A Survey on Robotic Surgery

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Abstract- **In present days, use of robots is increasing in industrial applications. Robotic systems used in hospitals are becoming one of the most useful applications of robotic technology. Robots in hospitals help healthcare staff because they are accurate, precise and do not tire; in fact they are revolutionizing health care services. They play an important role in the medical field mainly from hospital pharmacies or surgeries to equipment robots. Robotics is being introduced to medicine because they allow for unprecedented control and precision of surgical instruments in very critical procedures. The goal of the robotic surgery field is to design a robot that can be useful to perform beating-heart surgery safely. Robots in the field of surgery have dramatically changed the procedures for better results. The most useful advantage of Robotic Surgery to the patient is the decrease in pain and scaring. Possible tiny incisions also cause many other advantages that make Robotic Surgery even though there is some risk. Along with the obvious rewards to the patient, Robotic Surgery system is very advantageous to the healthcare. In order to use the robots in hospitals for surgery, robot needs to change its behaviour timely. This paper explains an overview of robotic operation, different modes of operation, classification of surgical robots. Also an example surgical robot and its working is explained briefly.**

Keywords- Robotic Surgery, Operation Mode, Surgical Procedure

INTRODUCTION

Computer has made a very vital impact on society. The use of computer technology has affected every field in society. The use of computers saves time and effort and reduces the overall cost to complete a particular task. Advancement in computer technology has lead to robotic technology.

The improvement of robotics has also caused robots to become more widespread across various industries ranging from manufacturing to health care. Accuracy with which robots can operate has lead to the use of robots in healthcare systems.

Robots used in hospitals are becoming one of the most useful applications of robotic technology. Since robots are precise and do not tire, they help medical staff in hospital; that means they are revolutionizing medical services. They are playing a major role in the medical field mainly from hospital pharmacies or surgeries to equipment robots.

A. EVENT HANDLING

An important technique on which robotics is based is Event handling.

In computing, an event is an action or occurrence detected by the program that may be handled by the program. In robotics source of event is a hardware device such as a timer or any type of sensor. Even program can trigger its own custom set of events as well. A computer program that changes its behaviour in response to events is said to be event-driven. Event handling is the simplest form of multitasking. Event handling includes the receipt of an event at some event handler from an event producer and subsequent processes. Following are the processes involved in event handling:

- Identifying the destination to forward the event.
- Making the forward.
- Receiving the forwarded event.
- Taking appropriate action as a response to the event.
- The event handler forwards the event to event consumer.

Event driven systems are typically used when there is some asynchronous external activity that needs to be handled by a program.

Robotic surgery includes performing all these processes carefully. Sensors sense the condition of the surgical atmosphere and generate events. Control system in robots handles the events. It uses some actuators to perform actions.

II. OVERVIEW OF ROBOTIC SURGERY

Robotic surgery is a method to perform surgery using very small tools attached to a robotic arm. The surgeon who has to perform surgery controls the robotic arm with a computer. Medical robots require specific safety measures, kinematics, hardware and software since

- They have to cooperate with the medical staff and accomplish tasks in contact with the patient
- They have to posses application-specific functionalities
- They have to accomplish non-repetitive tasks in unstructured environments
- They have to be sterilizable and MRI-compatible.

All these are achieved using various control modes.

A. OPERATION MODES

In general, robots can operate in different control modes, namely *"Autonomous"*, *Hands-on"* and *"Tele-Operated"* mode.

Autonomous mode: the robot automatically drives the tool on a target which is predefined. A fully autonomous robot can work without human assistance, move without manual control and gain required information about environment.

Hands-on mode: the user manually drives the robot in the space. These robots act as assistance tools which give sensitive information of the condition and perform critical task that are difficult to achieve with human hand.

Tele-operated: the user movement on the master is replicated by the robot though a suitable mapping. This is the major mode used in robotic surgery. The operation is performed with the help of three components, namely "Master model", "Slave model" and "Communication system".

