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A Thirteen Degree of Freedom Tele-Robotic Surgical ARM System with Efficient Tactile Sensors in the Manipulators

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Abstract—*Telemedicine is a new and promising application in the field of medical science. Medical consulting and remote medical procedures or examinations became more effective with the development of interactive audiovisual systems and remote mobile robotic platforms. Tele-presence requires real time video transmission. Fixed mounting of video device on mobile robotic platform limits the video projection at certain view angle, thus restricting the remote doctor in obtaining the fine and accurate visual information of the patient. To circumvent the problem, this paper presents a flexible robotic arm with vision system. A thirteen degree of freedom (DOF) robotic arm with extending and retracting feature enables the remote doctor to articulate the attached video device on robotic arm to target area on patient.*

The increasing requirement for robotic applications in dynamic unstructured environments is motivating the need for dextrous end-effectors which have the wide variety of tasks and objects encountered in these environments. The human hand is a very complex grasping tool that can handle objects of different sizes and shapes. This hand gripper is the wide working space compared with its physical dimensions and the capability to deal with objects in working environment conditions. This capability is achieved by using force/torque sensor and by properly controlling and coordinating the gripper and the carrying arm Note that with this control structure, it is also very simple to connect the arm/gripper system using Internet to other computational resources or robotic devices, for example to emulate tele-operation tasks.

Keywords— *Robotic arm, tele-surgery, tactile sensor, Bio telementry,*

I. INTRODUCTION

The increasing rate of patients being admitted to hospitals and health care centers are calling for a new type of medical assistance [1] . Various telemedicine systems have been developed since past years to assist medical personnel as well as the patients. The practice of telemedicine for medical examinations means that people can undergo medical examinations at anytime and anyplace [2]. Similarly, tele-operation or tele-surgery support surgical procedures on human without the presence of surgeon nearby the patient. Increasing applications of medical robotics even introduced new medical procedures such as minimal invasive surgery technique which is targeted on special cases Tele-presence robots, patient lifting robots and rehabilitation robots are becoming an alternate solution for man power shortage in the medical field [1]. There are only few low-cost tele-medical devices and robots such as TheraDrive [6] available. Current research and development in telemedicine has introduced various types of robotics platforms which enables complicated and challenging tasks to be completed easily and effectively. Introduction of RP-7 Robots by In Touch Health effectively extend the physician's reach to manage patient care by eliminating time and distance barrier. Tele-surgery robots with used in minimal invasive surgery is highly effective and safe since it reduces trauma, eliminate large incision area, implicitly and recovery time of patients.

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Manipulation capability is important for a robot. Interaction between a robot hand and objects can be properly controlled only if suitable sensors are available. In particular, information about the forces applied at the contact, the contact location, other indirect measurements, e.g. estimate of mass object, its inertia ellipsoid, or even non mechanical measurements, may play a crucial role to implement secure grasp and safe manipulation tasks. In the past two decades several robot hands and dexterous grippers have been developed.

The major goals have been on one hand that of studying and implement newer mechanical solutions in order to increase miniaturization and dexterity, and, on the other, to investigate manipulation models and control techniques. At mechanical level study on dextrous grippers has mainly focused on the actuation and kinematics aspects. With very few exceptions (e.g. tendon actuated mechanisms, and their numerous variants, still represent an effective way to implement compact manipulators. Actuation of tendon based robot grippers poses various technical problems. Tendons coupling on one hand, friction and elasticity on the other, pose important problems for the control of tendon actuated mechanisms.

However, the mechanical accuracy required to design a miniature (e.g. human sized) dextrous gripper, is by far less than an equivalent design based on gears or other stiff transmission mechanism. Recently the tendency is to create robot hands more compact and high integrated sensors system, in order to increase the grasping capability and in order to reduce cabling through the finger, the palm and the arm. As a matter of fact, miniaturization and cabling harness represents a significant limitation to the design of small sized embedded sensor.

II. Design Methodology

A remote surgical robot was developed and integrated which consist of a command centre, server and a dextrus robotic arm with tactile sensor. The overall system is illustrated as in Figure.1. The robot aids surgeon to remote operate the patient by incorporating a flexible arm which further increase the effectiveness of tele robotic surgery

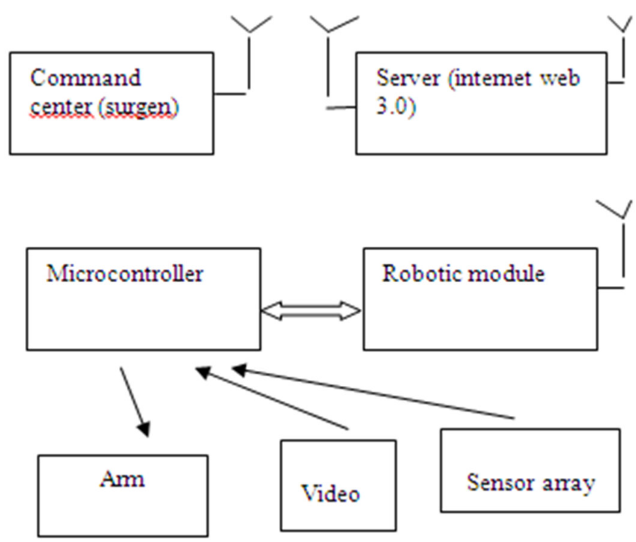

Figure 1. Framework of remote patient surgery system

A. Command Centre

Command centre is basically a laptop or a desktop used by the remote doctor to control the robotic fingers attached with a robotic arm. The doctor will be able to navigate the mobile robot and control the flexible arm through internet. The video from the visual device on the robotic arm is also transmitted in real time to the doctor's computer through internet. The user friendly interface displays the real time video. The doctor can communicate to the medical assistants or nurse through the audio transmitted by the mobile robot

B. Server

Server is the 'brain' of this entire system, where server regulates and monitors the entire doctor and patient interaction. All the essential data are saved in server. The remote doctor can access to any patients data and information anytime.

