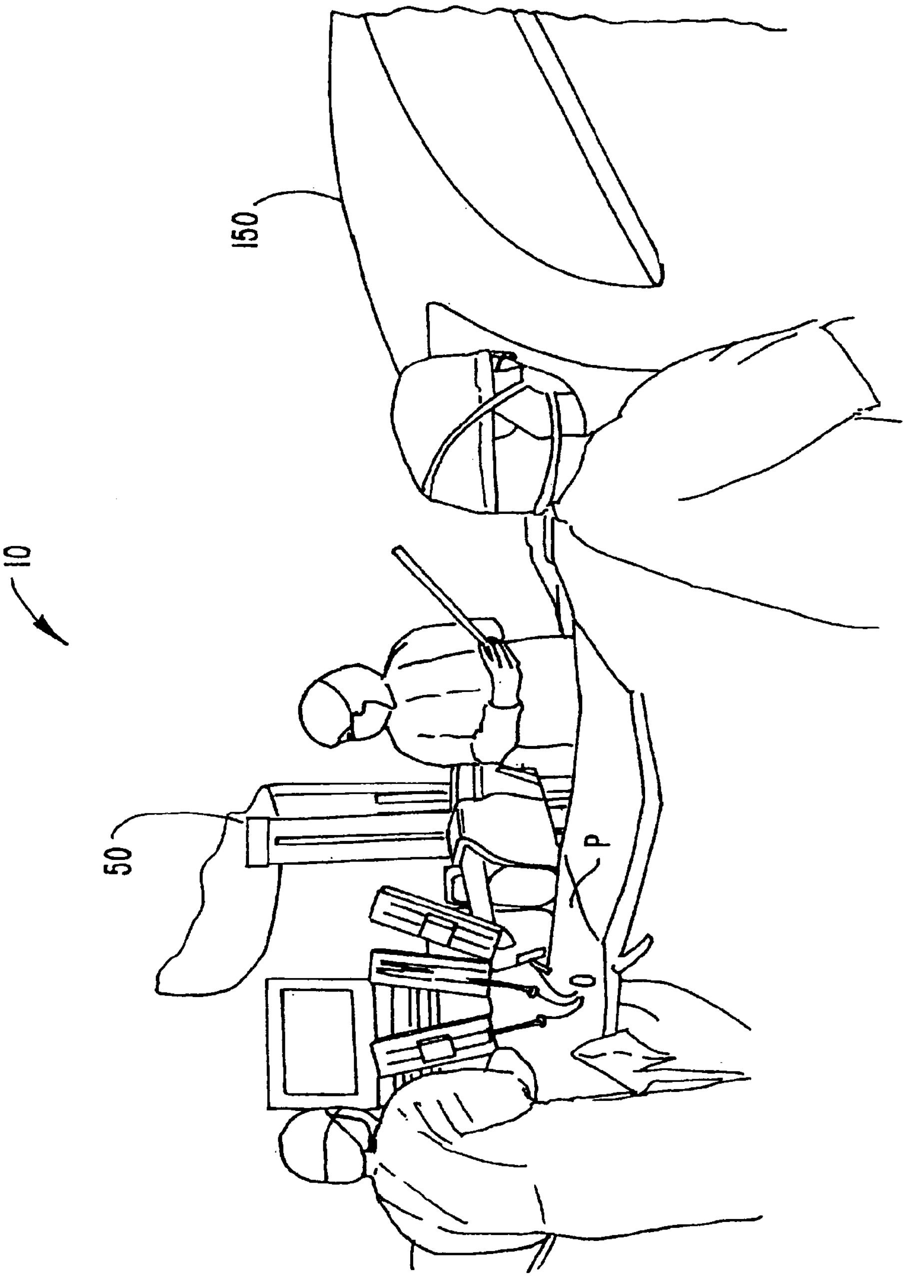


FIG. 1.

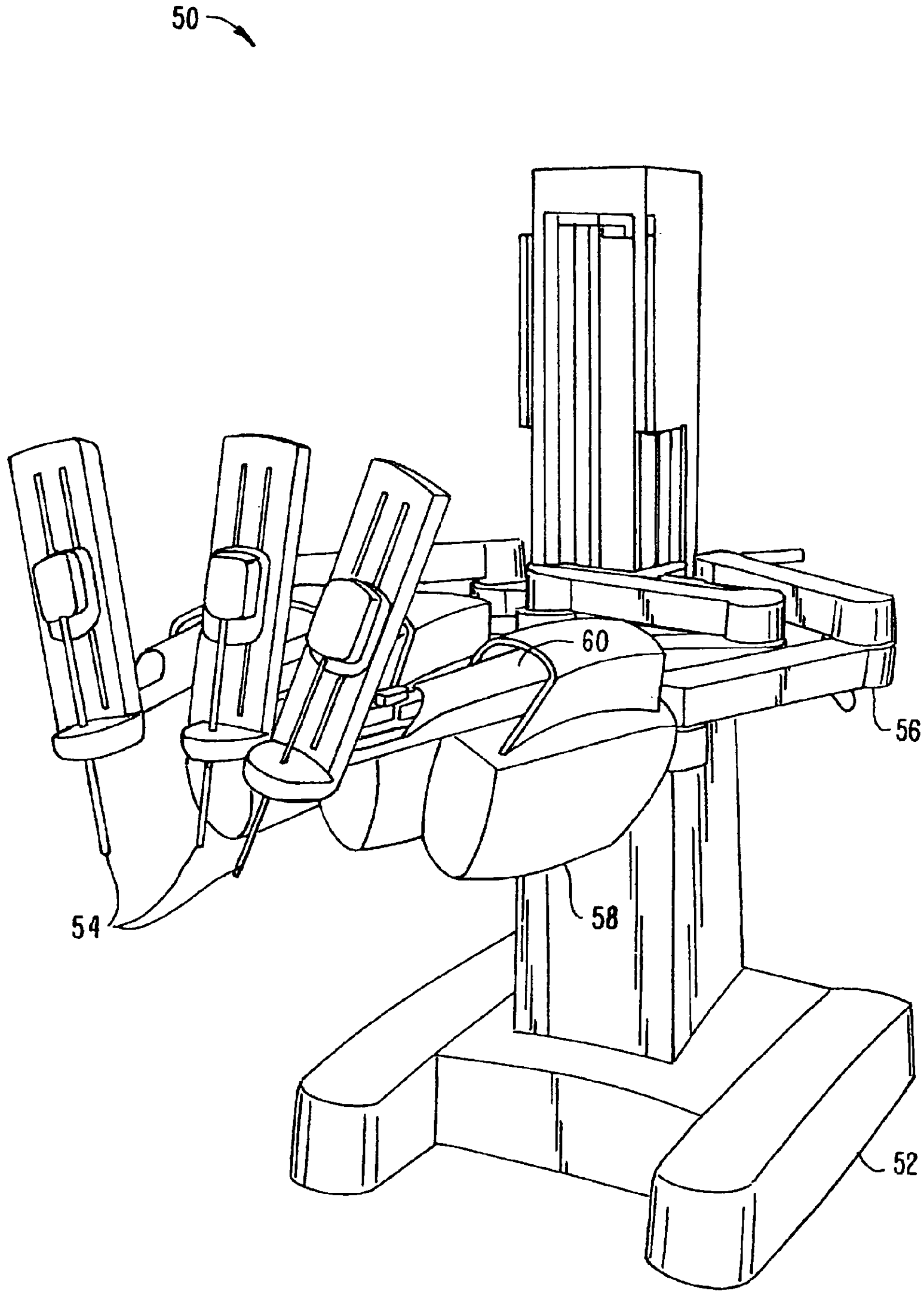


FIG. 2.

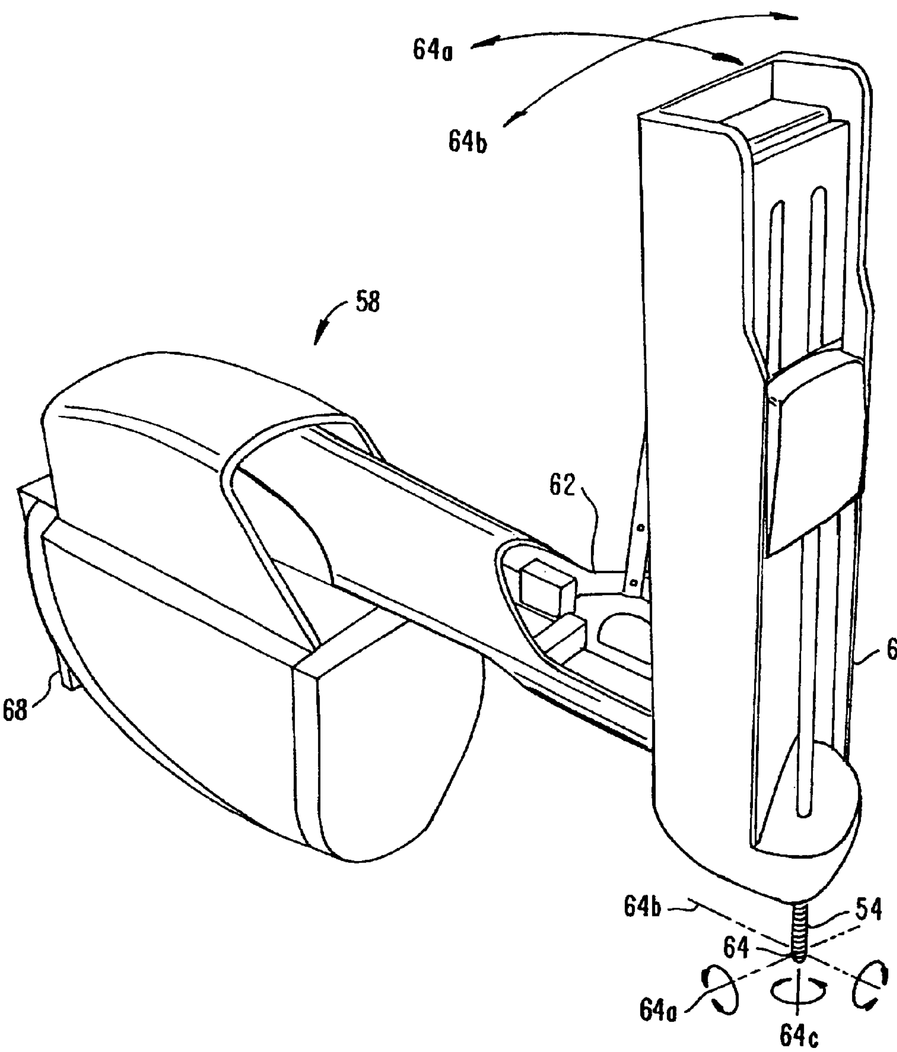
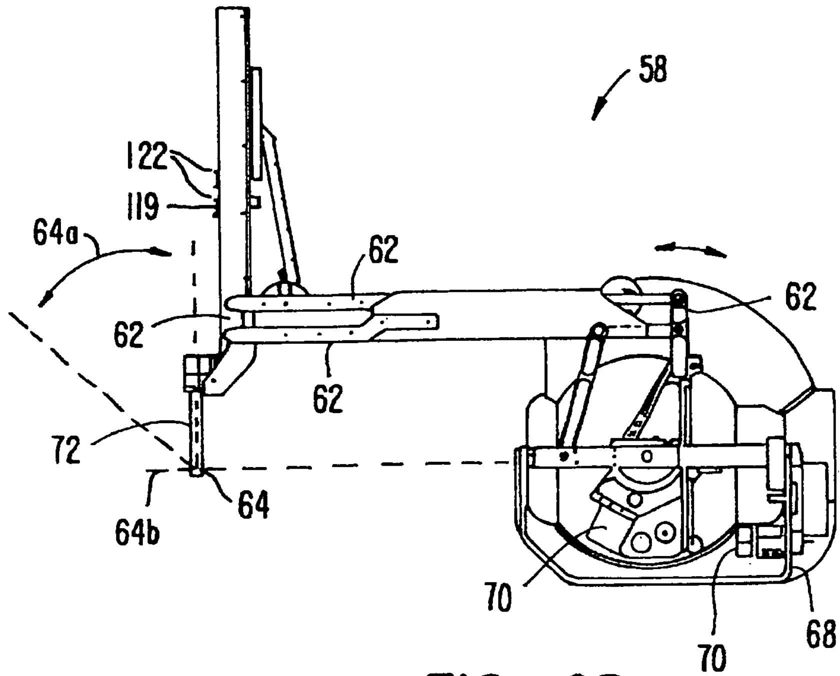


FIG. 2A.



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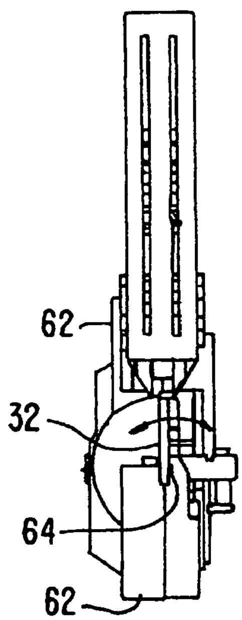


FIG. 2C.

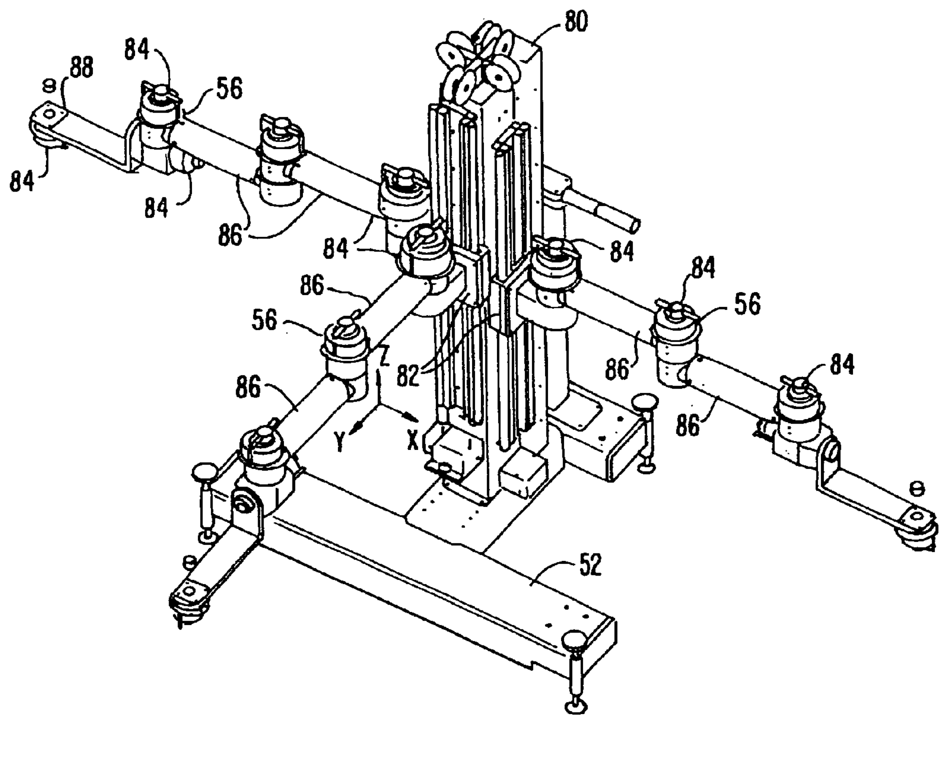


FIG. 3.