Fig 1 Demonstration of a supervisory-controlled robotic system

III. CLASSIFICATION OF SURGICAL ROBOTS

Not all surgical robots are equal. The robotic surgery systems can be broadly classified into three categories: 1)supervisory-controlled systems,2) telesurgical systems and 3)shared-control systems.

A. SUPERVISORY-CONTROLLED ROBOTIC SURGERY SYSTEMS

Supervisory controlled systems are the most automated surgical robots. But even these robots cannot perform surgery without any human assistance. In fact, surgeons must do preparation work with surgery patients before the robot can operate as shown in fig 1.

That's because supervisory-controlled systems follow a specific set of instructions when performing a surgery. The human surgeon must input some data into the robot, which then initiates Robotics in a series of controlled motions and completes the surgery. There's no room for error -- these robots can't make adjustments in real time if some error occur. Surgeons must observe robot's actions and be ready to intervene if something doesn't go as planned. The reason surgeons use robots is that they can be precise, so can reduce trauma for the patient and a shorter recovery period.

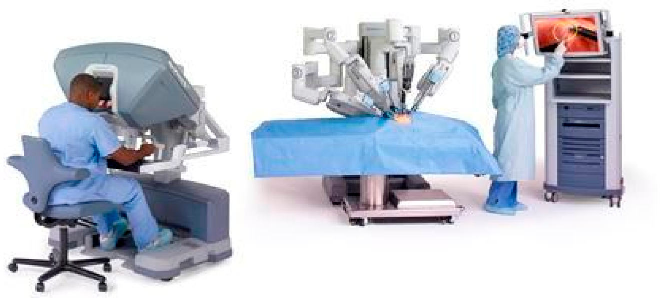

Fig 2 Demonstration of Telesurgical system

B. TELESURGICAL SYSTEMS

Teleoperation indicates operation of a machine at a distance. **Tele surgery** (also known as **remote surgery**) is the ability for a doctor to perform surgery on a patient even though they are not physically present in the location. It is a form of tele presence. This type of system generally consists of one or more arms, a master controller and a sensory system giving feedback to the user. Most of these robots are controlled by surgeons at the location of the surgery. Remote surgery is possible with telesurgical systems, where the physical distance between the patient and the surgeon is immaterial. Which is shown in fig 2. It promises to allow the experts to be available to patients all over the world, with no need for patients to travel long distance to get treatment.

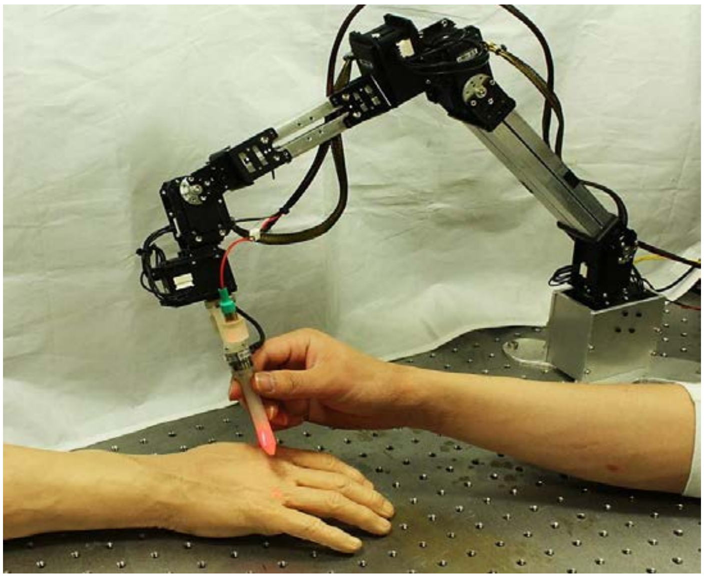

Fig 3 Demonstration of Shared control robotic surgery systems

C. SHARED-CONTROL ROBOTIC SURGERY SYSTEMS

Shared-control robotic systems aid surgeons during surgery, but the surgeon does most of the work as shown in fig 3. Here the surgeons must operate the surgical instruments by themselves. The robot monitors the surgeon's performance and provides support and stability through active constraint. The user manually drives the robot in the space. These robots act as assistance tools which give sensitive information of the condition and perform critical task that are difficult to achieve with human hand.

