Implementation of Current Sensing Technique for Providing Force Feedback in Robotic Surgical Application

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ABSTRACT A modern surgical technique named as Minimally Invasive Surgery (MIS) has been evolved to overcome the conventional Laparoscopic surgery. This surgery is performed with small incisions by inserting small robotic tools. An configuration of "master-slave" tool has been used where the robotic tool mimics the movement of the surgeon. However, there is a limitation of providing force feedback from slave handle to master handle which reduces the performance of surgery. The work presented in this paper deals with the current sensing technique to implement the force feedback from slave handle to master handle. Depending upon the pulses of position sensor from master side, the motion is processed and transferred to the slave side. The processing part of both the handles of slave and master has been done under the environment of LabVIEW and NI-cRIO. The process of measuring the force to be provided for feedback to the master handle has been employed by using the current sensing technique. The proposed method will improve the effectiveness of performance of surgery in Robot Assisted Surgical System for providing haptic feedback.

KEYWORDS *Current Sensing, Force Feedback, Motion Transfer, Robotic Surgery, Robot Assisted Minimally Invasive Surgery (RMIS), Degree of Freedom (DoF).*

INTRODUCTION

Robotic Assisted Surgery is a promising technology as it causes minimal pain and minimal blood loss as compared to the Laparoscopic surgery. In the advanced technology of surgery, Robot Assisted Minimally Invasive Surgery (RMIS) has its unique identification. The features associated with this type of surgery like increased precision, human motion tremor filtering, increased external reach in the human body and reduced risk of infection has made it one of the prominent fields of research [1]. Although the system provide many facilities, still the overall performance in surgery relies on surgeon's skill. Since it depends upon the surgeon's skill to operate a master device there is always the possibility of damage to the tissue due to excessive grasping force or possible slips during the operation [2]. There are some techniques which are being developed to overcome this limitation. The technique of providing force feedback is called as haptic. Haptic introduces the sense of touch which are mechanically stimulated with the help of computer, virtual objects and through telerobotic devices. There are three sensory systems present in the human for sense of touch; kinesthetics, cutaneous and haptic. Kinesthetics is also called as tactile feedback in which learning takes place by carrying out physical activities. Cutaneous is a type of sensation stimulated by the organ in the skin. Force feedback is a method of giving "force" as type of touch feeling. For example, devices which contains joysticks, etc. The recreation of virtual objects through computer or control of various devices and machine physically, is typically a haptic technology [3]. In RMIS the methods have been developed for representing the interaction between surgeon and patient by providing kinesthetics or tactile sensations.

There are two purposes to use the haptic interface in robotic surgery [4]. It sends position information to the slave handle and also measures the force in touching of tissues and gives feedback to the master handle. Different systems are developed to perform robotic surgery however none of them has a mechanism that gives the information about the movement of end tool [5]. The technique to provide such information to the surgeon in RMIS will increase the efficiency and performance of the surgery.

The research has been uncertain for integration of force sensors at the tip of surgical instruments. A piezoresistive tactile sensor has been designed by King et al. [6] to employ it at the surgical tool tip. The direct contact forces has been measured by this sensor. However,it lacks in providing the essential functionality of the surgical gripper. Another development is of a multi axis contact force by Lee et al. [7] which has been integrated into the surgical forceps. This introduces the capability of multi axis force sensing. However, due to non-linearity and complexity, it cannot measure the force information accurately. Qasaimeh et al. [8] developed a PVDF- based microfabricated tactile sensor. The approach was successful in grasping force information. The sensor has been mounted on the surgical grasper. However, it was found to be insufficient for providing contact force information.

Another research zone in the advancement of haptic capacities is in telerobotic systems taht is; Da Vinci, Black Falcon. The Black Falcon was created in late 90s and is capable of 8-DoF teleoperator slave with a dextrous wrist for minimally invasive surgery (MIS) [9]. However it has limitations of inconsistency in motion of tools, lack of tactile and force feedback and lack of adroitness during the surgical. These were overcome by using the Black Falcon. This was done by using a force reflection device, PHANToM. The PHANToM device has 6-DoF which has been given for slave manipulator. The functioning of PHANToM has been divided into two sections, a 2-DoF Endo-Wrist and a 4-DoF Laparoscopic Grasper. However, there is some limitation with this technique in telesurgery system [10]. During long duration surgery, the chances of error increases as it lacks in haptics. There is difficulty in making appropriate force sensors for haptic feedback so it still lacks in robotic system. Another development of force feedback technique has been developed by Alekh et al. [11]. It employs current sensing technique for measuring the force acting by the obstruction and provides the feedback to the master handle. However, this system do not provide the real time processing.