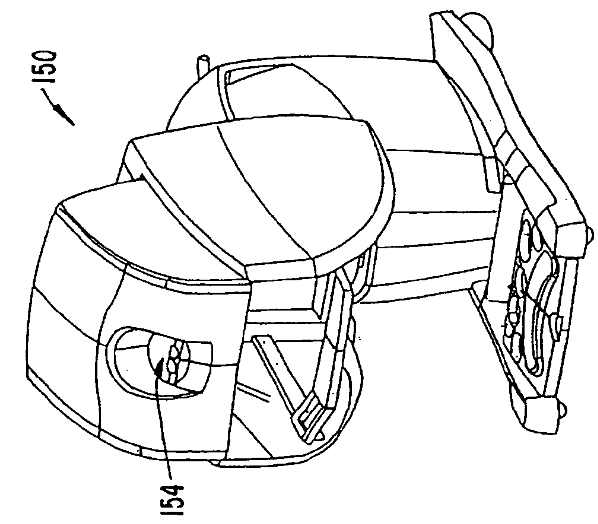


FIG. 8B.

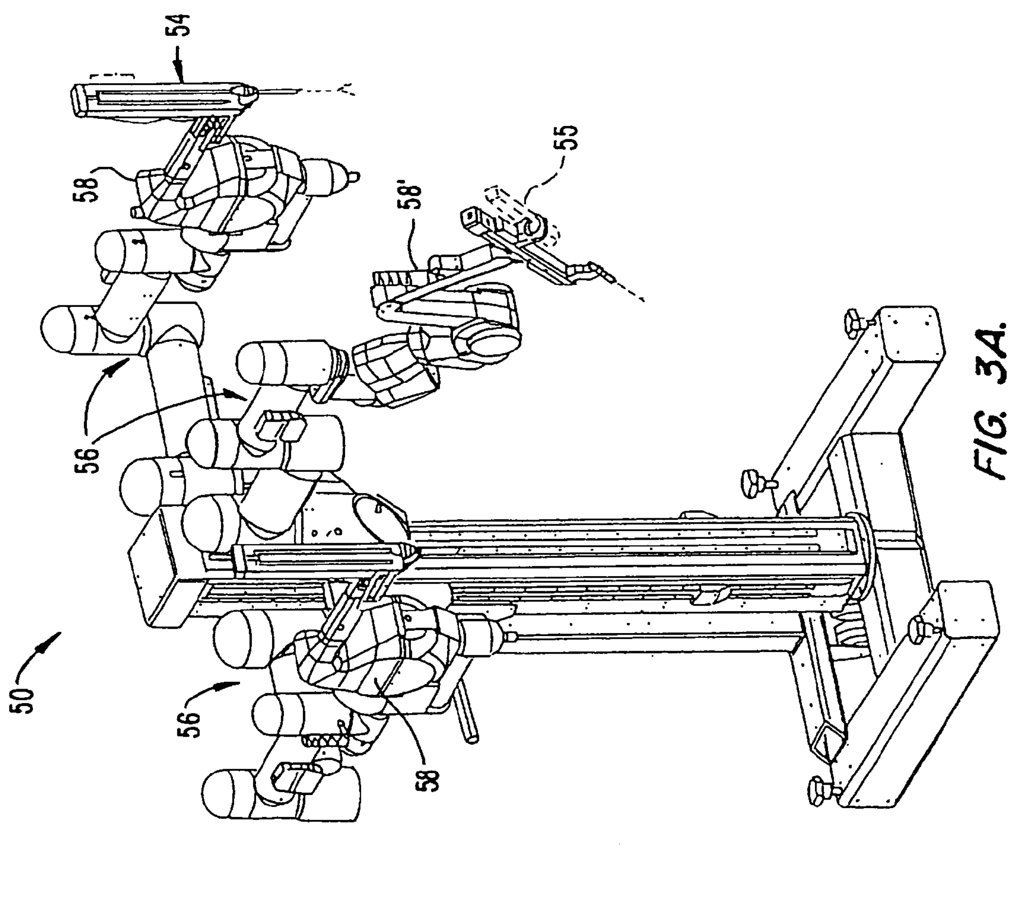
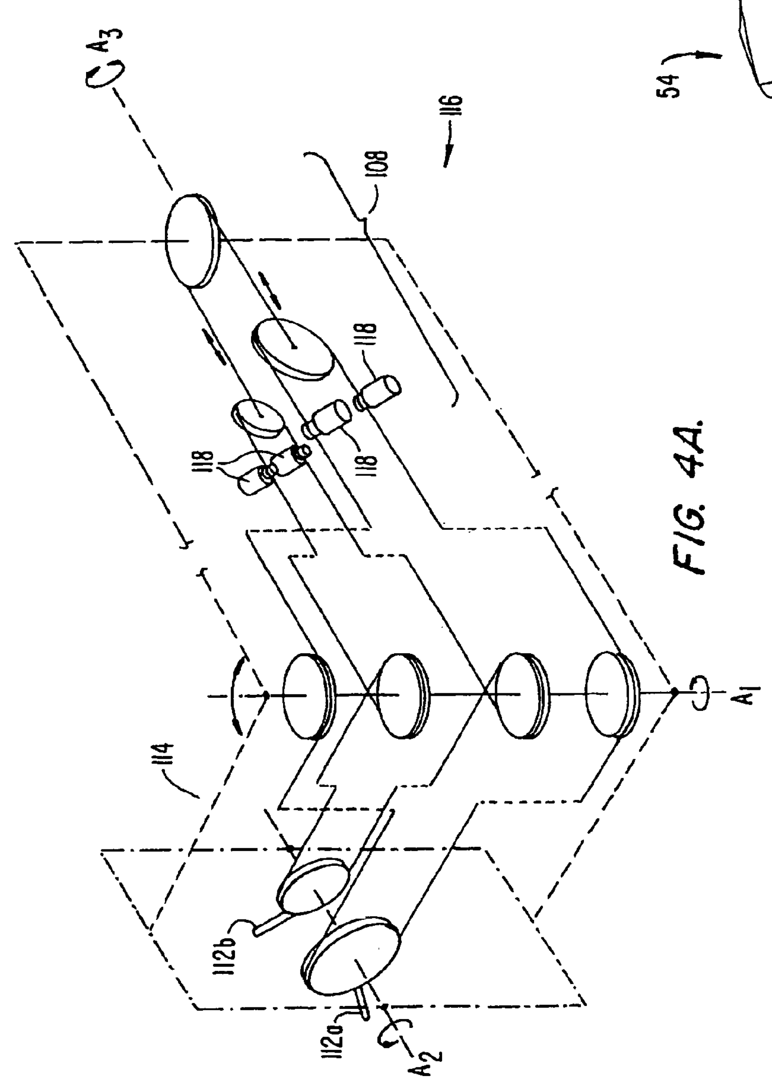


FIG. 3A.



A_3
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A_1
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112b
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A_2

FIG. 4A.

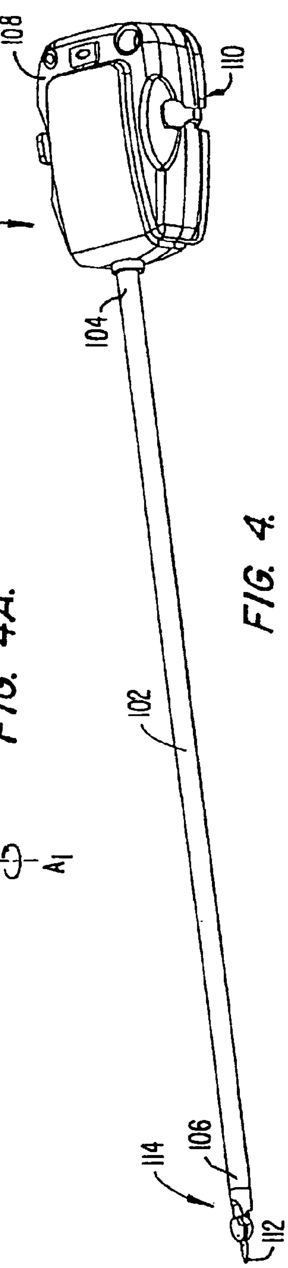

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FIG. 4.

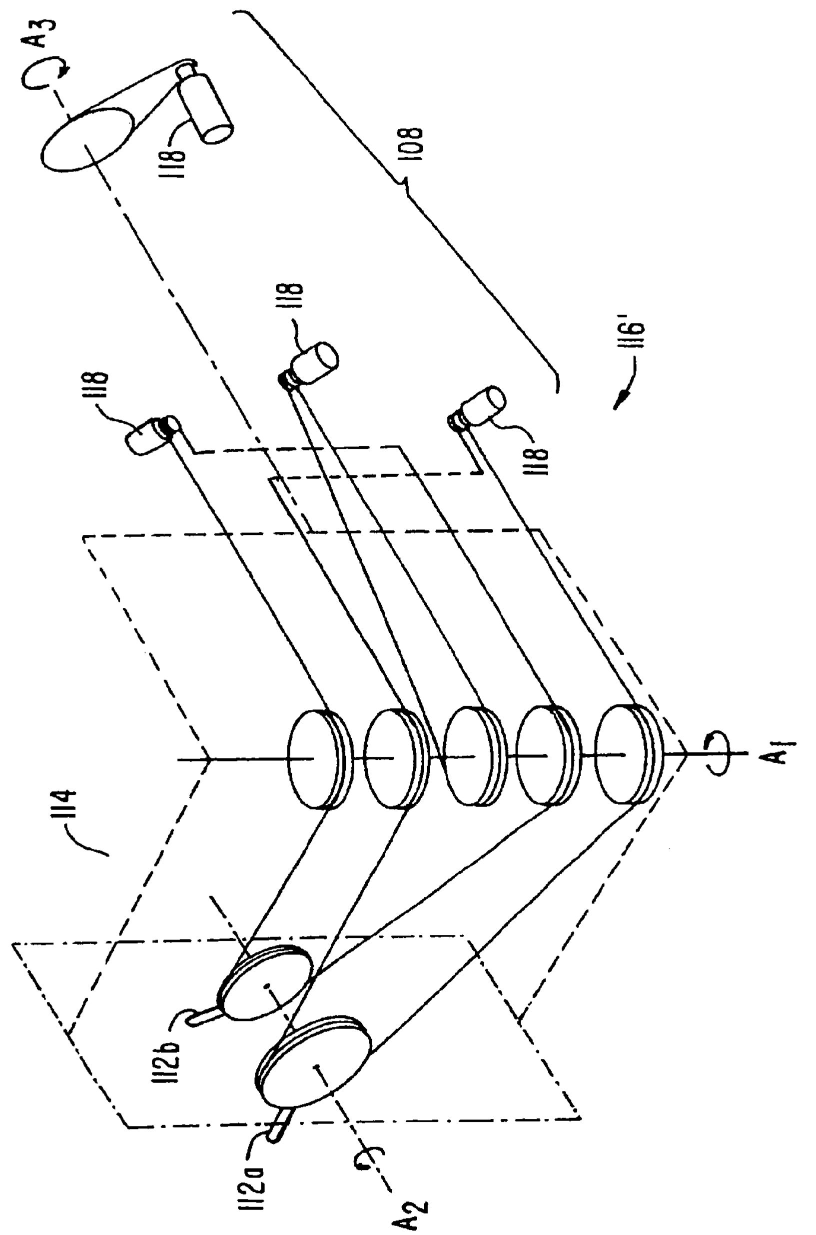


FIG. 4B.

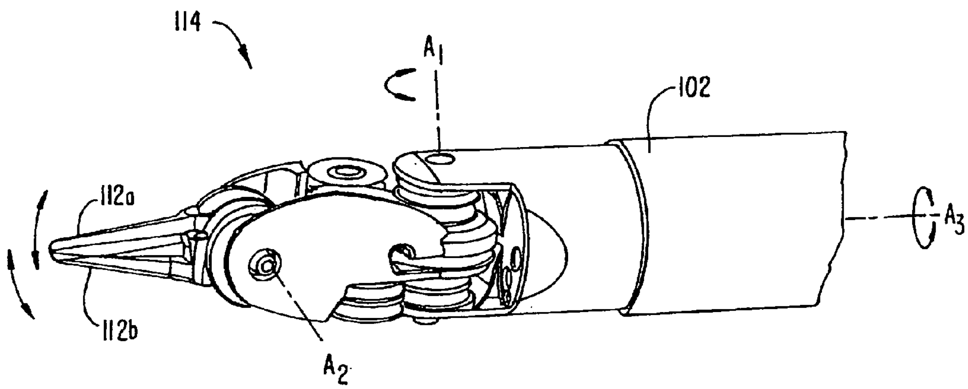


FIG. 5A.

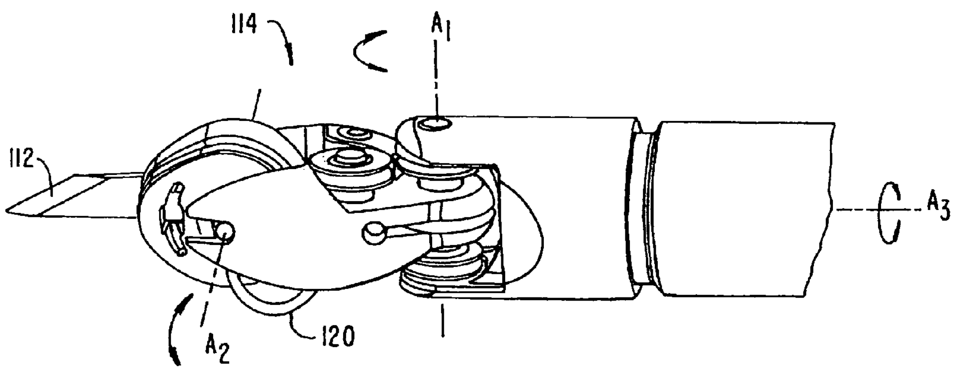


FIG. 5B.

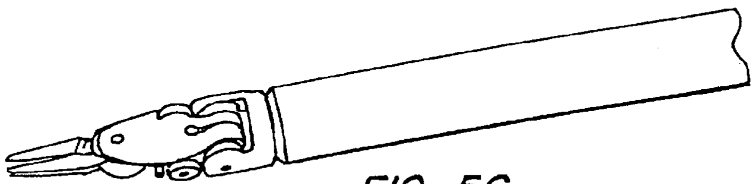


FIG. 5C.

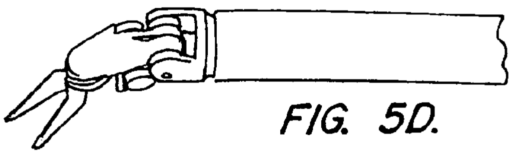


FIG. 5D.

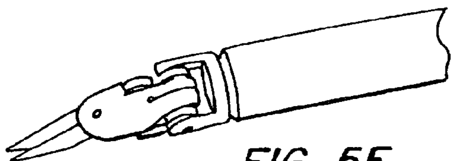
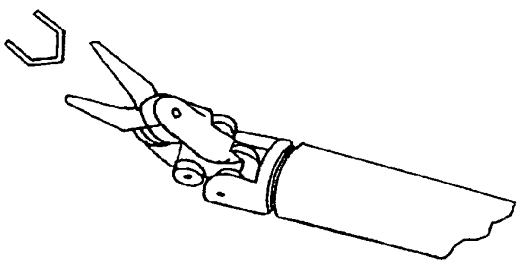


FIG. 5E.