IV. AN EXAMPLE SURGICAL SYSTEM: NEUROSURGICAL ROBOT

This neurosurgical is like a hybridization of the above explained three types of robots. So for this robot to perform neurosurgery the robot needs to operate in all the three modes depending on the condition.

A. The NearLab neurosurgical suite

Figure 4 shows different parts of the neurosurgical suite. Namely, (1) LWR actuator, (2) Tele operation master, (3) IR markers and (4) Optical tracker

The **LWR actuator** is responsible for robotic arm movement. Features 7 Degrees of Freedom, an accuracy of 1mm and a repeatability of 0.05mm that allows the user to get the internal sensors information and to provide motion commands with control frequencies up to 1 kHz, which is the frequency of the internal controller; the LWR also features torque sensors on each joint, which allows to measure the external torque on the joint itself, compensating the weight of the tool attached to the robot flange. As a master device, here Geomagic Touch, a small serial robot arm is used which can measure the motion of the handle and gives force feedback to the user.

The **optical tracking system** is used as a supervisor of the system in order to measure and check the performances of the control architecture; its stated accuracy is 0.15mm in a pyramidal working volume of about 25m3

Tele operation master replicates the scenario on some display through which the surgeon is capable of giving instructions to the actuator. Instructions given by the surgeon are converted into proper form of events which have to be handled by actuators.

IR marker is used to point to required position on the body part where surgery is getting done.

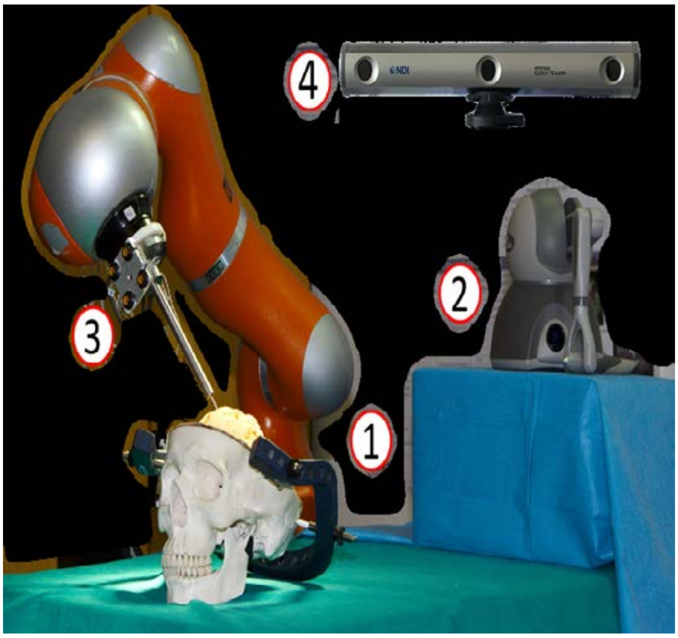

Fig 4 Neurosurgical Suite

The fig 5 shows the devices as blocks with a thin line and the different components, written using OROCOS for the blocks with thick solid line, ROS for the blocks with dashed line, and standard C++ applications for the blocks with medium thickness borders. The communication lines among the components are described in the legend in top left corner while the coloured lines shares the same data type identified by the label on the line itself.

