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An Inexpensive Experimental Setup for Teaching The Concepts of Da Vinci Surgical Robot

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***Abstract*— Robot-assisted surgery is an alternative to conventional laparoscopic and traditional open surgical techniques. Currently, the primary commercially available robot-assisted surgical system, the da Vinci surgical robot does not provide end effector interaction forces to the operator. The prime goal of this work was to construct and develop a robotic arm of low cost for surgical operation. The robotic arm was developed with five degrees of freedom and it is capable of performing simple tasks such as light weight material handling, drilling and cutting operation. The robotic arm is implemented with several servo motors acts as a link between the arms and performs arm movements. Additionally our goal was to develop a sensing system to evaluate the end effector tool-tissue or bone interaction forces to perceive force feedback. Sensors such as force sensor and ultrasonic sensor were developed to measure surgical tool's force and the depth. The visual feedback is perceived by attaching a video camera to the robotic arm for monitoring the surgical operations. Additionally different surgical tools were fitted to the robotic arm and an embedded system allowing the attachment of surgical tool to perform its operation.**

***Keywords*— End effector, force feedback, robotically - assisted surgery, telesurgery, telemanipulator, tool-interaction force, visual feedback**

I. INTRODUCTION

Robotically-assisted surgery is a technique used to perform surgery using tiny surgical tools attached to a robotic arm. The surgery is performed indirectly by the surgeon on controlling the robotic arm with a computer. The surgeon performs surgery remotely or from a distant place. Robotically-assisted surgery was developed to overcome the limitations of minimally-invasive surgery and to enhance the capabilities of surgeons performing open surgery.

In robotically assisted minimally invasive surgery, rather than directly moving the surgical instruments, the surgeon controls the instruments with a help of a telemanipulator or over the computer control. [1]

Telesurgery allows surgeons to implement life-saving procedures without the need of travelling to remote corners of the world. The teleoperated surgical robot offers many opportunities for providing critical care to the people.

Surgeons would also be able to provide important medical care to wounded soldiers from a remote place by avoiding dangerous exposure in an active battle field. Telesurgery is more advantageous when compared to conventional robotic surgery by teleoperating over long distances. Operating from a remote place the surgeon relays only on the visual feedback to perform the operation. Therefore, the system must be able to provide high quality video with minimum possible latencies. In the presence of force feedback, the surgeon gets an extra option and it is beneficial by minimizing damage to the tissues and organs during the surgical procedures. [2]

A. Need For Robotic Surgery

The robotically-assisted surgery is used to reduce some of the hand tremors and movement of the surgeon that makes the surgery in a very precise and accurate manner. This technique provides increased manipulability and dexterity. The use of tiny instruments in the robotic surgery results in less blood loss and blood transfusion during the surgery. [3] On comparing the traditional surgery with robotically-assisted surgery it provides various benefits to the patients. It includes shorter hospital stay, less post operative pain, less blood loss and transfusions, less scarring, and less post-operative problems.

B. Robotic Surgical System

A surgical robotic system includes one or more arms which are controlled by the surgeon, a master controller (doctor console), and a sensory system giving feedback to the user. A telemanipulator system is a remote manipulator system that allows the surgeon to perform the normal movements associated with the surgery. The robotic arms carry out those movements using end-effectors. Hence it helps to perform the actual surgery on the patient.

In computer-controlled systems the surgeon uses a computer to control the robotic arms and its end-effectors, in these systems telemanipulator is used for the input. The advantage of using the computerized method is that the surgeons need not to be present near the patient. This leads to the possibility for remote surgery. Remote surgery is also known as telesurgery.

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It is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location. It is a form of telepresence. There are many surgical systems available. The one of the most widely using system is da Vinci surgical systems. The da Vinci Surgical System is an advanced robotic surgical system designed to facilitate complex surgeries using a minimally invasive approach. It does not execute on its own, its movements are controlled by the surgeon. The da Vinci surgical system is available for performing the gynaecologic surgery, cardiac surgery, urologic surgery, thoracic surgery, general surgery, head and neck surgery procedures. [4] The da Vinci System consists of a surgery room and a patient-side cart with four interactive robotic arms controlled from the console. Three of the arms are for tools that hold objects, and can also act as scalpels, scissors, bovies, or unipolar or bipolar electro cautery instruments. The fourth arm carries an endoscopic camera with two lenses that gives the surgeon full stereoscopic vision from the console. The surgeon sits at the console and looks through two eye holes at a 3D image of the procedure, while manoeuvring the arms with two foot pedals and two hand controllers. In contrast, the da Vinci allows the surgeon to operate from a seated position at the console, with eyes and hands positioned in line with the instruments. To move the instruments or to reposition the camera, the surgeon simply moves his/her hands. By providing surgeons with superior visualization, enhanced dexterity, greater precision and ergonomic comfort, the da Vinci Surgical System makes it possible for more surgeons to perform minimally invasive procedures involving complex dissection or reconstruction.