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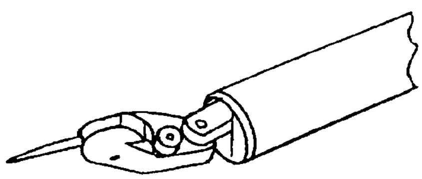

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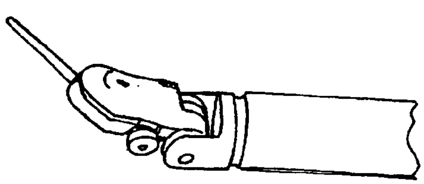
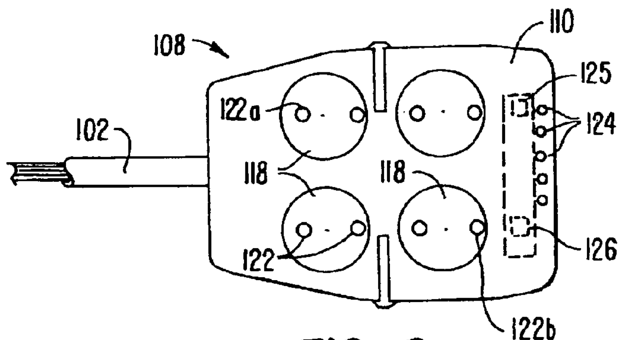


FIG. 5H.



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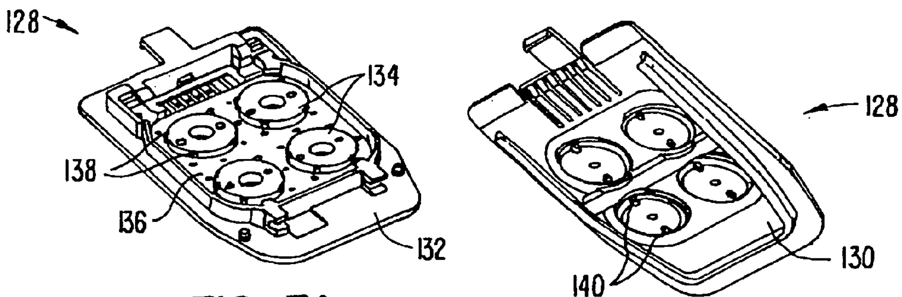


FIG. 7A.

FIG. 7B.

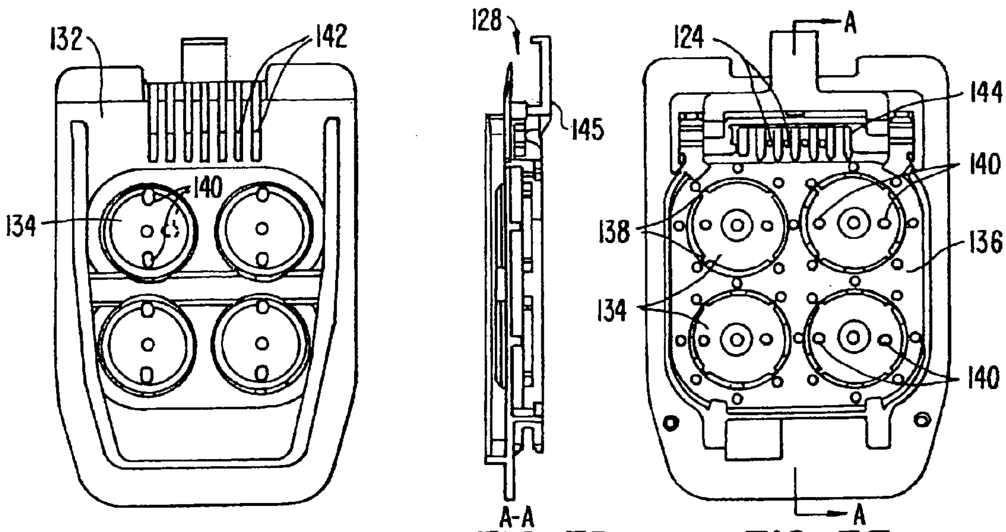
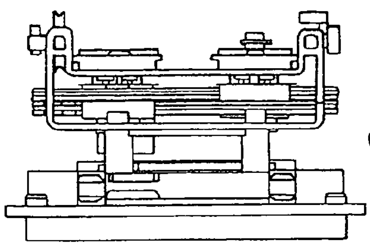


FIG. 7C.

FIG. 7D.

FIG. 7E.



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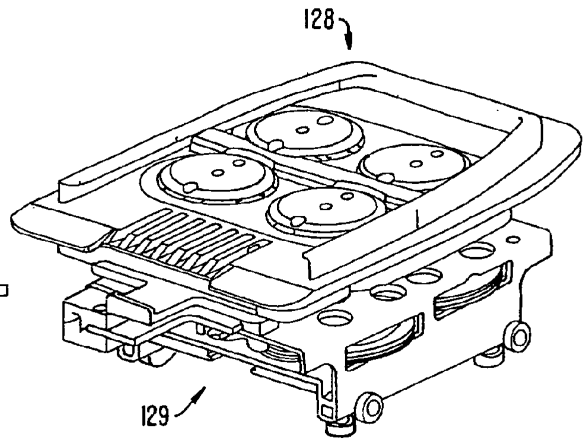

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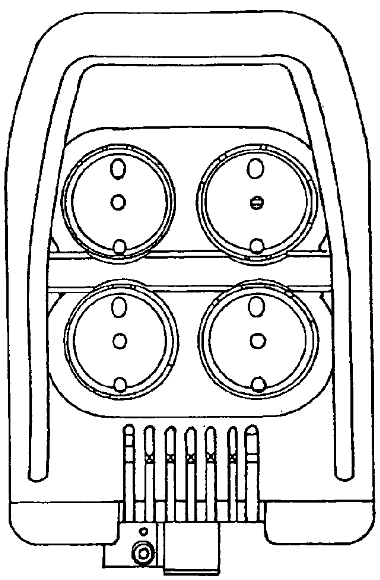

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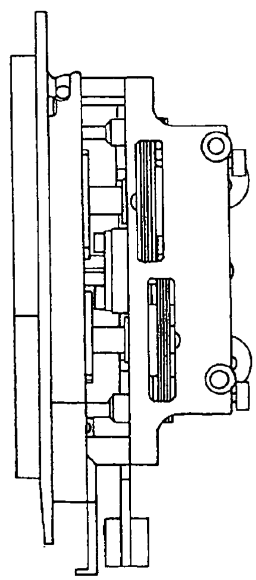
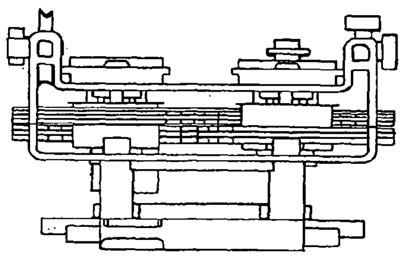


FIG. 7I.



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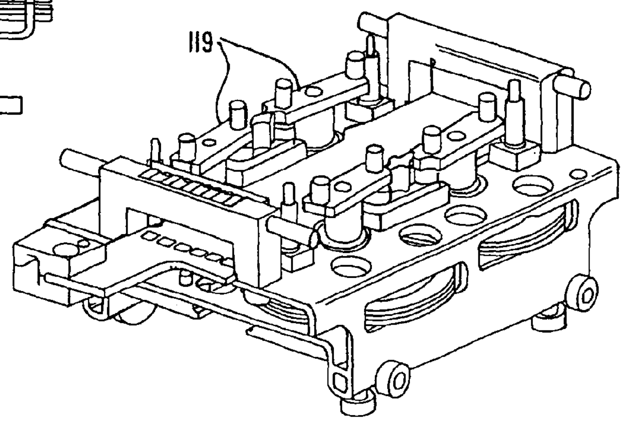
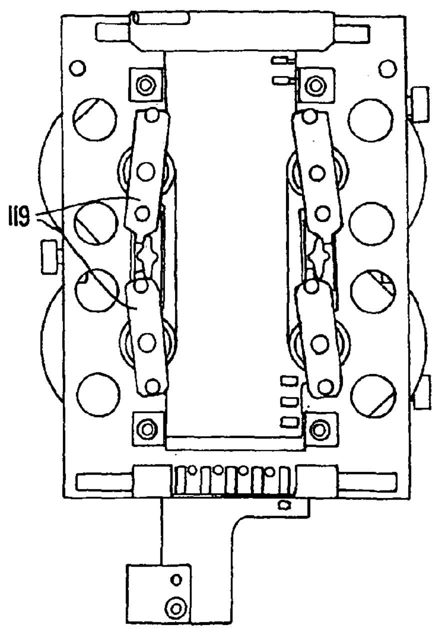


FIG. 7J.



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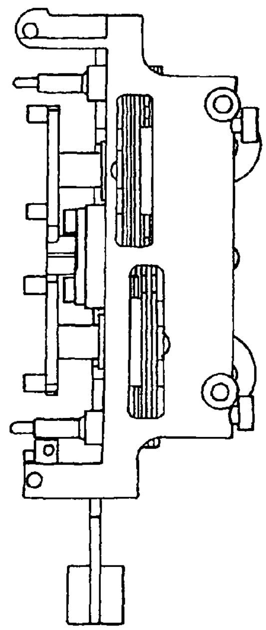
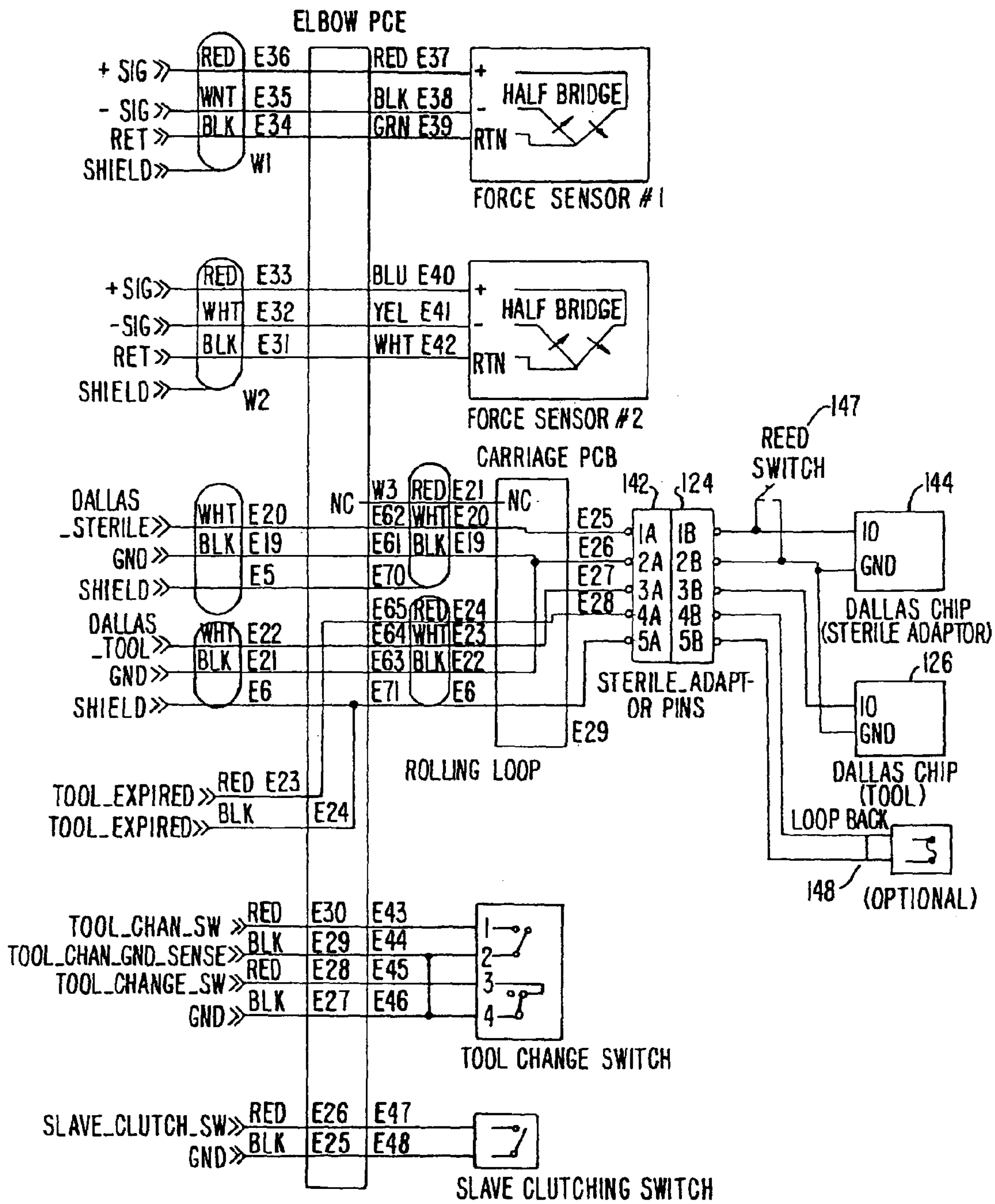


FIG. 7L.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- SIG
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RTN
FORCE SENSOR #1
+SIG
-SIG
RET
SHIELD
RED E33
WHT E32
BLK E31
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BLU E40
YEL E41
WHT E42
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RTN
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REED SWITCH
CARRIAGE PCB
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124
144
DALLAS _STERILE
GND
SHIELD
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BLK E19
E5
NC
W3
RED E21
E62 WHT E20
E61 BLK E19
E70
NC
E25
E26
E27
E28
1A 1B
2A 2B
3A 3B
4A 4B
5A 5B
IO
GND
DALLAS CHIP (STERILE ADAPTOR)
DALLAS _TOOL
GND
SHIELD
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E6
E65 RED E24
E64 WHT E23
E63 BLK E22
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STERILE_ADAPT-OR PINS
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1
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SLAVE_CLUTCH_SW
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BLK E25 E48
SLAVE CLUTCHING SWITCH

FIG. 8.