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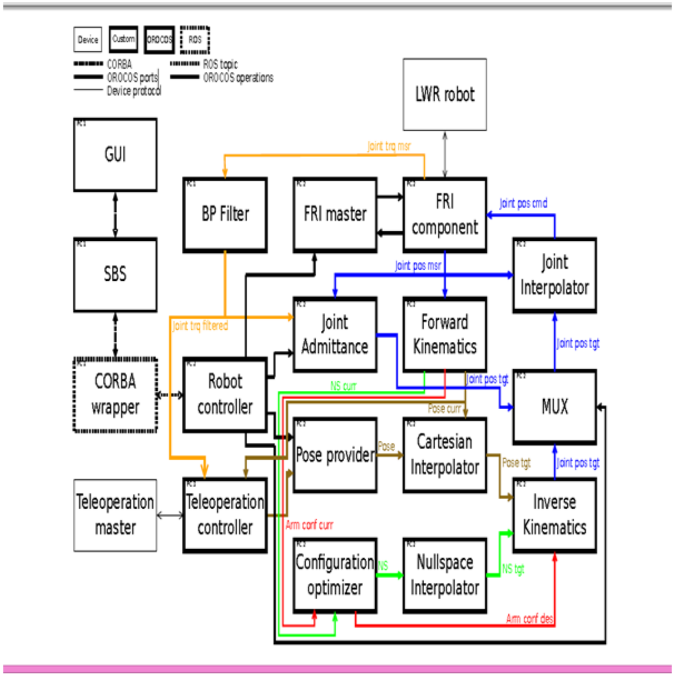

Fig. 5 The control schema

The control architecture described in this paper was developed using different frameworks and middleware. The use of middleware for the communications enables the possibility to have a modular and scalable architecture. In Fig. 2.8, the different modules are represented with their connections. In particular, the core modules are:

- *GUI*: Provides an interface for the user to select the desired behaviour for the robot system, written using C++ and the Qt2 framework;
- *SBS*: when a switching event is reached the module retrieves the desired parameters and behaviour for the devices and forwards that information to the controllers;
- *CORBA wrapper*: the module wraps the information from the SBS and delivers them on a ROS topic to the robot controller module;
- *Robot controller*: manages the transition phase from a control mode to the following one and enables the different functionalities of the other components;
- *Joint admittance*: it implements an admittance controller in joint space.
- *Pose provider*: it provides the Cartesian pose in the robot Coordinate Frame (CF) in the different modalities;
- *Kinematics*: analytic version of the forward and inverse kinematics.
- *Configuration optimizer*: a module to define the constraints on the solution of the inverse kinematics for redundant robots.
- *Interpolator*: given a target in the task space, it calculates the via points from the source to the target using the trapezoidal velocity profile;
- *FRI modules*: components used to handle the communication of the commands and sensors data to and from the robot through the FRI.
- *Configuration optimizer:* takes care of handling the redundancy of the robot by constraining the configuration of the robot to the one assumed by the robot itself at start up (this does not cause any loss of generality in this analysis).
- *Pose provider:* forwards the data from the *Teleoperation controller DuringTele-operation*
- *Teleoperation controller:* which, given the current robot pose and the desired command from the master side, calculates the desired pose of the robot in the robot base CF.

B. Workflow, states and transitions

A surgical procedure encompasses different steps in which the surgical staff executes different tasks: a robot which has to act as a surgeon assistant has to change its behaviour according to the needs of the current step of the intervention. A simplified scenario was drawn for the current paper, and it foresees the following five steps for the robot:

1) Go to home position (*Homing*);
2) Autonomously approach the patient (*Autonomous*);
3) Hand-guided to the target (*Hands-on*);
4) Move according to a master device (*Tele-operation*);
5) Keep the current pose and stop the procedure (*Steady*).