Although various techniques have been introduced by the researchers, however, it has still been found difficult to provide accurate force feedback in RMIS. This affects the performance of surgery. Thus, there is a need to design a system where these limitations can overcome. This paper aims in the direction of removal of this limitation by designing a real time current sensing technique for providing the haptic feedback.

SYSTEM DESCRIPTION

The methodology of this research work deals with the master hand and slave hand of robotic surgical system. When the surgeon sits at the master console, he moves the handle with his hand. This hand motion is then sent for the computation. The performance of the work depends on two working sections; the computing module and the processing module.

Computing Module:- The computing module deals with the measurement of the signals coming from the surgeon and external obstruction. The motion coming from the surgeon's hand is measured and controlled to the drive the slave handle accordingly. Both master handle and slave handle are coordinated between each other. The concept behind the motion coordination is that the surgeon can sit at the master console and operate the robotic tools.

The signal coming from the surgeon hand is sent to the processing module. After the processing of the signal, it is sent to the slave handle. This ensures the motion coordination. While doing the surgery, obstructions like in cutting tissue is sensed by the computing system. Due to this obstruction, the current increases and introduces a torque in the slave motor. This change in current is measured and sent back to the master tool through feedback loop. Thereby, this change in current produces a force on the motor connecting at the master handle which may be integrated in future with the surgical robot which can provide feedback with respect to touching the tissues at the patient side.

Processing Module:- The processing module has been carried out through software LabVIEW and hardware NI-cRIO. The controlling applications has been carried out using by using the software program. The motion from the slave hand is controlled by the Proportional Integral and Derivative (PID) Controller. The PID controller makes the manipulation of signal easier by adjusting the gain parameters i.e. proportional, integral and derivative parameters. This makes the system adaptive according to the hand motion coming from the slave tool.

Another module used in driving the motor at slave side is Pulse Width Modulation (PWM). PWM is a technique to control the signal by switching digitally. The information or signal can be encoded using the PWM modulation technique. In the speed controlling of motor the PWM switching provides a facility to implement it. By regulating the duty cycle of the PWM, the motor speed has been controlled. The duty cycle of PWM depends upon the output of PID controller. Both module make the motion coordination easier. The complete methodology discussed above as Computing module and processing module is shown as a schematic in figure 1.

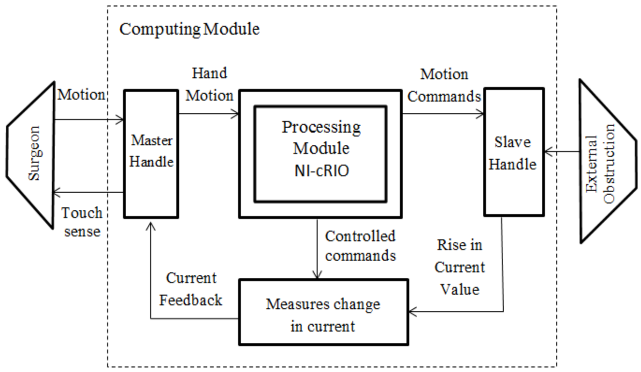

Figure 1. Block Diagram of Methodology

The system has been designed with a robotic surgical system by designing a master handle and slave handle. A 1-DoF of master handle has been designed where position sensor has been used to sense the motion. This position sensor has a resolution of 12-bit and have magnetic technology which make its performance better. The surgeon hand motion from master handle to slave handle has been transferred using the sensor mounted on the arm.

The slave handle, it has been developed by a geared DC motor (Maxon RE 16ϕ16). This special drive is required for driving the motor according to the sensor pulses coming from master side. The gear ratio of this motor is 1:84 having a Counts Per Turns (CPT) of 128. The Maxon RE-16 motor has precious metal brushes which is special and rare drive for ensuring low and constant contact resistance. At the slave side, obstruction has been provided using different weights. A pulley and belt arrangement has been employed for the proper positioning of slave sides. The pulley is parallel to the motor shaft and the belt is provided for the connection between motor and weight. The whole setup has been configured through NI- cRIO- 9024 along with its chassis. The module used are NI 9205 for analog input and NI 9505 for motor driver. The performance of LabVIEW software along with its instrumental module are very efficient and fast as it has a resolution of 16-bits. The figure 2 shows the arrangement of master and slave side of the system.