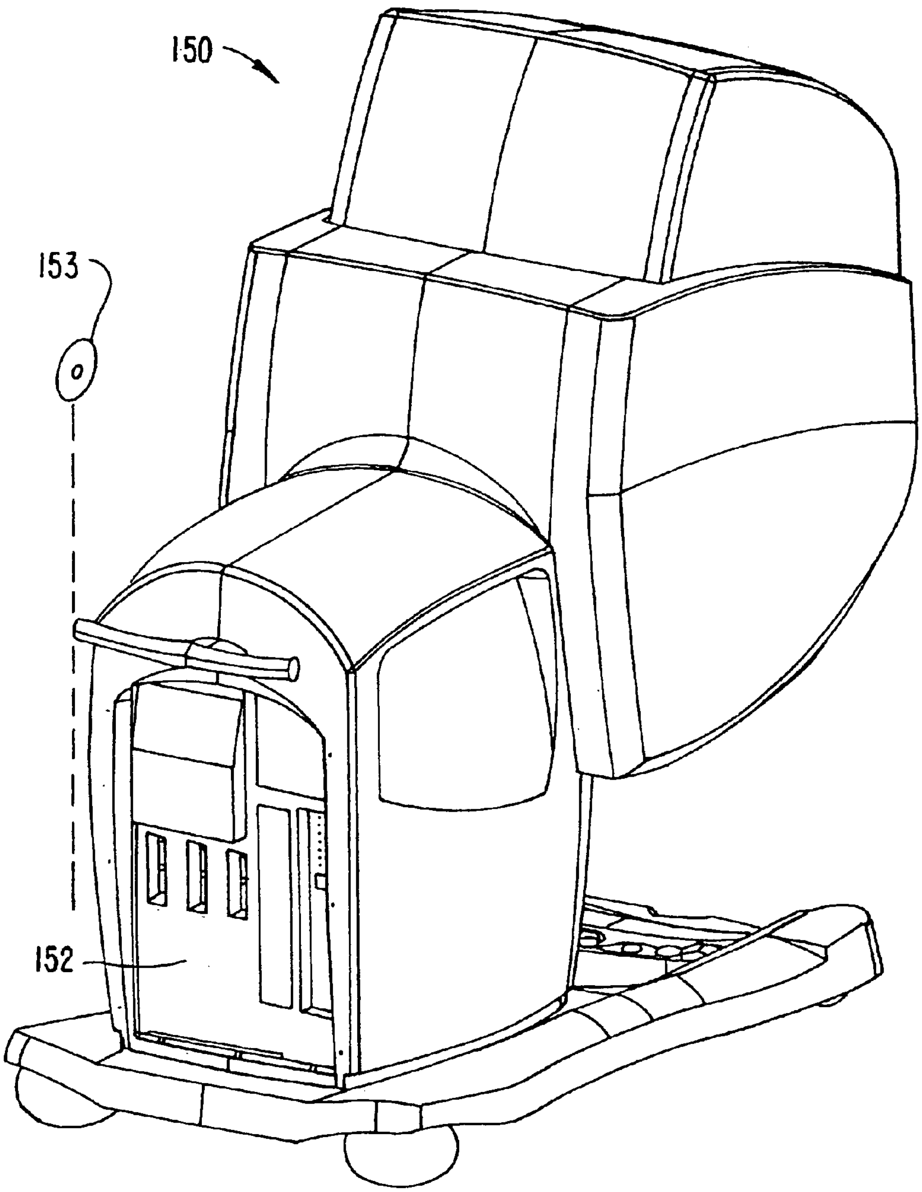
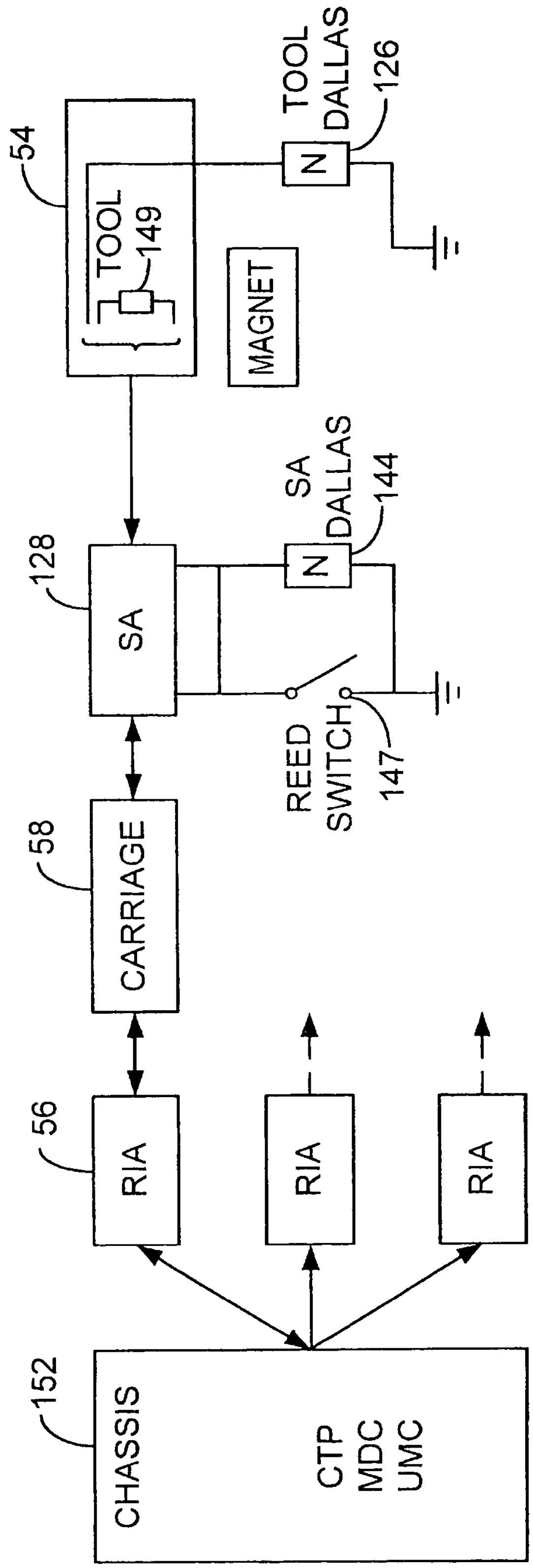


FIG. 8A.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TOOL
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RIA
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RIA
152
CHASSIS
CTP
MDC
UMC

FIG. 9.

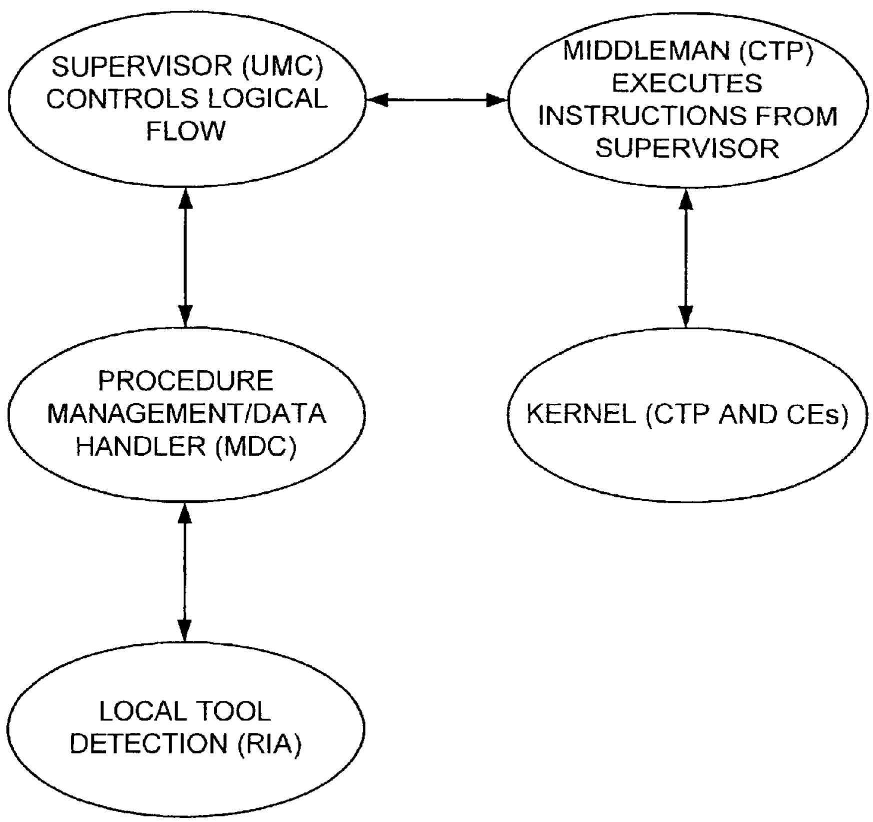
SUPERVISOR (UMC) CONTROLS LOGICAL FLOW
MIDDLEMAN (CTP) EXECUTES INSTRUCTIONS FROM SUPERVISOR
PROCEDURE MANAGEMENT/DATA HANDLER (MDC)
KERNEL (CTP AND CEs)
LOCAL TOOL DETECTION (RIA)

FIG. 10.

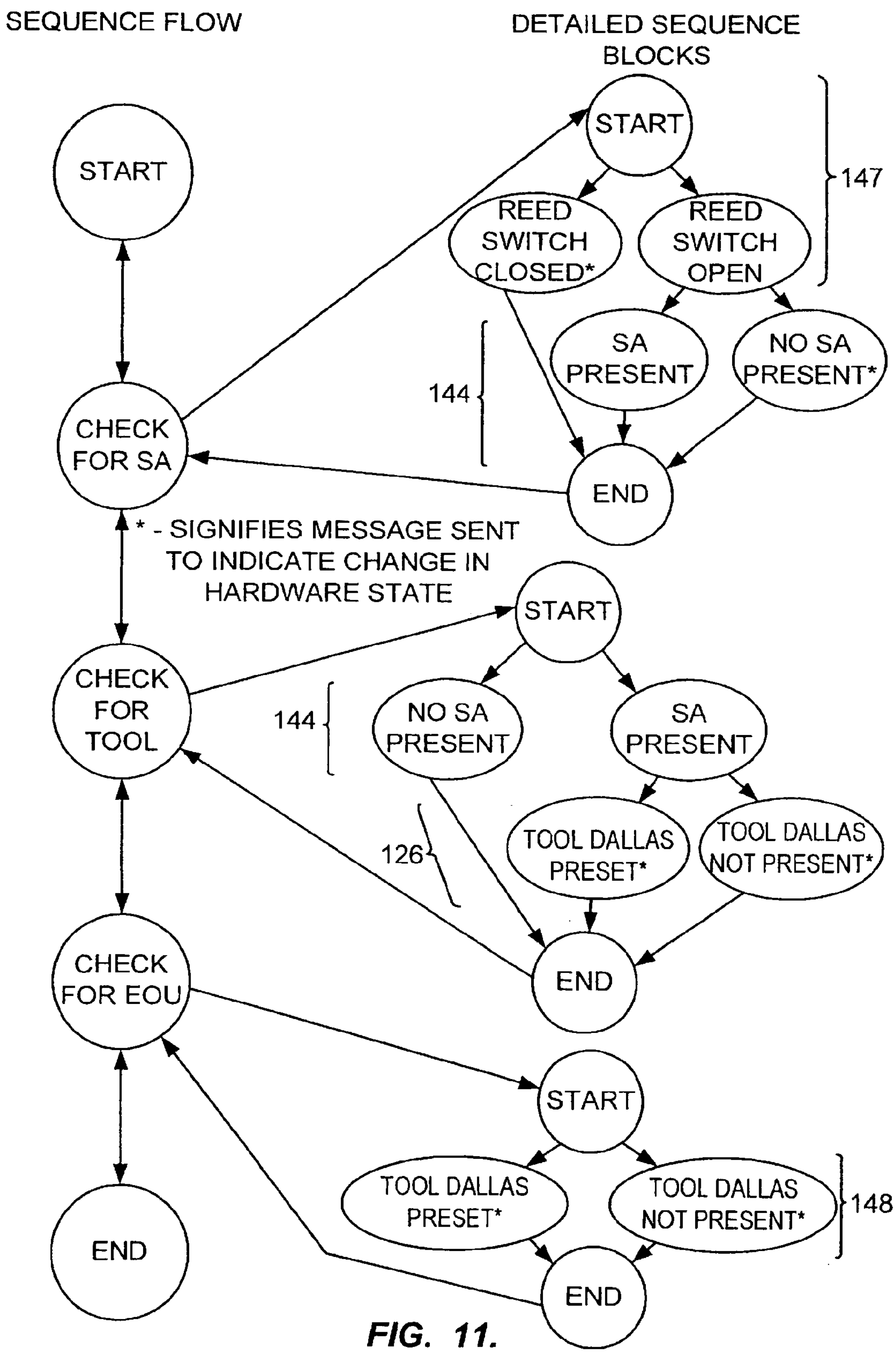
SEQUENCE FLOW
DETAILED SEQUENCE BLOCKS
START
CHECK FOR SA
CHECK FOR TOOL
CHECK FOR EOU
END
START
REED SWITCH CLOSED*
REED SWITCH OPEN
147
144
SA PRESENT
NO SA PRESENT*
END
* - SIGNIFIES MESSAGE SENT TO INDICATE CHANGE IN HARDWARE STATE
START
144
NO SA PRESENT
SA PRESENT
126
TOOL DALLAS PRESET*
TOOL DALLAS NOT PRESENT*
END
START
TOOL DALLAS PRESET*
TOOL DALLAS NOT PRESENT*
148
END

FIG. 11.

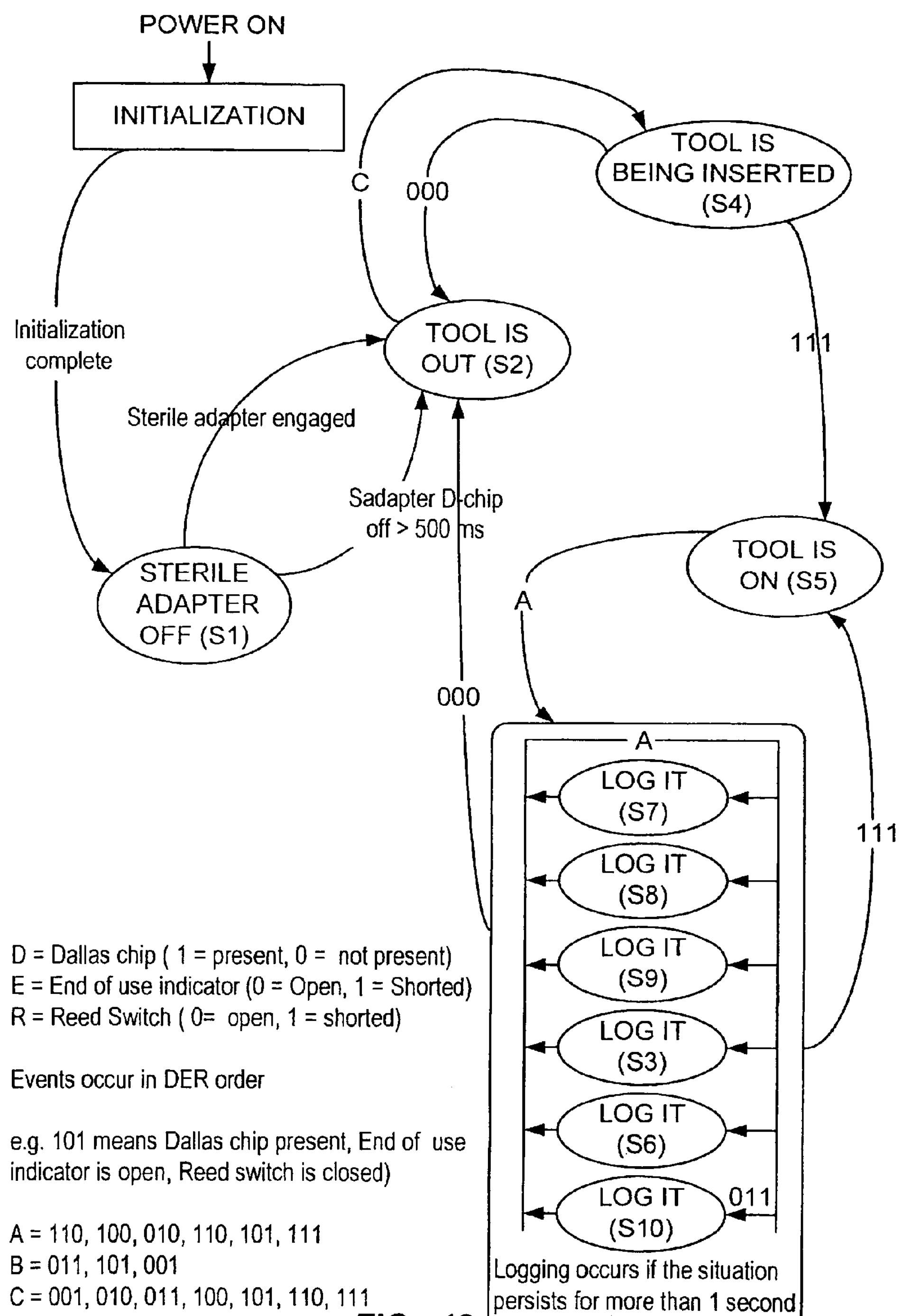
POWER ON
INITIALIZATION
Initialization complete
STERILE ADAPTER OFF (S1)
Sterile adapter engaged
TOOL IS OUT (S2)
Sadapter D-chip off > 500 ms
C
000
TOOL IS BEING INSERTED (S4)
111
TOOL IS ON (S5)
A
000
111
A
LOG IT (S7)
LOG IT (S8)
LOG IT (S9)
LOG IT (S3)
LOG IT (S6)
LOG IT (S10)
011
Logging occurs if the situation persists for more than 1 second
D = Dallas chip (1 = present, 0 = not present)
E = End of use indicator (0 = Open, 1 = Shorted)
R = Reed Switch (0= open, 1 = shorted)
Events occur in DER order
e.g. 101 means Dallas chip present, End of use indicator is open, Reed switch is closed)
A = 110, 100, 010, 110, 101, 111
B = 011, 101, 001
C = 001, 010, 011, 100, 101, 110, 111

FIG. 12.