For the patient, da Vinci procedure can offer all the potential benefits of a minimally invasive procedure, including less pain, less blood loss and less need for blood transfusions. Moreover, the da Vinci System can enable a shorter hospital stay, a quicker recovery and faster return to normal daily activities.

C. Need For Sensors In Robotic Surgery

Even though the da Vinci surgical system performs surgery with greater precision, dexterity, enhanced vision to the surgeon it doesn't provide end effector or surgical tool interaction forces to the user or surgeon. These surgical tool interaction forces can be calculated and assessed by developing a sensory system. The sensory system comprise of sensors such as force sensor and an ultrasonic sensor which helps in calculating the tool interaction forces and provides the force feedback to the user or surgeon.

These sensors are incorporated to the surgical robotic arm that will aid in evaluating the surgical tool's force and its depth while performing surgical operation. Force feedback is a method of control which allows the operator to feel what the remote manipulator or robotic arm is doing. It helps the operator to move the manipulator and operate on various functions by sensing the force at the end effector. This force information is of great value when operating a manipulator arm from a remote location because the operator cannot feel the direct touch with the subject. [5]

D. Knowledge Gap

Berkelman, et al developed a small and light weight teleoperated surgical robotic system which can be teleoperated from a distance. [6] However, their system is advantageous because it can be teleoperated by a surgeon but it cannot measure the tool-tissue interaction force which helps to perform operation in an accurate and precise manner. Lum, et al designed and developed a teleoperated robot which has two spherical manipulators which easily manipulates surgical instruments about a remote centre. [7] Lum, et al faced difficulties in communication at longer distances and they didn't concentrate on providing force feedback to the user. Yeh-liang Hsu, et al developed a automatic bone drilling system to prevent excessive protrusion using fuzzy controller, but they didn't work on other surgical tools such as surgical knife etc. [8] Till now in robotic surgery, teleoperated robot has been developed by providing the visual feedback and tactile feedback to the operator or surgeon.

The force feedback (provided by sensors such as force sensor and ultrasonic sensor) combined with visual feedback is lacking in the robotic surgical system. Incorporation of force sensor and ultrasonic sensor during surgical operation (both drilling and cutting) provide the force feedback to the user.

II. Materials And Methodology

A. Materials used

The materials used in this project were 5 Servo motors (3 nylon & 2 metal gears), joints, basal plate, gripper, DC motor with drilling bit, surgical knife, arduino mega 2560 microcontroller, ULN 2003 IC, resistor, force sensor, ultrasonic sensor ,camera, printed circuit board, card board, connecting wires and switching adapter (5V/12V).

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B. Robotic arm construction

The design of the robotic arm or manipulator has the similar functions of human hand. The design or type of robot used in this project is of jointed arm configuration. The links of the robotic arm is connected using the joints which allow rotational movement and it forms a kinematic chain. The free body diagram in figure 1 describes the structure of the robotic arm and its parts. It includes a base, shoulder, elbow, wrist and an end effector. They look similar to the human hand in functions especially in movement so they are called as articulated arm.