The different steps require different behaviours for the devices in the environment, thus it is fundamental to switch from one behaviour to another during the intervention without stopping the devices or having unpredictable movements due to a mis-handled transition, i.e. bad settings in the initial parameters of the following controller. The trigger to switch between steps is based on events like pressing buttons or touching the devices, and, for doing so, the surgeon is provided with an interface that allows the control of the devices: as long as the surgeon requires to switch to the following step, (s)he creates an event by pressing a button on the GUI or by touching the robot, as shown in Fig. 2.9. In the

GUI is present a button that goes to the next step in the list; in case of the event towards the *Hands-on* step, the trigger event is raised by the contact between surgeon and robot: in fact, the user is allowed to touch the robot only during the cooperative mode, while in all the other steps this contact has to be considered as a fault, the user has to be warned and the robot has to reach a safe state eventually moving it away. When one of the described events is detected, the SBS is triggered and it loads the parameters for the devices which are stored in a dedicated Data Base (DB), and it streams them through a ROS topic; the *Robot Controller* module, depending on the new set of parameters, enables different features on the other modules, such as the *Joint Admittance* and the *Pose Provider*, using OROCOS operations that are executed in the caller thread. In particular, in the control mode Hands-on, the *Joint Admittance* is enabled, while in the other three modes the *Pose provider* module is enabled; the Multiplexer (MUX) component then connects its output to the correct input depending which is the current active control mode.

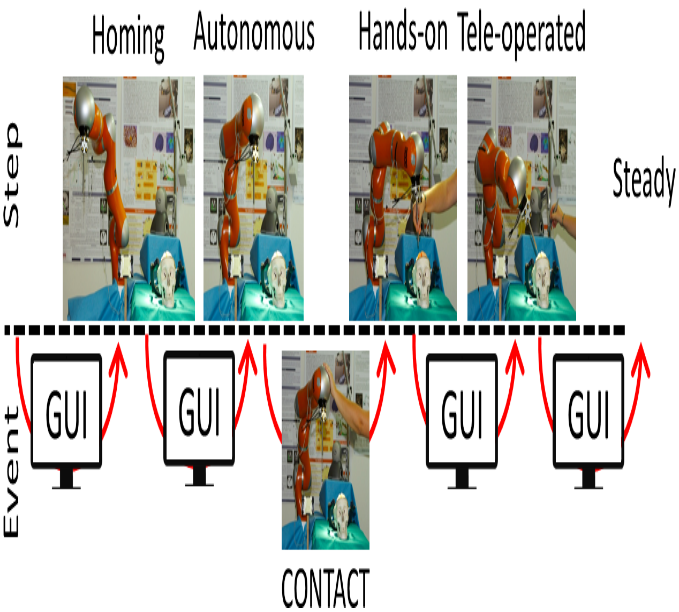

Fig. 9 Animated schema of the possible steps and transitions event

V. ADVANTAGES

A. BENIFITS FOR DOCTORS

- Surgery with smaller cuts compared to open surgery can be performed with robotic systems because of the possibility of small, precise movements.
- The surgeon can make small, precise movements using these systems. This allows the surgeon to give treatment through a small cut that once could be done only with open surgery.
- The surgeon can also see the area so that surgery is performed more easily, letting the surgeon move in a more comfortable way.
- Access to hostile (e.g., X-rays) or space-constrained areas (inside of a patient or imaging system) is easy.

B. BENIFITS FOR PATIENTS

- Faster recovery
- Less pain and bleeding
- Less risk of infection
- Shorter hospital stay
- Smaller scars

VI. CONCLUSION

Although still in its infancy, robotic surgery has already proven itself to be very important, particularly in areas which are not accessible to classical laparoscopic type of procedures. It seems like robotic systems will replace conventional and legacy laparoscopic instruments in less technically demanding procedures. Furthermore, it has the potential to expand surgical treatment modalities beyond the limits of human ability. Whether the benefits of robotics systems overcome the cost to implement it or not, seems it remains to be worked out. Further research must evaluate cost effectiveness or a true benefit over conventional therapy for robotic surgery to take full root. Within the next few years robotic surgery seems to replace most of the conventional surgery, because of the possibility of high precision with robotic surgery is beyond the reach of human hand.

However, many of current advantages in robotic assisted surgery ensure its continued development and expansion. One exciting possibility in improvement is expanding the use of preoperative (computed tomography or magnetic resonance) and intra operative video image fusion to better guide the surgeon in dissection and identifying pathology.

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