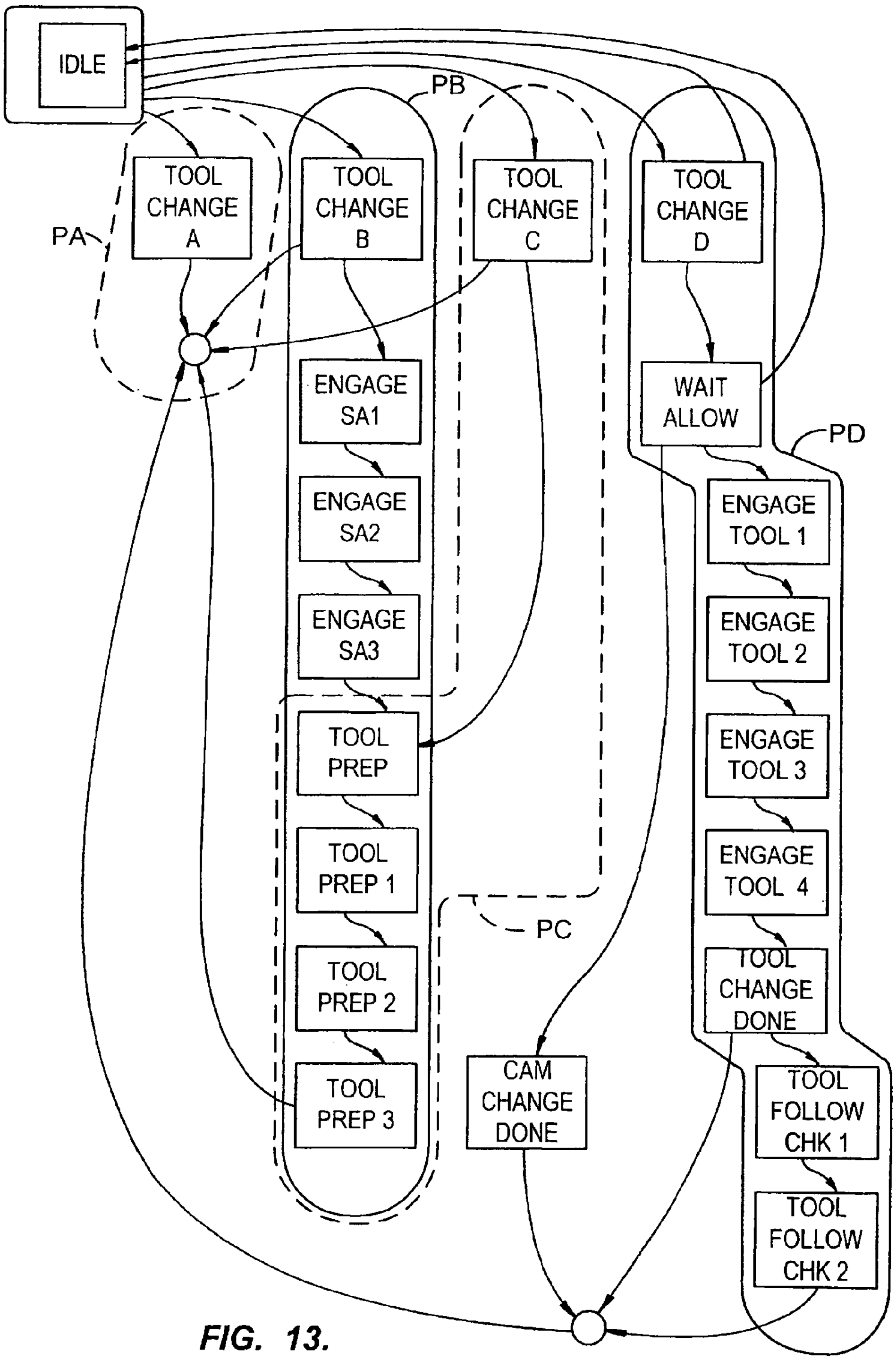
IDLE
TOOL CHANGE A
TOOL CHANGE B
TOOL CHANGE C
TOOL CHANGE D
PA
PB
PC
PD
ENGAGE SA1
ENGAGE SA2
ENGAGE SA3
TOOL PREP
TOOL PREP 1
TOOL PREP 2
TOOL PREP 3
WAIT ALLOW
ENGAGE TOOL 1
ENGAGE TOOL 2
ENGAGE TOOL 3
ENGAGE TOOL 4
TOOL CHANGE DONE
TOOL FOLLOW CHK 1
TOOL FOLLOW CHK 2
CAM CHANGE DONE

FIG. 13.

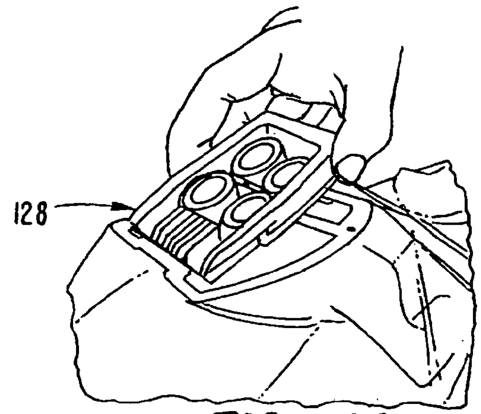

FIG. 14A.

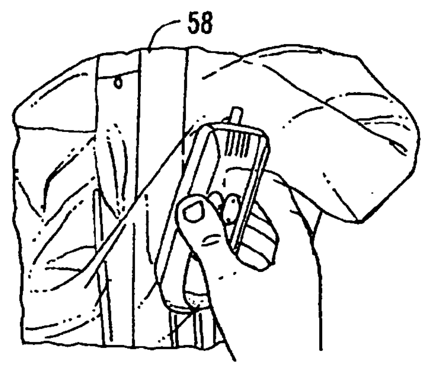

FIG. 14B.

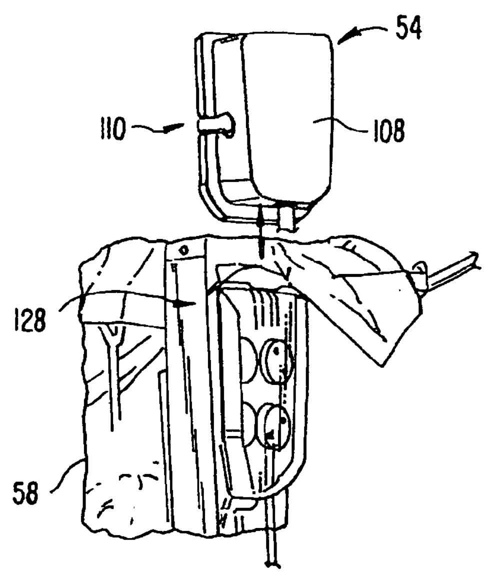

FIG. 14C.

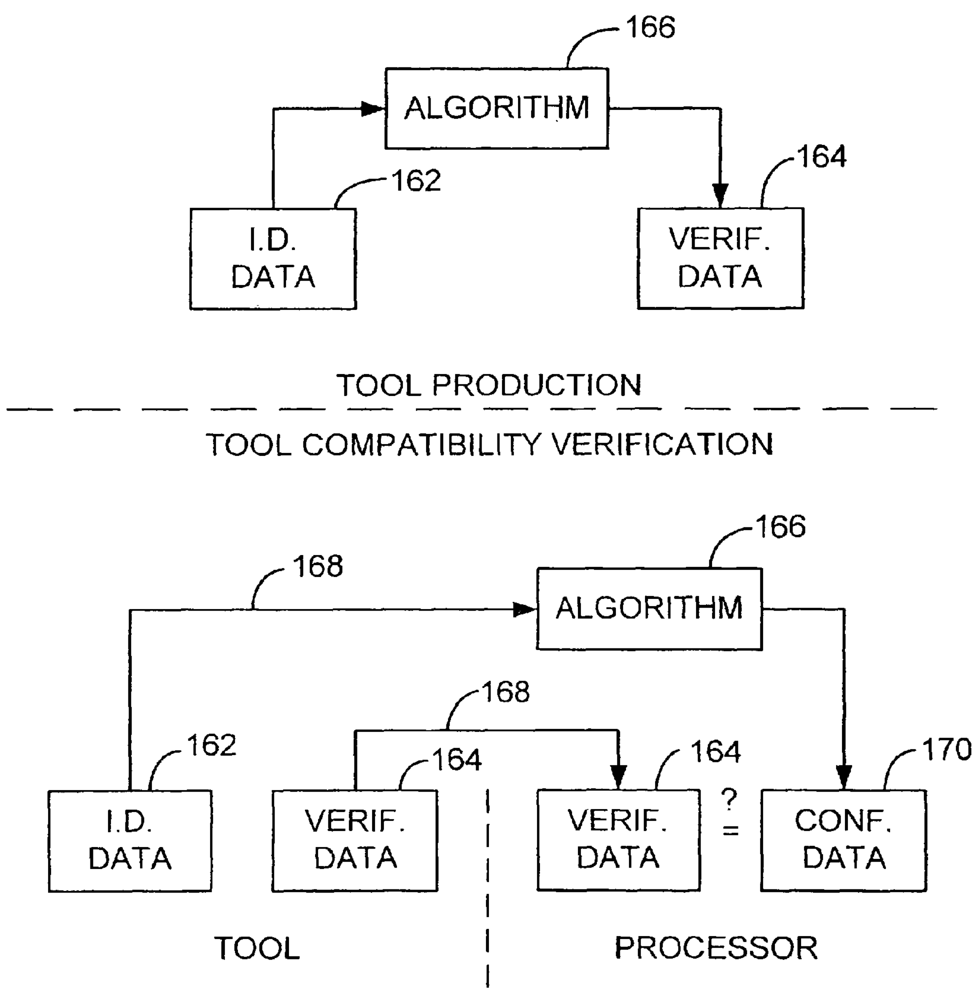
166
ALGORITHM
162
164
I.D.
DATA
VERIF.
DATA
TOOL PRODUCTION
TOOL COMPATIBILITY VERIFICATION
166
168
ALGORITHM
168
162
164
164
170
I.D.
DATA
VERIF.
DATA
VERIF.
DATA
?
=
CONF.
DATA
TOOL
PROCESSOR

FIG. 15.

MECHANICAL ACTUATOR INTERFACE SYSTEM FOR ROBOTIC SURGICAL TOOLS

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application is a divisional of U.S. patent application Ser. No. 10/316,666 filed on Dec. 10, 2002 now U.S. Pat. No. 7,524,320. U.S. patent application Ser. No. 10/316,666 is a continuation of U.S. patent application No. 09/929,453 filed on Aug. 13, 2001, now U.S. Pat. No. 7,048,745 and is a divisional application of U.S. patent application No. 09/759,542 filed Jan. 12, 2001, now U.S. Pat. No. 6,491,701, which is a continuation application of U.S. patent application No. 09/418,726 filed Dec. 6, 1999, now U.S. Pat. No. 6,331,181, and in turn also claims priority to U.S. Provisional Patent Application No. 60/111,713 filed on Dec. 8, 1998; U.S. patent application No. 09/398,958 filed Sep. 17, 1999, now U.S. Pat. No. 6,394,998; and U.S. Provisional Patent Application No. 60/116,844 filed on Jan. 2, 1999, entitled "*Surgical Tools For Use In Minimally Invasive Telesurgical Applications*". The entirety of the above-referenced applications is herein incorporated by reference.

This application also incorporates by references the following U.S. Design patent application Nos.: 29/097,544 filed on Dec. 8, 1998, entitled "*Portion Of An Interface For A Medical Instrument*", now U.S. Pat. No. D441,862; 29/097,552 filed on Dec. 8, 1998, entitled "*Interface For A Medical Instrument*" now U.S. Pat. No. D444,555; 29/097,550 filed on Dec. 8, 1998, entitled "*Portion Of An Adaptor For A Medical Instrument*", now U.S. Pat. Nos. D438,617; and 29/097,551 filed on Dec. 8, 1998, entitled "*Adaptor For A Medical Instrument*", now U.S. Pat. No. D441,076.

BACKGROUND OF THE INVENTION

This invention relates to robotically assisted surgery, and more particularly provides surgical tools having improved mechanical and/or data interface capabilities to enhance the safety, accuracy, and speed of minimally invasive and other robotically enhanced surgical procedures.

In robotically assisted surgery, the surgeon typically operates a master controller to remotely control the motion of surgical instruments at the surgical site. The controller may be separated from the patient by a significant distance (e.g., across the operating room, in a different room, or in a completely different building than the patient). Alternatively, a controller may be positioned quite near the patient in the operating room. Regardless, the controller will typically include one or more hand input devices (such as joysticks, exoskeletol gloves, master manipulators, or the like) which are coupled by a servo mechanism to the surgical instrument. More specifically, servo motors move a manipulator or "slave" supporting the surgical instrument based on the surgeon's manipulation of the hand input devices. During an operation, the surgeon may employ, via the robotic surgery system, a variety of surgical instruments such as tissue graspers, needle drivers, electrosurgical cautery probes, etc. Each of these structures performs functions for the surgeon, for example, holding or driving a needle, grasping a blood vessel, or dissecting, cauterizing, or coagulating tissue.

This new method of performing robotic surgery has, of course, created many new challenges. One such challenge is that a surgeon will typically employ a significant number of different surgical instruments during each surgical procedure. The number of independent surgical manipulators will often be limited due to space constraints and cost. Additionally, patient trauma can generally be reduced by eliminating the number of tools used at any given time. More specifically, in minimally invasive procedures, the number of entry ports into a patient is generally limited because of space constraints, as well as a desire to avoid unnecessary incisions in the patient. Hence, a number of different surgical instruments will typically be introduced through the same trocar sleeve into the abdomen during, for example, laparoscopic procedures. Likewise, in open surgery, there is typically not enough room adjacent the surgical site to position more than a few surgical manipulators, particularly where each manipulator/tool combination has a relatively large range of motion. As a result, a number of surgical instruments will often be attached and detached from a single instrument holder of a manipulator during an operation.

Published PCT application WO98/25666, filed on Dec. 10, 1997 and assigned to the present assignee (the full disclosure of which is incorporated herein by reference) describes a Multicomponent Telepresence System and Method which significantly improves the safety and speed with which robotic surgical tools can be removed and replaced during a surgical procedure. While this represents a significant advancement of the art, as is often true, still further improvements would be desirable. In particular, each tool change which occurs during a surgical procedure increases the overall surgery time. While still further improvements in the mechanical tool/manipulator interface may help reduce a portion of this tool change time, work in connection with the present invention has shown that the mechanical removal and replacement of the tool may represent only one portion of the total interruption for a tool change. U.S. Pat. No. 5,400,267 describes a memory feature for electrically powered medical equipment, and is also incorporated herein by reference.

As more and more different surgical tools are provided for use with a robotic system, the differences between the tool structures (and the interaction between the tool and the other components of the robotic system) become more pronounced. Many of these surgical tools will have one or more degrees of motion between the surgical end effectors and the proximal interface which engages the tool to the holder of the manipulator. The desired and/or practicable ranges of motion for an electrosurgical scalpel may be significantly different than those of a clip applier, for example. Work in connection with the present invention has found that even after a tool is properly placed on the surgical manipulator, the time involved in reconfiguring the robotic system to take advantage of a different tool, and to perfect the master controller's effective control over the degrees of motion of the tool, may add significantly to the total tool change delay.