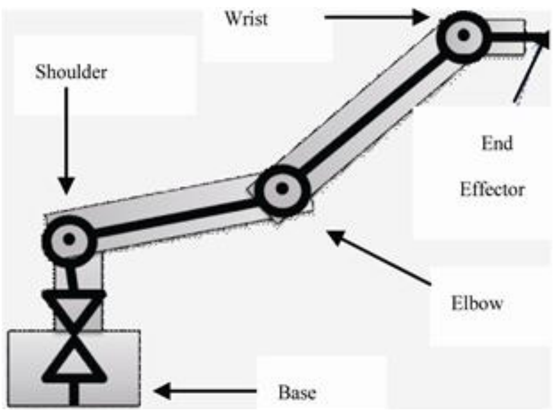

Fig.1 Free body diagram

1) Selection of motor

Many different motors are available in the market like servo motors, stepper motor, and DC motor (with and without gears). These different motors are used according to their applications and requirements. Servo motors are used when there is a need for high torque and precise position. If high torques are not required stepper motors are used. Dc motors are used for high torque alone. Here in this project servo motors were used for the accurate and precise operation; dc motor was also used for high torque drilling operation on biological materials such as bones, tissues etc. Figure 2 represents the picture of servo motor and DC motor, each joint were connected by servo motor. The links or joints were used for joining base, shoulder, elbow and wrist is made up of thin sheet of plastic and they were less in weight. This helps the robotic arm to perform the operation very easily. For fixing servomotors with the plastic joints screws and nuts were used. The entire setup was mounted on a cardboard. Totally five high torque servomotors had been used out of which three were nylon gear servo motors and remaining two were metal gear servo motors. To the base, wrist, end effector nylon gear servo motors were fixed. To the elbow and shoulder metal gear servo motors were used for balancing and lifting the weight.

Fig.2 Servo motor and DC motor

2) End effector selection

The end effector is probably one of the most important and most complex parts of the system. The end effector varies mainly according to the application and the task that the robotic arm accomplishes for; it can be pneumatic, electric or hydraulic. [9]Since our robot arm was based on an electric system, we may choose electric basis of end effector. The end effector is controlled by a servo motor and the total five servo motors used in the robot arm that aids in moving the entire setup. Initially, gripper which is commercially available was fixed to the end effector for pick and drop operation. It was used to lift light weight materials. For surgical operation such as drilling and cutting, surgical tools such as DC motor with drilling bit and surgical knife were used. They were fitted to the end effector servo motor using a shaft. One of the shaft was fitted with drilling tool (DC motor with drilling bit) and the other end was fixed with cutting tool (surgical knife).The surgical tools fitted to the robotic arm using shaft for surgical operation were shown in the figure 3. The power requirement for the robotic arm to operate was 5 to 6V DC 10 Amp power supply. It could be either battery or an AC power supply rated at 5-6VDC. The entire setup of robotic arm is shown in the figure 4.

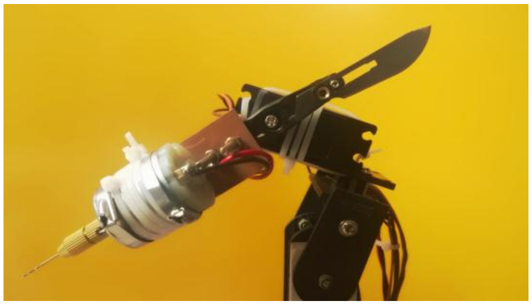

Fig.3 End effector tool

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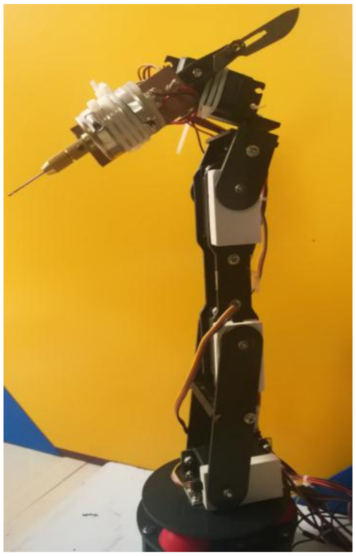

Fig.4 robotic arm complete assembly

3) Servo motors connection

All standard servo motors have three wire connectors for connecting to any device. Two Wires are for Power that is VDD and GND, VDD is +4.8V to 6V GND is for Ground. General wire colours are tabulated in the table I.

TABLE I
GENERAL WIRE COLOURS FOR CONNECTING SERVO MOTORS

Signal	VDD	GND
White	Red	Black
Orange	Red	Brown
Yellow	Red	Black
Orange	Red	Black
Blue	Red	Black

4) Fitting of sensors

The sensors used in this project are force sensor and ultrasonic sensor. Both these sensors were used to optimize the handling of the surgical tools while producing depression in the subject such as bone, tissue etc.Ultrasonic sensor capable of emitting and receiving ultrasonic waves was fitted to (end effector) area behind the driller as shown in the figure 5 (DC motor with drilling bit). The time interval between the emission and reception of the ultrasonic radiation was measured; it also provides the condition of subject (bone, tissue or any other material) and how much depth it was drilled.

