IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. IV (Jan – Feb. 2015), PP 58-60
www.iosrjournals.org

Hand gesture actuated robotic arm's motion with haptic feedback for surgical applications

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Abstract: *Human-robot symbiotic systems have been studied extensively in recent years, considering that robots will play an important role in the future. Similarly robotic surgery has seen a lot of advancement in the past decade. They are based on either a pre-programmed instruction for a particular surgical method or a manually controlled system where the surgeon gives the robot instructions during the surgery. These systems possesses the limitations of poor judgment, limited hand-eye co-ordination, it's rather limited to simple procedures only and really expensive. This paper proposes a simple gyroscopic and force sensitive based robotic arm apparatus which is controlled by hand gestures. Innate hand gestures can be used as a discerning and robust method to interact with the surgical robot. The movement of fingers and wrists of the surgeon procures a signal which is used by the motors of the robotic arm. This unique methodology can be implemented as a resilient telesurgical system for low cost and high accuracy surgical demands.*
Keywords: *Robotic surgery, Accelerometers, Robotic arm*

I. Introduction

Surgical condition is generally defined as any condition that requires suture, incision, excision, manipulation, or other invasive procedure that may or may not require local, regional or general anesthesia. Approximately, there are around 234 million major surgeries performed each year all over the world. That means one out of 25 people will have a major surgery in a given year [1]. Traditional surgical methods facade postoperative infection, pain and prolonged time to complete recovery. One of the obstructive problems with microsurgery is the physiologic tremor while holding the surgical instruments. The surgeon's physiologic tremor of about 40μm can be reduced to 4μm by the use of a robot interface. Moreover, the robot-assisted surgery is highly précised, miniaturized, and with smaller incisions required, grounding reduced pain, reduced blood loss and less operative time that relieve the patient from all the risks accompanying prolonged stay under anesthesia and provides quicker healing time. The robotic arm has a very high perception power. It mimics the movement of glove worn by the user, when the glove is tilted in the forward direction or any such direction, the arm will spontaneously follow the suit. The algorithms for the robotic arm make them capable of direct, safe and effective interaction with humans. The ultimate motive of robot assisted hand gestures based surgery is to give the surgeon unprecedented control in a minimally invasive environment and to allow surgeons to leapfrog the contemporary tedious and tiring surgical procedures. A gesture is a form of non-verbal communication. Hand gesture recognition acts as a highly adaptive interface between the user and the robotic arm, allowing an ease of operation by using a series of fingers and hand movements. Robotic surgeries have the potential to expand surgical treatment modalities beyond the limits of human ability [2].

But the current preprogrammed instruction based robotic surgery is restricted to basic tasks, with the surgeon providing detailed preoperative commands or exact move-for-move instructions to complete the task. Besides inexplicably high cost, such an approach of the system poses the limitations of poor verdict, limited dexterity, inadequate and fragile hand-eye coordination that consequently restricts surgical efficiency [3]. The large size of the system using cumbersome procedures becomes difficult to operate over relatively smaller patients. As the preprogrammed instructions given to such system becomes more and more complicated, there is an increasing need for more complex hardware and software components for better and faster response. This in turn increases the possibility of error exponentially. Therefore, these systems are rather limited to relatively simple procedures. One of the major issues in the current surgical systems is the absence of haptic feedback which can be very helpful in dire circumstances [4].

To overcome these limitations, in this paper, we present a surgeon-robot hand gesture recognition based cooperative system. The form and level of anthropomorphism and the simplicity of the design are the key features of this system. This includes a OWI-360 robotic arm that is operated and controlled wirelessly with the help of hand gestures which transmit signals to the robot through an auto device that is, the Hand Gesture Control Device (HGCD) fixed on the gloves being worn on hands by the surgeon, rather than controlling it manually through a conventional joystick controller. The glove houses the circuitry which can control the robotic arm. The robotic arm will move and act in the manner depending on the movement of the fingers and the wrist of the surgeon. The robot is programmable and can move in all the directions- up, down, left, right wherever the surgeon desires. The highly sensitive and précised accelerometer used here, acts as a compiler between the hand gestures and robotic arm movement. It can measure acceleration in all the three orthogonal axes. The basic principle of operation behind the accelerometer is the displacement of a small proof mass etched into the integrated circuit and suspended by small beams. Flex sensors are used to procure signals from the movement of wrist and finger. It can be used to control the motion of gripper for "grab and release" functions. For generating a haptic feedback in case of tactile motions, Force Sensitive Resistors (FSRs) are used. When there is no contact in FSRs it acts as an open circuit. With increase in force the resistivity decreases and the circuit is closed for Miniature Vibrations Motor to receive the signals. The whole process can be done wirelessly, adding dexterity to the user. Radio Frequency signals are preferred which can be done with the help XBee modules. The analog signals are converted to the digital values using an analog to digital converter embedded within a microcontroller. Since accelerometers are being used, therefore minimal hardware system is required and hence is of low cost and smaller in size [5]. The represented system is anticipated to radically enhance the learning curve, allowing trainees to get hold of surgical skills in a short time while improving patient safety by reducing surgical errors.

II. Methodology

A very realistic Hand gesture control device (HGCD) is designed which can be worn by the surgeon as a glove. The glove provides input to the robotic arm about the position and rotation of the hand using ADXL 335 3-axis accelerometer and SEN10264 Flex Sensors. It consists of a triple axis accelerometer which helps the user to acquire the signals from HGCD when the user moves his/her hand in any axis. The OWI-360 robotic arm provides 5 DOF's (Degrees of Freedom). Followed by the accelerometer, there is a Control unit as well, a ATMEGA48 microcontroller which can be used for motor unit driver as well as Encoder/Decoder for Xbee Module. . This model is robust because of the implication of highly accurate electronic sensors and efficient algorithms. The robotic arm has a closer interaction with the user with high capacities of perception and action. The interaction between the user and the robotic arm becomes possible through hand gesture actuation. The accelerometer detects the motion in the corresponding X, Y, and Z direction. The gestures like left, right, forward, backward made by the human hand are identified and converted to electric signal that is in to an analog voltage by the accelerometer. Received signals are sent to a compatible microcontroller which assigns the discrete motor control commands to the individual motors of robotic arm.