In light of the above, it would be desirable to provide improved robotic surgery tools, systems, and method. It would further be desirable to provide techniques for reducing the total delay associated with each tool change. It would be especially desirable if these enhanced, and often more rapid, robotic tool change techniques resulted in still further improvement in the safety and reliability of these promising surgical systems.

BRIEF SUMMARY OF THE INVENTION

The present invention generally provides improved robotic surgical devices, systems, and methods for preparing for and performing robotic surgery. The robotic tools of the present invention will often make use of a memory structure mounted on a tool, manipulator arm, or movable support structure. The memory can, for example, perform a number of important functions when a tool is loaded on the tool manipulator: first, the memory can provide a signal verifying that the tool is compatible with that particular robotic system. Secondly, the tool memory may identify the tool-type (whether it is a scalpel, needle grasper, jaws, scissors, clip applier, electrocautery blade, or the like) to the robotic system so that the robotic system can reconfigure its programming to take full advantage of the tools' specialized capabilities. This tool-type data may simply be an identification signal referencing further data in a look-up table of the robotic system. Alternatively, the tool-type signal provided by the tool may define the tool characteristics in sufficient detail to allow reconfiguration of the robotic programming without having to resort to an external table. Thirdly, the memory of the tool may indicate tool-specific information, including (for example) measured calibration offsets indicating misalignment between the tool drive system and the tool end effector elements, tool life data (such as the number of times the tool has been loaded onto a surgical system, the number of surgical procedures performed with the tool, and/or the total time the tools has been used), or the like. The information may be stored in some form of non-volatile memory such as one-time programmable EPROM, Flash EPROM, EEPROM, battery-backed-tip SRAM, or similar memory technology where data can be updated and retained in either a serial or random access method, or with any of a wide variety of alternative hardware, firmware, or software. The invention further provides improved engagement structures for coupling robotic surgical tools with manipulator structures.

In a first aspect, the invention provides a robotic surgical tool for use in a robotic surgical system. The robotic surgical system has a processor which directs movement of a tool holder. The tool comprises a probe having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the probe. An interface is disposed adjacent to the proximal end of the probe. The interface can be releasably coupled with the tool holder.

Circuitry is mounted on the probe. The circuitry defines a signal for transmitting to the processor so as to indicate compatibility of the tool with the system.

The tool will often comprise a surgical instrument suitable for manipulating tissue, an endoscope or other image capture device, or the like. Preferably, the signal will comprise unique tool identifier data. The processor of the robotic surgical system may include programming to manipulate the tool identifier according to a pre-determined function or algorithm so as to derive verification data. The signal transmitted to the processor will often include the verification data. Alternative compatibility signals may include a signal which is listed in a table accessible to the processor, an arbitrary compatibility data string, or the like.

In another aspect, the invention provides a robotic surgical component for use in a robotic surgical system having a processor and a component holder. The component comprises a component body having an interface mountable to the component holder. The body supports a surgical end effector, and a drive system is coupled to the body for moving the end effector per commands from the processor. Circuitry is mounted on the body and defines a signal for transmitting to the processor. The signal may indicate compatibility of the component with the system, may define a component type of the component, may indicate coupling of the component to the system, and/or may indicate calibration of the component. Typically, the component will comprise a surgical tool, a manipulator arm, a pre-positioning linkage supporting the manipulator arm, or the like.

In another aspect, the invention provides a method for installing a robotic surgical component in a robotic surgical system. The method comprises mounting the component to a component holder. A signal is transmitted from the component to a processor of the robotic surgical system. The component is articulated in response to the signal per commands of the processor.

In many embodiments, compatibility of the component with the robotic surgical system will be verified using the signal transmitted from the component to the processor. This can be accomplished by providing unique identification data on the component, and deriving verification data from the identification data according to an algorithm. The verification data is stored with a memory of the component, the signal transmitted to the processor including both the identification and verification data. The algorithm may then be performed on the transmitted unique identification data with the processor, and the results compared with the verification data. Advantageously, this method can take advantage of unique identification data which is often unalterably stored in a memory of commercially available integrated circuits.

In another aspect, the invention provides a robotic surgical tool for use in robotic surgical systems having a processor. The tool comprises a shaft having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the shaft. The end effector has a plurality of degrees of motion relative to the proximal end. An interface is disposed adjacent the proximal end of the shaft. The interface can be releasably coupled with a robotic probe holder. The interface comprises a plurality of driven elements. A plurality of tool drive systems couple the driven elements to the degrees of motion of the end effector. The tool drive system has calibration offsets between a nominal relative position of the end effector and the driven elements, and a measured relative position of the end effector and driven elements. A memory stores data indicating the offsets. The memory is coupled to the interface so as to transmit the offsets to the processor.

In yet another aspect, the invention provides a robotic surgical system comprising a plurality of tools of different tool-types. Each tool comprises an elongate shaft with a cross-section suitable for introduction into an internal surgical site within a patient body via a minimally invasive opening. A distal surgical end effector is coupled to the shaft by at least one joint. The joint is drivingly coupled to a proximal interface by a tool drive system. Circuitry of the tool transmits a tool-type via the interface. The tool types may optionally differ in at least one characteristic such as joint geometry, end effector geometry, drive system characteristics, end effector or drive system strength, or the like. The system also includes a robotic manipulator including a linkage supporting a tool holder. The tool holder releasably receives the interface. A manipulator drive motor drivingly engages the linkage so as to move the tool holder relative to the opening and position the shaft within the surgical site. A tool drive motor is coupled to the tool holder so as to drivingly engage the tool drive system and articulate the joint. A processor is coupled to the tool holder. The processor has programming that effects a desired movement of the end effector by transmitting drive signals to the tool drive motors of the manipulator. The processor reconfigures the program for the different joint geometries based on the tool-type signals.

In another aspect, the invention provides a robotic surgical system comprising a surgical tool having a surgical end effector and an interface. A manipulator assembly has a base and a tool holder for releasably engaging the interface. A plurality of tool engagement sensors are coupled to the tool holder. Each tool sensor produces a signal when the interface engages the holder. A processor is coupled to the tool engagement sensors. The processor has a tool change mode and a tissue manipulation mode. The processor requires tool signals from each of the sensors before changing the tool change mode to the tissue manipulation mode. The processor remains in the tissue manipulation mode when at least one, but not all, of the tool signals is lost.

The tools used in robotic surgery will be subjected to significant structural stress during use. The stress may result in temporary loss of an engagement signal from an engagement sensor. By providing at least two, and preferably three engagement sensors, the surgical procedure can continue safely with the loss of an engagement signal from an individual sensor so long as the system can still verify proper engagement between the manipulator and tool. This arrangement results in a robust tool engagement sensing system that avoids frequent delays during the surgical procedure as might occur from the loss of an individual signal.

In yet another aspect, the invention provides a robotic surgical system comprising a manipulator assembly having a base and tool holder which moves relative to the base. The tool holder has a plurality of drive elements. A sterile drape covers at least a portion of the manipulator. A sterile tool has a proximal interface and distal end effector. The distal end effector has a plurality of degrees of motion relative to the proximal interface. The degrees of motion are coupled to drive elements of the interface. An adapter is disposed adjacent the sterile drape between the holder and the interface. The adapter comprises a plurality of movable bodies. Each movable body has a first surface driven by the drive elements of the holder, and a second surface driving the driven elements of the tool.

In yet another aspect, the invention provides a robotic surgical tool for use with a robotic manipulator having a tool holder. The tool holder has magnetically actuatable circuitry. The tool comprises a probe having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the probe. An interface adjacent the proximal end of the probe is releasably coupleable with the holder. The interface comprises a magnet positioned so as to actuate the circuitry of the holder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a robotic surgical procedure in which a surgeon at a master station directs movement of robotic surgical tools effected by a slave manipulator, and shows an assistant preparing to change a tool mounted to a tool holder of the slave.

FIG. **2** is a perspective view of a robotic surgical arm cart system in which a series of passive set-up joints support robotically actuated manipulators (typically, the center arm would support a camera).

FIG. **2**A is a perspective view of a robotic surgical manipulator for use in the cart system of FIG. **2**.

FIGS. **2**B and C are side and front views, respectively, of the linkage of the robotic manipulator of FIG. **2**, showing how the manipulator maintains a remote center of rotation along a shaft of the surgical tool.

FIGS. **3** and **3**A are perspective views of exemplary cart structures with positioning linkages which support the robotic manipulators in the system of FIG. **2**.

FIG. **4** is a perspective view of an exemplary tool according to the principles of the present invention.

FIGS. **4**A and B are schematic views of alternative drive systems for the tool of FIG. **4**.

FIGS. **5**A through H are illustrations of a variety of surgical end effectors of differing tool-types.

FIG. **6** illustrates the mechanical and electrical interface of the tool of FIG. **4**.

FIGS. **7**A through E illustrate an adapter for coupling the interface of FIG. **6** to the surgical manipulator.

FIGS. **7**F through I illustrate the adapter of FIGS. **7**A through E mounted to a holder or carriage of the manipulator.

FIGS. **7**J through M illustrate the holder, its driving elements, and its electrical contacts.

FIG. **8** is a wiring diagram for the tool of FIG. **4**, the adapter of FIGS. **7**A-E, and related components of the robotic system.

FIGS. **8**A and B are rear and front views of the master console, respectively.

FIG. **9** is a functional block diagram schematically illustrating the signal path hardware of the tool change system.

FIG. **10** is a schematic diagram illustrating the interaction between the software modules related to tool change.

FIG. **11** is a logic flow chart illustrating an exemplary method for sensing engagement of a tool with the manipulator.

FIG. **12** is a flow diagram illustrating how the tool engagement signals are used to change the operating state of the robotic system.

FIG. **13** illustrates the tool engagement method steps initiated by the processor in response to a change in operating state during tool changes.

FIGS. **14**A through C illustrate mounting of the adapter of FIGS. **7**A through E to a manipulator arm, and of mounting the tool of FIG. **4** onto the adapter.

FIG. **15** schematically illustrates an exemplary tool compatibility verification algorithm according to the principles of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides robotic surgery systems, devices, and methods. Robotic surgery will generally involve the use of multiple robotic arms. One or more of the robotic arms will often support a surgical tool which may be articulated (such as jaws, scissors, graspers, needle holders, microdissectors, staple appliers, tackers, suction/irrigation tools, clip appliers, or the like) or non-articulated (such as cutting blades, cautery probes, irrigators, catheters, suction orifices, or the like). One or more of the robotic arms will often be used to support one or more surgical image capture devices such as an endoscope (which may be any of the variety of structures such as a laparoscope, an arthroscope, a hysteroscope, or the like), or optionally, some other imaging modality (such as ultrasound, fluoroscopy, magnetic resonance imaging, or the like). Typically, the robotic arms will support at least two surgical tools corresponding to the two hands of a surgeon and one optical image capture device.

The present invention will find application in a variety of surgical procedures. The most immediate applications will be to improve existing minimally invasive surgical procedures, such as coronary artery bypass grafting and mitral and aortic valve repair and/or replacement. The invention will also have applications for surgical procedures which are difficult to perform using existing, minimally invasive techniques, such as Nissen Fundoplications. Additionally, it is anticipated that these surgical systems will find uses in entirely new surgeries that would be difficult and/or impossible to perform using traditionally open or known minimally invasive techniques. For example, by synchronizing the movements of the image capture device and/or surgical tools with a tissue undergoing physiological movement (such a beating heart), the moving tissue may be accurately manipulated and treated without halting the physiological movement. Additional potential applications include vascular surgery (such as for the repair of thoracic and abdominal aneurysms), general and digestive surgeries (such as cholecystectomy, inguinale hernia repair, colon resection, and the like), gynecology (for fertility procedures, hysterectomies, and the like), and a wide variety of alternative procedures.

Referring now to FIG. **1**, the robotic surgical system **10** generally includes master controller **150** and a robotic arm slave cart **50**. Master controller **150** generally includes master controllers (not shown) which are grasped by the surgeon and manipulated in space while the surgeon views the procedure views a stereo display. The master controllers are manual input devices which preferably move with six degrees of freedom, and which often further have an actuatable handle for actuating tools (for example, for closing grasping saws, applying an electrical potential to an electrode, or the like). In this embodiment, the master control station **150** also includes a processor, as will be described in more detail hereinbelow.

Robotic arm cart **50** is positioned adjacent to patient body P and moves tools having shafts. The shafts extend into an internal surgical site within the patient body via openings O. As illustrated in FIG. **1**, one or more assistant may be present during surgery to assist the surgeon, particularly during removal and replacement of tools. Robotic surgery systems and methods are further described in co-pending U.S. patent application Ser. No. 08/975,617, filed Nov. 21, 1997, the full disclosure of which is incorporated herein by reference.

Robotic arm cart **50** is shown in isolation in FIG. **2**. Cart **50** includes a base **52** from which three surgical tools **54** are supported. More specifically, tools **54** are each supported by a series of manually articulatable linkages, generally referred to as set-Lip joints **56**, and a robotic manipulator **58**. It should be noted that these strictures are here illustrated with protective covers extending over much of the robotic linkage. It should be understood that these protective covers are optional, and may be limited in size or entirely eliminated in some embodiments to minimize the inertia that is manipulated by the servo mechanism, to limit the volume of moving components so as to avoid collisions, and to limit the overall weight of cart **50**.

Cart **50** will generally have dimensions suitable for transporting the cart between operating rooms. The cart will typically fit through standard operating room doors and onto standard hospital elevators. The cart should have a weight and wheel (or other transportation) system that allows the cart to be positioned adjacent an operating table by a single attendant. The cart should have sufficient stability in the transport configuration to avoid tipping at minor discontinuities of the floor, and to easily withstand overturning moments that will be imposed at the ends of the robotic arms during use.

Referring now to FIGS. **2**A-C, robotic manipulators **58** preferably include a linkage **62** that constrains movement of tool **54**. More specifically, linkage **62** includes rigid links coupled together by rotational joints in a parallelogram arrangement so that tool **54** rotates around a point in space **64**, as more fully described in issued U.S. Pat. No. 5,817,084, the full disclosure of which is incorporated herein by reference. The parallelogram arrangement constrains rotation to pivoting about an axis **64***a*, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints **56** so that tool **54** further rotates about an axis **64***b*, sometimes called the yaw axis. The pitch and yaw axes intersect at the remote center **64**, which is aligned along a shaft **66** of tool **54**.

Tool **54** has still further driven degrees of freedom as supported by manipulator **58**, including sliding motion of the tool along insertion axis **64** (the axis of shaft **66**), sometimes referred to as insertion. As tool **54** slides along axis **64***c* relative to manipulator **58**, remote center **64** remains fixed relative to base **68** of manipulator **58**. Hence, the entire manipulator is generally moved to re-position remote center **64**.

Linkage **62** of manipulator **58** is driven by a series of motors **70**. These motors actively move linkage **62** in response to commands from a processor. Motors **70** are further coupled to tool **54** so as to rotate the tool about axis **66**, and often to articulate a wrist at the distal end of the tool about at least one, and often two, degrees of freedom. Additionally, motors **70** can be used to actuate an articulatable end effector of the tool for grasping tissues in the jaws of a forceps or the like. Motors **70** may be coupled to at least some of the joints of tool **54** using cables, as more fully described in U.S. Pat. No. 5,792,135, the full disclosure of which is also incorporated herein by reference. As described in that reference, the manipulator will often include flexible members for transferring motion from the drive components to the surgical tool. For endoscopic procedures, manipulator **58** will often include a cannula **72**. Cannula **72** supports tool **54**, allowing the tool to rotate and move axially through the central bore of the cannula.