By using the ultrasonic sensor the subject can be drilled to a desired depth.Force sensor is fitted behind the subject on flat surface as shown in the figure 6. The tool interaction force with the subject during surgical operation (drilling and cutting operation) can be estimated with this force sensor when it is placed behind or outside the subject (patient body). This method is known as indirect force sensing. Indirect force sensing method overcomes miniaturization constraints as well as sterilization issues associated with direct force sensing. This method is also called as overcoat method. The robotic arm comprising of five servo motors and DC motor was connected to the ardunio microcontroller. Other than servo motors and DC motor, force sensor and ultrasonic sensor were also connected to the ardunio microcontroller. The force sensor strip was connected to the ardunio microcontroller using a resistor.

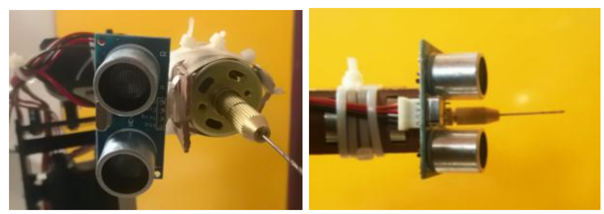

Fig.5 End effector tool with ultrasonic sensor

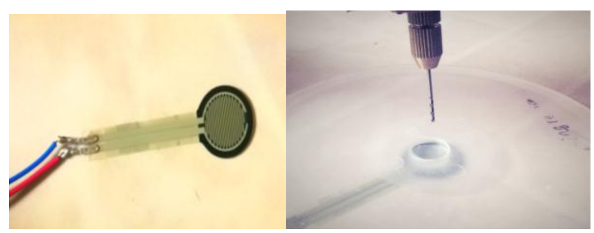

Fig.6 force sensor under flat surface

C. Robotic arm control

The Robotic arm can be autonomous or controlled manually. In manual mode, a trained operator (programmer) typically uses a portable control unit to operate the robotic arm manually. The control for the robot arm consists of two levels: A microcontroller and a computer-based user interface. The electronic scheme of control is shown in Figure 7.

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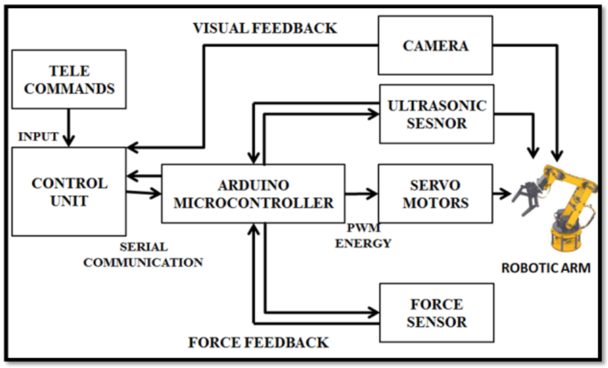

Fig.7 Electronic scheme of control

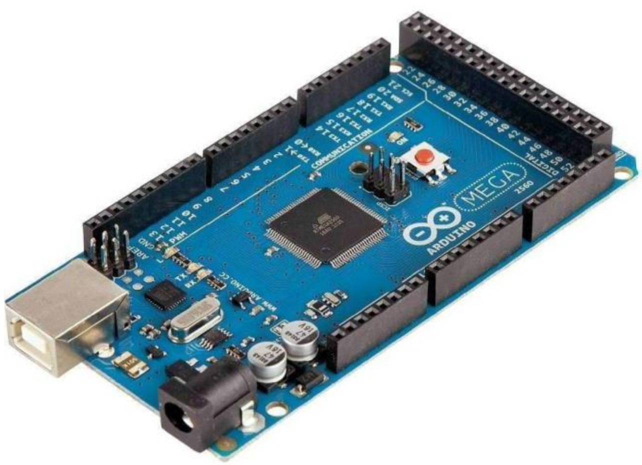

Fig.8 Arduino mega 2560 microcontroller

The microcontroller used is AT mega 2560 which is already comes with a programming board titled “Arduino”, as shown in figure 8. The programming language is very similar to C and it controls I/O ports and serial communication. This microcontroller was chosen because of the affordable price, and it is very easy to reprogram. The microcontroller was programmed by using arduino IDE. Arduino IDE is a cross platform application written in java and it is derived from the IDE for processing programming language and wiring projects. The movements of the different servomotors at various angles were co-ordinated using a program developed in the ardunio IDE and dumping the program in to the ardunio mega 2560 microcontroller. This results in entire robotic arm to move in desired direction which helps in performing the surgical operation.