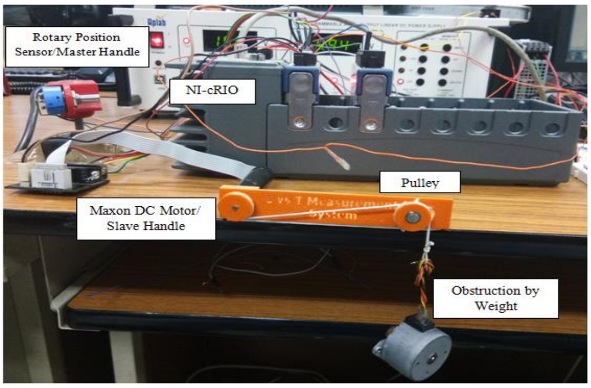

Figure 2. A Prototype Design of Master- Slave Configuration

RESULTS AND DISCUSSIONS

The designed system is configured for establishing and proving the haptic principle in real time. For this, prototype employs force sensing method by using current sensing technique. After the signal processing through PID and PWM of the signal at the master handle the signal is passed on to the slave side, for functioning of this system. The motion transfer has been done through current sensing. The flowchart of the developed system functioning is shown in figure 3.

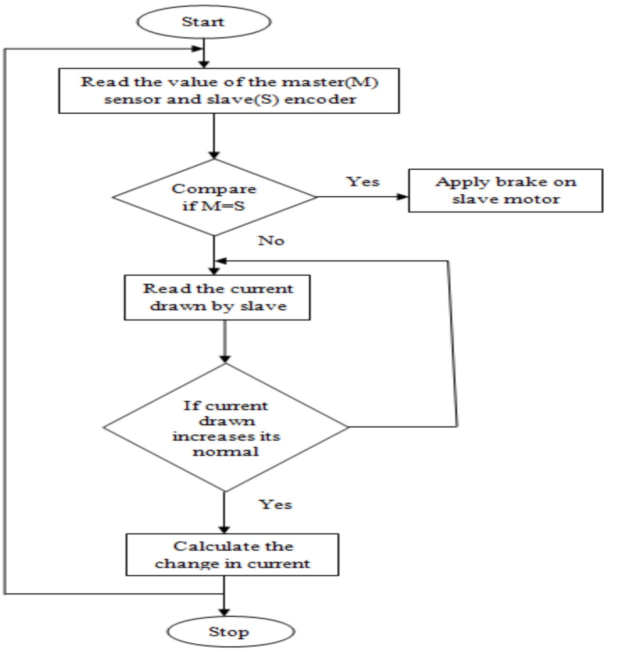

Figure 3. Flow Chart of Execution Process for real time force feedback

The coordination between the master and slave is important for the haptic feedback system. The developed system is able to sense the force acting on the slave side and this force is transformed in the form of change in current. Further, this current is given to the master side as a force feedback. This feedback is directly proportional to the amount of force sensed by the slave side, and as this sensed current value is increased to a value that is higher than the normal working value, the PWM of the master motor increases. In this prototype the force is provided using different weights which opposes the rotation of slave motor in any particular direction which causes the current to increase above the normal working value and provided as a feedback to the master side. This increased current on the slave side plotted through Digital Signal Oscilloscope shown in figure 4. As shown in graph the current is increased above normal current value according to the force applied on the slave motor and again fall back to normal value after releasing the force. The rise and fall period of the graph shows the period in which force is applied and released.

The system works in the real time module, which makes it more effective. The detection of current using the NI-Crio module is more accurate and faster as it have 9600 bits per second and communication rate of 1000 Mbps which provides faster performance. The special drive Maxon motor RE 30 is more sensitive than Maxon motor RE 16 used in previous research. This sensitiveness can give the synchronized feedback for real time application.

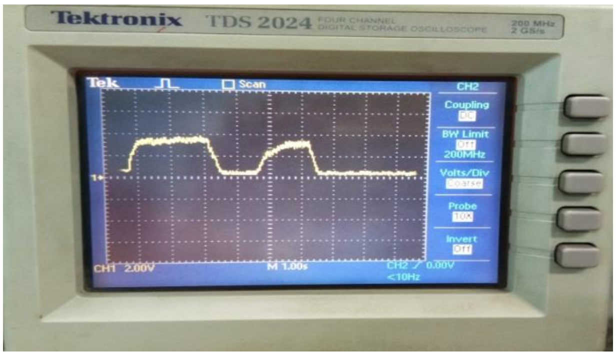

Figure 4. Rise in current due to obstruction by weight.

CONCLUSION AND FUTURE SCOPE

The aim of this work was to sense current for master slave type haptic device for the current sensing technique used for haptic system design for providing feedback of the force to the master side for the real time robotic surgery. Although, RMIS has the potential to overcome various conventional surgery limitations but still there are some more challenges that should be overcome for the robotic surgery to be more precise and effective.

The presented work will be further used in providing haptic feedback in real time for robotic surgery and its effectiveness will be assessed. Robotic surgery applications are growing but still there are various limitations in the path of the development of haptic feedback devices and more research efforts make robotic surgery more realizable and reliable. The development is required in terms of instrumentations and sensor inputs so that the single and multiple Dof master slave haptic device can be developed in future real time application for robotic surgery.

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