As described above, manipulator **58** is generally supported by passive set-up joints **56**. Exemplary set-up joint structures are illustrated in FIG. **3**. The exemplary set-up joint system includes three types of structures. First, a vertical column **80** supports vertically sliding joints **82** that are used to position manipulator **58** along the vertical or Z axis. Second, rotary joints **84** separated by rigid links **86** are used to horizontally position manipulators **58** in the X-Y plane. Third, another series of rotary joints **84** mounted adjacent a manipulator interface **88** rotationally orients the manipulators.

The stricture of column **80**, vertical sliding joints **82**, and base **52** can be understood with reference to FIG. **3**. Beginning with base **52**, the base will generally distribute the weight of the robotic structures and the forces imposed on the robotic arms. Column **80** extends upward from base **52**, and may optionally comprise a box steel structure. Sliding joints **82** are counterbalanced by weights mounted with column **80**. Sensors (typically in the form of potentiometers) indicate vertical position of slider joints **82**, and also indicate the rotational position of each rotary joint **84**. As the structure of the joint elements is known, the processor can accurately determine the position and orientation of the manipulator base. As the position of the tool and tool end effector will be known relative to the manipulator base, the processor can further accurately determine end effector position and orientation, as well as how to effect movement in a desired direction by articulating one or more the driven joints.

Each of rotational joints **84** and slider joints **82** includes a brake. The brake prevents articulation about the joint unless the brake is released, the brake being normally on. The brakes at all the joints are actuated in unison by a button on the set-up joints, thereby allowing the operating room personnel to position the manipulator in space when the brake is released. Additional rotational joints similarly allow the orientation of the manipulator to be set while the brake is released. The exemplary set-up joint structure is more fully described in co-pending application Ser. No. 09/368,309, filed Aug. 3, 1999, the full disclosure of which is incorporated herein by reference.

An alternative set-up joint structure is illustrated in FIG. **3**A. In this embodiment, an endoscope **55** is supported by an alternative manipulator structure **58'** between two tissue manipulation tools. It should be understood that the present invention may incorporate a wide variety of alternative robotic structures, including those described in U.S. Pat. No. 5,878,193, the full disclosure of which is incorporated herein by reference. Additionally, while the data communication between a robotic component and the processor of the robotic surgical system is primarily described herein with reference to communication between tool **54** and the processor of the robotic surgical system, it should be understood that similar communication may take place between circuitry of a manipulator, a set-up joint, an endoscope or other image capture device, or the like, and the processor of the robotic surgical system for component compatibility verification, component-type identification, component calibration (such as off-set or the like) communication, confirmation of coupling of the component to the robotic surgical system, or the like.

An exemplary tool **54** is illustrated more clearly in FIG. **4**. Tool **54** generally includes a rigid shaft **102** having a proximal end **104** and distal end **106**. A proximal housing **108** includes an interface **110** which mechanically and electrically couples tool **54** to the manipulator. A surgical end effector **112** is coupled to shaft **102** by a wrist joint **114** providing at least 1 degree of freedom, and ideally providing at least 2 degrees of freedom.

As illustrated in FIG. **4**A, a drive system **116** mechanically couples first and 10 second end effector elements **112***a*, **112***b* to driven elements **118** of interface **110**. Drive system **116** is more fully described in U.S. Pat. No. 5,792,135, the full disclosure of which is incorporated herein by reference. Stated simply, the drive system translates mechanical inputs from driven elements **118** into articulation of the wrist about first and second axes A**1**, A**2**, as well as into actuation of the two element end effector by relative movement of the end effector elements about axis A**2**. In addition, driven elements **118** can effect rotation of the end effector about the axis of shaft **102** (A**3**) by rotating the shaft relative to proximal housing **108**, and allowing the cables to twist (within a limited angular range) within the shaft.

A wide variety of alternative drive systems might be employed, including alternative cabling arrangements, drive chains or belts, hydraulic drive systems, gear trains, or the like. In some of these drive systems, motion of end effector **112** about the axes may be coupled to multiple driven elements **118**. In other embodiments, there may be a one to one correspondence between driven elements **118** and motion of an end effector element about an axis. Still other embodiments may require fewer (or more) driven elements to effect the desired degrees of freedom, for example, when a single element end effector is provided. Hence, manipulation of the end effector via interface **110** will generally involve some reconfiguration of the robotic system during the tool change. One alternative drive system **116'** is shown in FIG. **4**B.

Exemplary wrist structures and surgical end effectors are illustrated in more detail in FIGS. **5**A and **5**B. A Potts scissor is illustrated in FIG. **5**A, while a 15 degree scalpel electrically coupled to a conductor **120** for electrosurgery is illustrated in FIG. **5**B. These different tool-types have wrists **114** which may have differing separation distances between their axes A**1**, A**2**, differing range of motions about each axes, different joint binding positions or singularities, and/or other differences in their axial geometries. Additionally, these two different end effector structures will have different strengths, different inertias, different effective gearing ratios between motion about their axes and movement of driven elements **118**, and the like. Still further differences between these two tool-types, and/or between either of these tools and tools of other types, include the presence or absence of an electrosurgical capability, the useful life of the tool (in time, procedures, or tool change operations), the ability to replace end effector elements, and the like. It should be understood that alternative wrist joint arrangements are possible.

Still further end effectors for additional different tool-types are illustrated in **5**C-**5**H. FIG. **5**C illustrates a DeBakey forceps, while FIG. **5**D illustrates a microforceps. Potts scissors are again illustrated in FIG. **5**E, and a clip applier is illustrated in FIG. **5**F. Another scalpel is illustrated in FIG. **5**G, while FIG. **5**H illustrates an electrocautery probe. It should be understood that a wide variety of alternative end effectors for differing tool-types may be provided, and that several of these tool-types may be used during a single surgical procedure. Hence, the tools of the present invention may incorporate any of the illustrated end effectors, or any other end effector which is useful for surgery, particularly at an internal surgical site.

Interface **110** of a proximal housing **108** is illustrated in FIG. **6**. As seen schematically in FIG. **4**A, driven elements **118** provide mechanical coupling of the end effector to drive motors mounted to the manipulator. Driven elements **118** each include a pair of pins **122** extending from a surface of the driven element. An inner pin **122**A is closer to an axis of rotation of each driven elements **118** than an outer pin **122**B, which helps to ensure positive angular alignment of the driven element. Interface **110** further includes an array of electrical connecting pins **124** coupled to a memory structure **126** by a circuit board within housing **108**. In the exemplary embodiment, memory **126** comprises Dallas part No. DS 2505.

Surgical tools **54** will generally be sterile structures, often being sterilizable and/or being provided in hermetically sealed packages for use. In contrast, the complex servo mechanism of cart **50** and manipulator **58** may be difficult and/or impossible to fully sterilize between procedures. Instead, a sterile drape will often cover at least a portion of the cart and manipulator structures to maintain the sterile environment around the patient.

As tools **54** will be removed and replaced repeatedly during many procedures, the tool holder could potentially be exposed to contamination if the interface directly engages the tool holder. To avoid contamination of the tool holder and possible cross contamination between patients, the present invention provides an adaptor for coupling interface **110** to the tool holder of the manipulator assembly.

White interface **110** is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

Referring to FIGS. **7**A-**7**E, adaptor **128** generally includes a tool side **130** and a holder side **132**. A plurality of rotatable bodies **134** are mounted to a floating plate **136** which has a limited range of movement relative to the surrounding adaptor structure normal to the major surfaces of the adaptor. Axial movement of the floating plate helps decouple the rotatable bodies from the tool when the levers along the sides of housing **108** are actuated (See FIG. **4**).

Rotatable bodies **134** are resiliently mounted to floating plate **136** by resilient radial members which extend into a circumferential indentation about the rotatable bodies. The rotatable bodies can move axially relative to plate **136** by deflection of these resilient structures.

When disposed in a first axial position (toward tool side **132**) the rotatable bodies are free to rotate without angular limitation. However, as the rotatable bodies move axially toward tool side **130**, tabs **138** (extending radially from the rotatable bodies) laterally engage detents on the floating plates so as to limit angular rotation of the rotatable bodies about their axes. This limited rotation can be used to help drivingly engage the rotatable bodies with drive pins of the holder, as the drive pins will push the rotatable bodies into the limited rotation position until the pins are aligned with (and slide into) openings **140**.

Openings **140** on the tool side **130** and holder side **132** of rotatable bodies **134** are configured to accurately align the driven elements **118** of the tool with the drive elements of the holder. As described above regarding inner and outer pins **122**A, **122**B of driven elements **118**, the openings **140** in each side of each rotatable body are at differing distances from the axis of rotation so as to ensure that the alignment is not 180° from its intended position. Additionally, each of the openings **140** is slightly radially elongate so as to fittingly receive the pins in the circumferential orientation. This allows the pins to slide radially within the openings and accommodate some axial misalignment between the tool and holder, while minimizing any angular misalignment and backlash between the drive and driven elements. Openings **140** on the tool side **132** are offset by about 90° from the openings on the holder side, as can be seen most clearly in FIG. **7**C.

Holder side of adaptor **128** includes another array of electrical connector pins **124**, and the tool side **132** of the adaptor includes slots **142** for receiving the pin array from the tool (as illustrated in FIG. **6**). In addition to transmitting electrical signals between the tool and holder, at least some of these electrical connections are coupled to an adaptor memory device **144** by a circuit board of the adaptor. A latch **145** releasably affixes the adaptor to the holder. A lip on the tool side **130** of adaptor **128** slidably receives laterally extending tabs of housing **108** adjacent to interface **110**. The interaction between pins **122** and openings **140** helps restrain the tool in the engaged position until the levers along the sides of the tool housing push the floating plate axially from the interface so as to release the tool. The holder **129** and drive elements **119** are shown (without the adjacent manipulator structure) in FIGS. **7**F through M.

Referring now to FIG. **8**, an exemplary circuit diagram illustrates the coupling of tool memory **126** and adaptor memory **144** to the wiring harness of the manipulator. The electrically coupling of tool memory **126** with the wiring of the manipulator may be used to sense the presence of the tool. Similarly, electrical coupling between the manipulator wiring system and adaptor memory **144** may be used as an adaptor engagement sensor. In the exemplary embodiment, two additional sensors are also provided to determine engagement of the tool and holder: a magnetic reed switch **147** (actuated by a magnet **125** of interface **110**), and a electrical coupling short **148** (or alternatively an end-of-life indicator) electrically coupling two of the pins **124** of tool **54**. The use of a magnetically actuated sensor mounted to the holder or adapter is particularly advantageous. The tool-mounted magnet will tend to maintain the signal from a magnetic sensor (despite small, stress induced movements of the tool), in part because of the magnetic field effects and/or hysteresis, once contact has been made. Optionally, adapter memory **144** may be read only when no tool is coupled to the adapter by "shorting" the adapter memory with the magnetic reed switch, so that the adapter is transparent to tool/processor communications after installation is completed.

An exemplary surgeon's workstation is illustrated in FIGS. **8**A and **8**B. Control station **150** includes processors **152** for the robotic circle mechanism. Also included in controller station **150** are a stereo imaging system **154** and a pair of controllers (not shown).

The surgeon will generally manipulate tissues using the robotic system by moving the controllers within a three dimensional controller work space of controller station **150**.

Processor **152** can calculate an image capture coordinate system via the sensors in setup joints **56** and manipulator **58** supporting the laparoscope, and can perform coordinate system transformations so as to generate signals to the drive motors of the manipulator that maintain alignment between the three dimensional image of the end effectors and the hand controllers within the controller work space. By maintaining this alignment, as the physician moves the hand controller in both position and orientation, the robotic surgery system allows the surgeon to manipulate the surgical tools as if the handle in the surgeon's hand and the end effector in the surgeon's field of view define a single contiguous surgical instrument. This provides an enhanced sense of presence and allows the surgeon to operate efficiently and accurately without performing mental coordinate transformations. The program instructions for effecting these processes may optionally be embodied in a machine readable code stored on a tangible media **153**, which may comprise an optical disk, a magnetic disk, a magnetic tape, a bar code, EEPROM, or the like. Alternatively, programming instructions may be transmitted to and from processor **152** using data communications systems such as an IO cable, an intranet, the internet, or the like. An exemplary control system is described in more detail in co-pending U.S. patent application Ser. No. 09/373,678, filed Aug. 13, 1999, for a Camera Referenced Cartesian Control System, the full disclosure of which is incorporated herein by reference.

The tool/adaptor hardware signal path is schematically illustrated in FIG. **9**. Processor **152** of master control station **150** comprises multiple separate processor boards supported by a chassis. In the exemplary embodiment, a control and transform processor CTP handles calculation of the coordinate system transforms for generating the proper instruction signals to send to servo motors. The control and transform processor CTP may comprise an Analog Device ADSP 21060 digital signal processor, or a wide variety of alternative commercially available processors. A master diagnostic controller MDC monitors and verifies the health of the processing and servo mechanical system. In the exemplary embodiment, the master diagnostic controller MDC comprises a Dallas DS 87C530 processor. A Dallas DS 87C520 processor is used as the user interface master controller UMC to handle the input and output to and from the surgeon seated at the console. Once again, these functions may alternatively be performed by a variety of commercially available processors. Hence, processor **152** may include a single processor, or a number of distinct processor structures coupled together, ideally in a distributed processing arrangement.

In the exemplary distributed processing arrangement shown in FIG. **9**, processor **152** makes use of a remote printed circuit assembly ("PCA") referred to as the remote interface adaptor RIA, which is coupled to the chassis by a wiring harness. A remote interface adaptor RIA is provided for each of the robotic arms of the system, typically including one PCA for the endoscope and two PCA's for the two surgical end effectors. The remote interface adaptor RIA also comprises a Dallas DS 87C 520 processor and couples the processor **152** to the holder or carriage of manipulator **58**. The RIAs **56** perform local processing for the manipulators, setup joints, and/or tools, and communicate with processor **152** using a high-level language. Manipulator **58** is, in turn, coupled to tool **54** by adaptor **128** as described above.

It should be noted that reed switch **147** may actually be mounted on carriage of manipulator **58**, and may be actuated by a magnet mounted on the tool **54**. Hence, reed switch **147** ensures that tool **54** is positioned in the holder of manipulator **58**, the reed switch acting as a tool sensor. Electrical coupling of the tool memory **126** and an electrical loop-back circuit **149** connecting pins of tool **54** each act as additional independent tool sensors. Optionally, an end-of-use detector such as a low resistance timed fuse, or the like, may change an electrical characteristic of the loop-back circuit to disqualify tools past the end of their safe lives. An expired tool may provide an indication to the system operator such as a pop-up flag, a color-change spot, or the like, to indicate the tool is at or near the end of its life. Optionally, a portable life indication device may be coupled to the tools before each procedure to determine if the tool has sufficient life to be used for the planned procedure.

A variety of alternative end of use indication systems might be provided to indicate that a tool is near or at the end of its useful life. For example a mechanical end of use indicator may be mounted in housing **108**, such as a colored button or tab which can pivot into view through an indication window of the housing. Such a button might be biased toward the viewable position, and initially held out of sight by a latch. The latch might be releasable by an actuator mounted to the carriage of manipulator **58**, for example, by the movement of a plunger of a solenoid on the manipulator. The sterile adapter or drape will preferably accommodate movement of such a plunger while maintaining sterile separation between the manipulator and tool. In general, providing a mechanical indicator on the tool for actuation by an actuation means of the manipulator can avoid the cost for end of use actuators mounted on each tool.

Referring now to FIG. **10**, the flow of the tool signals from the tool sensors during a tool change operation originates from the interaction between the remote interface adaptor RIA and the tool itself. The tool signals are transmitted per procedure management/data handler programming running on the master diagnostic controller MDC. The overall logic flow proceeds according to a supervisor program running on the user interface master control UMC according to the surgeon's input from the master console.