D. Results And Discussion

1) Results

Several accomplishments had been made with this project work, it includes the construction of robotic arm and performing surgical operations such as drilling and cutting using the surgical tools by giving telecommands to the robotic arm. The drilling and cutting operation with the subject is represented in the figure 9.

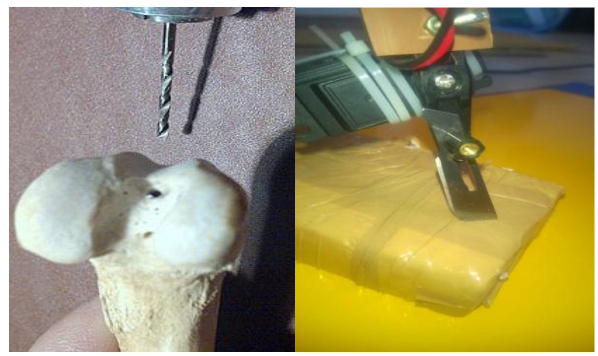

Fig.9 Drilling and cutting operation

The other work includes the measuring of tool interaction forces during the operation. The force sensor and ultrasonic sensor measures the tool interaction forces and they provide force feedback to the user. The measurement such as depth or distance value from the ultrasonic sensor and pressure value (denoted as P) from the force sensor strip were visualized in the serial communication software as shown in the figure 10. The drilling and cutting operations were monitored using video camera; it provides visual feedback to the user.

2) Discussion

Currently in robotic surgery, a small and light weight teleoperated surgical robotic system has been developed by providing the visual feedback to the operator or surgeon. The force feedback accompanied with visual feedback is lacking in the robotic surgical system. In this work incorporation of force sensor and ultrasonic sensor to the robotic surgical system provides the force feedback to the surgeon/user and incorporation of camera to the robotic surgical system provides visual feedback to the surgeon/user. Both will results in providing the surgeon the additional information about the surgery which facilitate to perform surgery in an effective manner.

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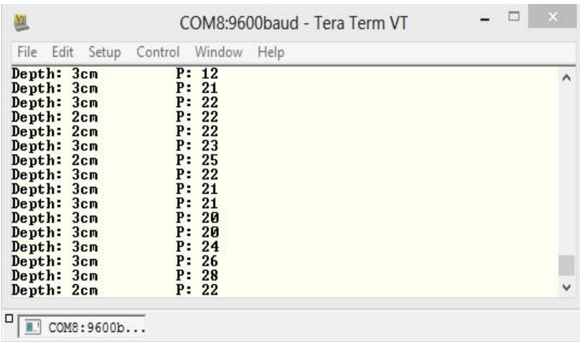

Fig.10 Output in Tera Term software

III. CONCLUSION AND FUTURE ENHANCEMENTS

A. Conclusion

This paper presents an inexpensive laboratory setup of da Vinci surgical systems for surgical operation. The laboratory setup has been made to accomplish tasks, such as drilling and cutting operation. The robot arm was constructed and built where servo motors were used to act links between arms and perform arm movements. The rotation range of the servo motor is less than 180º span, which decreases the region reached by the arm and the possible positions. The design of the robot arm was limited to five degrees of freedom since this design allows most of the necessary movements. The end effector is replaced by surgical tools for drilling and cutting operation. In order to perform more accurate operation and to provide force feedback and visual feedback different sensors and devices were used. To control the robot arm, a microcontroller, and a computer-based user interface was used. This system allows flexibility in programming and controlling method and the robotic arm can be controlled all of its movements from a computer, using serial communication. This robotic arm is distinct with others as being much cheaper than available robot arms; also it performs both cutting and drilling operations. And it also provides force and visual feedback simultaneously.

B. Future enhancements

In this work only one robotic arm was developed particularly for the drilling and cutting operation. In future, for stitching or suturing operation more than one or two robotic arm can be developed. Here serial communication played a vital role in the movement of the robotic arm; here it was controlled using the computer system. In future, by serial communication robotic arm can be controlled using mobile and other devices.

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