The analog values are converted to digital format with the help of an analog to digital converter that resides inside the microcontroller. Within the microcontroller memory, already exists some predefined ranges of values that have been stored for each type of motion X, Y and Z. When a motion occurs the controller checks the value and compares it with the predefined range of values. If the value is in that predefined range, then the controller identifies that the motion has occurred in X or Y or Z direction. Then according to the specification of accelerometer for one motion, two coordinate values change while the other one will remain the same. So for the left, right, up and down movements, some values are experimentally taken and a particular range is assigned. If the output of the analog accelerometer is in that range, then the controller will generate a particular code with respect to each motion i.e. 01 for left, 02 for right etc. These codes are generated in any of the port as per the program assigned. These binary signals are then used to control the individual motors of the robotic arm. The arm consists of 5 nos. of DC motors in order to provide five degrees of freedom to the system. The lowest point DC motors is attached in such a manner that it moves the upper base horizontally and from top to bottom ranging from 0-180 degree depending upon the values from the controller module.

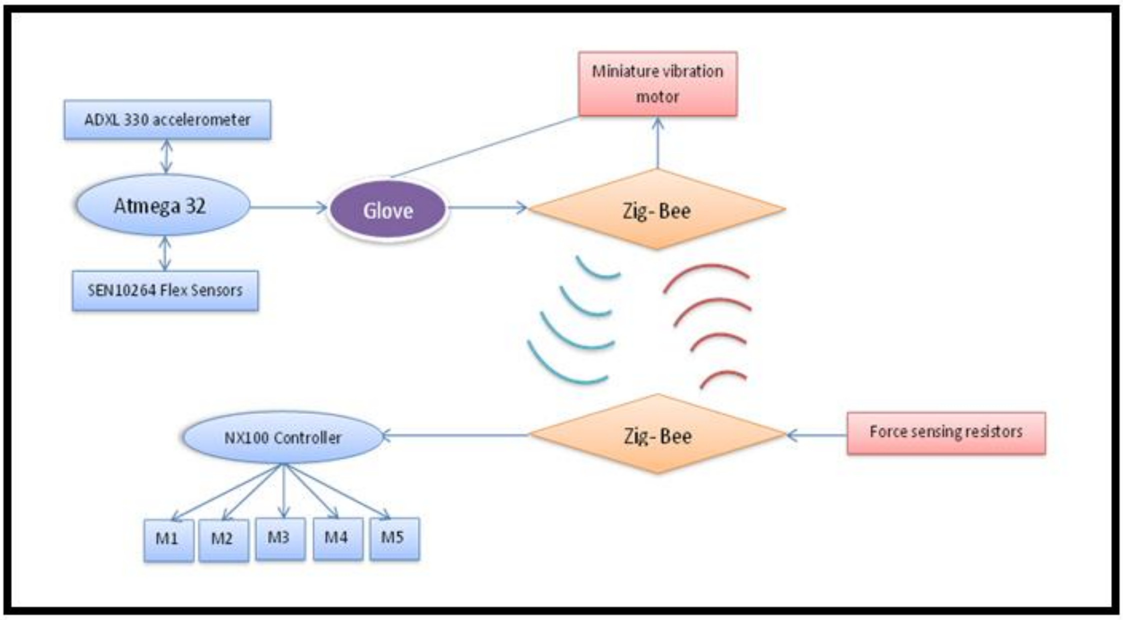

Fig.1: Block Diagram of the proposed design

There are three more motors attached for controlling the direction of the robotic arm in the Elbow, Wrist and Gripper. Flex sensors are attached to the forefinger to facilitate the grabber function. The level of the grip is determined by the degree of movement of the finger which helps in controlling the movement of the grabber.

For facilitating haptic feedback Force Sensitive Resistor are used at the gripper site. When the arm effector is in contact with a tactile source, the resistivity of the sensor decreases where it acts as a channel for actuating the movement of Miniature Vibration Motors placed the fingers of the user. This will create a sensation of touch which is critical during minimal invasive surgery.

For providing dexterity and comfort to the user, wireless control is implemented using RF signals. Xbee module is used for data transmission both at the Glove and the Robotic Arm site. To match the standards of critical wireless transmission, the delay of 120 millisecond's is acquired. On a more industrial application, fiber optic national grids can be used for asynchronous data transmission. This will help in reaching the rural areas which are ill-equipped for complex surgical processes.

III. Discussion And Conclusion

The paper presents a revolutionary and customary design of a hand gesture recognition based robotic surgery. This robotic arm is special because of its minimal hardware design that not only makes it simple but also a low cost and effective device. It can be easily used by the surgeon during surgery with less training period. It is an improvement on current telesurgical techniques because of its high accuracy, high efficiency and simple electronic circuit designs. This will give a more realistic experience to surgeons while doing surgery. It will change the existing concepts of human-machine interface and rather support biomimic of a human being by a machine. The HGCD device controls the individual motors of the arm in accordance with the input signal provided by the gestures of the user. It has the potential to deliver medical care services to those who cannot have direct access to the surgeons. The implementation of haptic feedback opens new dimensions in safety and precision. The usage of such an advanced technology is not restricted to one particular field. Many applications can be realized with the use of acceleration sensors. It also has major military and industrial applications which are yet to be exploited.

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