The supervisor directs the state of the robotic arms, and also perfects coupling between a mounted tool **54** and the holder of a manipulator by driving the servo motors in a predetermined manner, as shall be explained below. The supervisor software directs movement of the tool through a middleman program running on the control and transform processor CTP.

The middleman program accepts instructions from the supervisor to move the surgical end effectors in the desired direction, for example, and calculates the drive signals to be provided to the servo motors so as to effect that desired motion. In other words, the middleman program transforms the workstation space instruction into a joint space servo signal set for the servo motors to drive the end effectors.

It should be understood that the coordinate transformations used by the middleman to calculate the required servo signals will vary as the relationship between the field of view from the endoscope and the surgical end effectors varies. Deriving these coordinate transformations is well described in the patent literature, for example, in U.S. Pat. No. 5,696,837 and U.S. patent application Ser. No. 09/373,678, the full disclosures of which are incorporated herein by reference. In the control method illustrated in FIG. **10**, a Kernel program running on the control and transform processor CTP and Compute Engine processors CE's derives these transformations based on the information provided by the position sensors at the setup joints, manipulators, and the like.

Referring now to FIGS. **11** and **12**, processor **152** changes the operating state of the robotic system based on tool signals from the three tool engagement sensors (reed switch **147**, tool memory **126**, and end of use/pin short circuit **148**) and an adaptor signal sensed by coupling with the adaptor memory **144**. In the local tool detection procedure illustrated in FIG. **11** (which is performed at the remote interface adapter RIA with a cycle time of 35 milliseconds) the reed switch and adapter memory are first sensed to check for the presence of the adapter. So long as the adapter is present, the system then checks for the presence of the tool based on coupling with the tool memory **126**. The presence or absence of the tool is verified by checking for the end of use or pin short circuit **148** of the tool breadboard. The remote interface adapter RIA transmits the sensed signals from the sensor scan to the master digital controller MDC for use by the Procedure Management/Data Handler software.

As can be understood with reference to FIG. **12**, if the sterile adapter is not sensed (either upon start up or while the tool is removed), the robotic system remains in a sterile adapter off operating state S**1**. Once the sensor scan indicates that adapter **128** is present, program management data handler advances the operating state to a second operating state S**2** in which the system is awaiting engagement of interface **110** with the holder of the manipulator. If the signal from the adapter memory chip is lost for more than half a second the system returns to the adapter off state S**1**.

If at least one signal from the three tool sensors indicates engagement of the tool, the operating state advances to a Tool Being Inserted mode S**4**, and upon agreement of all three sensors that the tool is fully mounted on the holder, the system enters a Tool Is On operating state S**5** in which manipulation of the end effectors by the surgeon may be enabled.

The elongate shafts of tool **54** can induce significant mechanical stresses between interface **110**, adapter **128**, and the holder of the manipulator. As a result, one or more of the tool signals may be lost at least temporarily. If tissue manipulation were halted each time a tool signal were lost, the operation would be significantly delayed and total risk to the patient would increase. The present system takes advantage of the redundant tool signals by keeping the system in the Tool Is On operating state S**5** despite the loss of one or even two tool signals. If the loss of signal persists for more than a threshold time, the signal loss is stored for diagnostic purposes. Nonetheless, the system remains in the operating state, until all three tool signals indicate the tool is removed, at which point the system drops down to the Tool Is Out operating state S**2**. This procedure provides a much more robust approach than analyzing each tool signal independently.

Referring now to FIG. **13**, the instructions generated by the supervisor software running on the user interface master controller UMC as a result of the changes in state during a tool change procedure will generally follow one of four paths. If the adapter is not present and a tool has been taken off (or no tool and adapter are present at start tip), the supervisor notifies the user, for example, by displaying an icon on the stereo display and/or assistance monitor, per path PA. If an adapter has been mounted to the holder and no tool is engaged, the supervisor initiates manipulations of the driving elements of the holder which perfect mechanical coupling of the rotational bodies of adapter **128** with the driving elements of the holder per path PB.

As described in some detail with reference to FIGS. **7**A through E, rotatable bodies **134** can move axially relative to a floating plate **136**. Prior to perfecting mechanical coupling between the holder drive elements and the rotatable bodies, pins of driving elements (which are similar in configuration to the driven elements **118** of interface **110**) will push the rotatable bodies away from holder side **132** of adapter **128** and toward tool side **130**. In this rotationally limited axial position, tabs **138** of rotatable bodies **134** engage detents of the floating plate so as to prevent rotation of more than about 90°. This can ensure that the pins of the driving elements rotate relative to the rotatable bodies by driving the servo motors of the manipulator by more than 90°.

In the exemplary tool change engagement path PB, the servo motors of the manipulator are driven from a starting central position so as to rotate the drive elements by 180° in a first direction (for example, clockwise) in step ENGAGESA**1**. As the pins of the driving elements will only enter opening **140** of rotatable bodies **134** in a single angular orientation, it is possible that this step will be insufficient to perfect mechanical coupling. To ensure that coupling is complete, the supervisor therefore initiates rotation of the servo motors so as to turn the driving the elements by 360° in the opposite direction (in our example, counterclockwise) in step ENGAGESA**2**. At some point during the above two steps, pins **122** of the driving elements will be aligned with openings **144** of rotatable bodies **134** and the openings will receive the pins, thereby allowing the rotatable body to move axially to the freely rotatable position. The driving elements in rotatable bodies are then centered in their range of angular travel in step ENGAGESA**3**.

Once the steps of path PB have been performed so as to perfect mechanical coupling of the driving elements of the holder with the rotatable bodies of the adapter **128**, the supervisor directs the system to perform the procedure outlined by the second part of path PB. Basically, the driving elements (and rotatable bodies) are centered and centering is verified in preparation for mounting of a tool to the holder by rotating the servos right to their end of travel, left, and then halfway between tinder steps TOOLPREP**1**, **2**, and **3**, respectively. These centering and verification steps are also performed if a tool has been removed from the holder, per path PC.

In the final alternative procedure which will be described with reference to FIG. **13**, mounting of a tool on the adapter and holder results in the steps outlined in path PD. First, the system verifies that the tool is of the type which is allowable for use on this particular robotic surgical system. To determine compatibility, circuitry of the tool may send a signal indicating the tool-type to processor **152**. More specifically, data stored in tool memory **148** may be transmitted to the processor. In the exemplary embodiment, the data from the tool memory will include a character string indicating tool compatibility with the robotic system. Additionally, the data from the tool memory will often include a tool-type. In some embodiments, the data will also include tool offset calibration information. This data may be provided from the tool memory **148** in response to a request signal from the processor **152**. A simplified version of path PD is performed if a camera is changed, as shown.

Tool-type data will generally indicate what kind of tool has been attached in a tool change operation. For example, the tool-type data might indicate that Potts scissors or a scalpel has been attached to the holder. The tool-type data may include information on wrist axis geometries, tool strengths, grip force, the range of motion of each joint, singularities in the joint motion space, the maximum force to be applied via driven elements **18**, the tool transmission system characteristics including information regarding the coupling of driven elements **118** to articulation of an associated (or the interacting plurality of associated) joint motion, servo gains, end effector elements speeds, and the like.

Tool-type data may optionally be stored in memory of the robotic system. The signal from the tool may comprise an identifier referencing the relevant portion of data from the look-up table. This tool-type data may be loaded into a memory of processor **152** by the system manufacturer, the look-up table preferably being in the form of a flash memory, EEPROM, or the like. As each new tool-type is provided, the robotic system manufacturer can then revise the look-up table to accommodate the new tool-specific information. It should be recognized that the use of tools which are not compatible with the robotic surgery system, for example, which do not have the appropriate tool-type data in an information table, could result in inadequate robotic control over the end effector by both processor **152** and the surgeon.

In addition to the tool-type data indicated by the signals from tool **54**, tool specific information may be stored in the tool memory **148** for reconfiguring the programming of processor **152**. For example, there will often be some measurable misalignment or offset between and intended relationship between the wrist joint and end effector elements and the positions of driven elements **118**. To accommodate this misalignment without degrading the accuracy of the robotic control over the end effectors, the measured offsets may be stored in the tool memory and factored into the transforms generated by the Kernel. Hence, the storing of such calibration information can be used to overcome minor mechanical inconsistencies between tools of a single type. As described above, tool life and cumulative tool use information may also be stored on the tool memory and used by the processor to determine if the tool is still safe for use. Total tool life may be measured by clock time, by procedure, by the number of times the tool has been loaded onto a holder, and even by individual numbers of end effector actuations. Tool life data will preferably be stored in the memory of the tool using an irreversible writing process.

To perfect mechanical coupling between the driving elements of the holder (and the previously coupled rotatable bodies **134** of adapter **128**), the supervisor initiates a "turn one way, turn the other way, and center" operation similar to that described above. To limit the range of motion of driven elements **118** and ensure pins **122** enter openings **140** of adapter **128**, the holder may move axially to a proximal position so that the end effector is disposed within cannula **72** of manipulator **58** (see FIG. **2**B). The axial positioning and rotation (turn, turn, and center) of the end effector are performed under steps ENGAGETOOL**1**-**4**, respectively.

The tool-type (and preferably tool-specific) data from tool memory **148** and/or the look-up table is sent to the middleman and/or Kernel software running on the coordinate transformation processor CTP for driving the appropriate coordinate transformations and generating the servo drive signals, as generally described above with reference to FIG. **10**. The supervisor may then verify operation of the tool by manipulating the end effector per the calculated transforms, so as to complete the steps of path PD.

Methods for mounting adaptor **128** (together with a sterile drape) to the holder of manipulator **58** can be understood with reference to FIGS. **14**A and B. Subsequent mounting of tool **54** to adapter **128** generally comprises inserting the surgical end effector distally through cannula **72** and sliding interface **110** of tool **54** into engagement with a mounted adapter, as illustrated in FIG. **14**C. The tool can be removed and replaced by reversing the tool mounting procedure illustrated in FIG. **14**C and mounting an alternative tool in its place.

Referring now to FIG. **15**, an exemplary system and method for verifying compatibility of a tool with a robotic surgical system makes use of a unique identification data string that is irreversibly stored on an integrated circuit included in the circuitry of a tool or other component of the robotic surgical system. Advantageously, producers of such integrated circuits can include this unique identification data string on each integrated circuit such that no two integrated circuits include the same identification data. For example, Dallas DS 2505 may include a unique 64 bit identification data string which differs from the data strings of every other circuit of that part number.

The identification data string could be downloaded directly to the processor and compared with a table listing all identification data strings of circuits included in compatible tools. Such a table could then be updated each time additional tools were fabricated or outdated tools were retired.

To avoid continuously updating a compatible tool table, a verification data string **164** may be calculated from the unique identification data according to an algorithm **166**.

Algorithm **166** may be used as an encryption mechanism, typically using an arbitrary function which cannot easily be determined by sampling verification data and identification data from a few tools. Verification data string **164** may then be stored in a memory of the tool or other robotic component during tool production, typically using a non-volatile memory.

When the tool having identification data **162** and verification data **164** is coupled to the robotic surgical system, a signal **168** including these data strings may be transmitted to processor **152** as described above. By including, a tangible media with method steps for performing algorithm **166** in a system accessible by processor **152**, the processor can also perform the algorithm on the unique identification data so as to derive a conformation data string **170**. This can be compared with the verification data, thereby confirming compatibility of the tool with the robotic system. Algorithm **166** may include any of a wide variety of known encryption algorithms, or may be developed specifically for use in the robotic surgical system of the present invention.

The descriptions given above regarding the exemplary devices, systems, and methods of the present invention are provided by way of an example, and for clarity of understanding. A wide variety of changes, modifications, and adaptations of these specific embodiments will be obvious to those of skill in the art. Hence, the invention is limited solely by the following claims.

What is claimed is:

1. A method for performing robotic surgery on a patient, the method comprising coupling a surgical instrument to a robotic surgical system, the surgical system having a drive assembly operatively coupled to a control unit operable by inputs from an operator, the drive assembly having a plurality of actuator bodies which are movable in response to operator inputs, the surgical instrument comprising:

aproximal portion and a distal portion, the proximal portion comprising a first plurality of movable engaging interface bodies;

at least one distal end effector member;

a plurality of joints, at least one of the joints being coupled to the at least one distal end effector member, the joints being coupled to the plurality of movable engaging interface bodies by a plurality of drive members; the method further comprising:

coupling the movable engaging interface bodies to the plurality of actuator bodies;

moving a robotic manipulator arm supporting the instrument in at least one degree of freedom; and

moving the actuator bodies in response to operator inputs.

2. A method for performing robotic surgery on a patient, the method comprising

coupling an instrument to a drive assembly, the instrument comprising:

a shaft having a working end;

an end effector mounting formation positioned at the working end, the end effector mounting formation angularly displaceable about at least two axes;

elongate elements connected to the end effector mounting formation to cause selective movement of the end effector mounting formation about the axes in response to selective pulling of the elongate elements;

a support base positioned on an end of the shaft opposed to the working end; and

at least three rotatable driven elements angularly displaceably mounted on the support base and to which opposed ends of the elongate elements are coupled so that selective angular displacement or the driven elements causes the selective pulling of the elongate elements, the driven elements having axes which are parallel and spaced apart relative to each other; the method further comprising:

driving the at least three rotatable driven elements on the support base with at least three rotatable driving elements disposed on the drive assembly, each of the at least three driven elements sharing a single rotational axis with one of the at least three rotatable driving elements; and

moving a robotic manipulator arm supporting the instrument in at least one degree of freedom.

3. A method for performing robotic surgery on a patient, the method comprising:

coupling an instrument o a drive assembly, the instrument having a proximal portion and a distal portion, the proximal portion comprising a first plurality of rotatable bodies, the drive assembly comprising a second plurality of rotatable bodies, the first plurality of rotatable bodies coupled by drive members to a movable portion disposed at the distal portion;

engaging the first plurality of rotatable bodies with the second plurality of rotatable bodies;

rotating the second plurality of rotatable bodies to rotate the first plurality of rotatable bodies, each of the first plurality of rotatable bodies sharing a single rotational axis with one of the second plurality of rotatable bodies, wherein rotating the first plurality of rotatable bodies moves the movable port on disposed at the distal portion;

moving a robotic manipulator arm supporting the instrument in at least one degree of freedom;

inserting the instrument into an aperture on a patient; and

manipulating tissue with the distal portion of the instrument.

4. A method for performing robotic surgery, comprising:

providing an instrument removably couplable to a robotic arm drive assembly, said instrument comprising proximal and distal portions, said proximal portion comprising a first plurality of movable bodies engagable with a second plurality of corresponding movable bodies on the drive assembly, said instrument including at least one distal joint coupled to an end effector member, at least one of said first plurality of movable bodies being coupled to said at least one distal joint by at least one drive member, and said at least one drive member being housed in a shaft portion of said instrument extending between said proximal and distal portions;

coupling said instrument to said drive assembly by engaging the first plurality of movable bodies with the second plurality of movable bodies;

controlling operation of said drive assembly from a remote location no that the movable bodies of said drive assembly rotate one or more of the movable bodies of the instrument, thereby causing the at least one distal joint of the instrument to move;

controlling from the remote location movement in at least one degree of freedom of a robotic manipulator arm supporting the instrument, and

engaging tissue with the end effector member to perform surgery;

wherein at least one of said first plurality of movable bodies is a rotatable body, at least one of said second plurality of movable bodies is a corresponding rotatable body, and said at least one of said first plurality of movable bodies shares a single rotational axis with said corresponding one of said second plurality of movable bodies when said first and second plurality of movable bodies are operatively engaged.

5. The method of claim **1**, further comprising releasing the instrument from the drive assembly by operating a proximal latch.

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