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C. Mobile Robotic Platform

The mobile robotic platform is a robot which can move and interact with patients. This platform equipped with sensors, medical instruments, on board computer and video cameras for navigation and interaction. The mobile robot host the flexible robotic arm which is will be controlled by doctor to inspect and operate the patient. The command sent by the doctor through internet is received by the on board computer and the commands are executed by the microcontrollers through I/O ports. The computer is made to interact with the microcontrollers to perform other control actions.

D. Robotic Arm

The thirteen degree of freedom robotic arm is designed to cover the whole visual area of the patient in the bed. The unique feature of the robotic arm which is extendable and retractable enables the doctor to have a clear view of the patient. A video camera is attached with the effector of the arm with two ISO degrees of yaw and pitch movement HMI Digital Robot Servo motors. The whole arm can be rotated three dimensionally to provide a suitable working envelope for the robotic arm.

The robotic arm is controlled through a dedicated microcontroller unit which communicates to the on board computer through serial communication. The video camera used is a CCD camera with 22x digital zoom. This enables the doctor to zoom on the target area of the patient to get accurate and fine view without articulating the robotic arm closer to the patient.

III Flexible Hand System Design

The mechanism of a flexible hand gripper requires The (D.O.F); the hand system has 13 D.O.F included 1 D.O.F on the hand link. Note that the Joint 4 consists of the linear motor so that the fingertip can move as slide but other links just moving as rotate around a horizontal axis. In general a hand needs 9 D.O.F to move a target to any position and orientation. But our hand has 13 D.O.F so that the applications are very wide in the working environments, and the fingers are arranged so as to grasp the objects like circular and prismatic, etc. In order to achieve "lightning" high acceleration, we have developed a new actuator that allows a large current flow for a short time. Table 1 shows the specification for the actuator. mass of the hand should be as low as possible. It is highly desirable that the hand weigh less than 1kg. Furthermore the low mass of the finger mechanism is desirable not only to achieve flexible motion but also for stable control.

Our philosophy about dynamic manipulation is maximization of the power and minimization of the mechanism. In particular four factors are important: (1) light weight, (2) high speed and high acceleration, (3) accuracy, (4) possibilities of flexible grasping three fingers have been used, which is the minimum number to achieve a stable grasp. Each of fingers has 4 degrees of freedom The finger has strain gauges at the joint 1 and joint 2 for force control. In addition a 6-axis force/torque sensor and a tactile sensor are mounted on each fingertip.

The flexible motion imposes a heavy load on the finger mechanism. For this reason a simple mechanism should be used for reduction gear, transmission, etc. In most traditional hand systems a wire-driven mechanism is used. But this is not suitable for a lightweight mechanism, because it is large and complicated. In our hand a newly developed small harmonic drive gear and a high-power mini actuator are fitted in each finger link and all of these parts are hidden in the plastic case. A harmonic drive gear has desirable properties for control such as no backlash and a high reduction rate. The hand system consists of a camera at the centre position as shown in Fig. 2

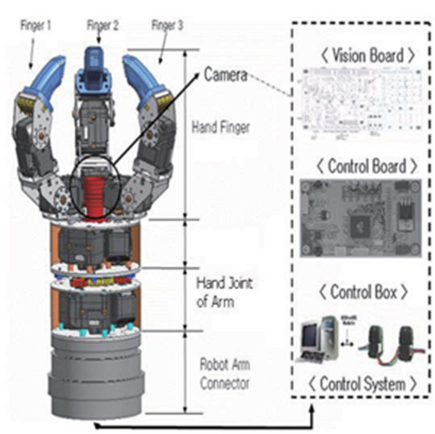

Fig 2. hand gripper control

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IV Tactile and Force Sensing

Manipulation control requires in general some sort of feedback which could provide information about the interactions occurring during contact between the gripper and the grasped object. Assumptions must be made about the nature of the contact and, on the base of the selected contact models, it is possible to specify the nature of feedback required to properly control the interaction. Detailed contact mechanics models are in general too complex to be taken into account in real-time control applications. In practice, simplified lumped parameter models are usually considered [7]. In the soft finger model it is assumed that also a torque, aligned with the normal to the surfaces in contact, arises. The model equations for these models are:

$$f = p$$
$$m = q + c \times p \qquad (1)$$

Where p and q are the contact force and torque (for soft finger models only), c is the contact location, and f and m are the measured force and torque. Bicchi and Salisbury, proposed procedures for computing p and q on the base of the measurements f and m. However a precise geometric model of the pressure (the robot finger) is required, and, except the case of simple geometries, the method is computationally intensive and critical for real-time implementation direct solution to the contact problem would be obviously possible if the contact location c would be directly measured. Therefore the availability of a direct force measurement and of the contact location allows directly to solve the point contact problem

A. Force/Tactile Sensor Design

At system level the goal is to develop to an integrated tactile/force sensors with embedded electronics to be placed on the phalanges of three fingers. The relevant problems considered have been: choice of appropriate force transducers, pressure transducers for contact measurements, integrated electronic design.

B. Force Sensor

As a force sensor, we have used the integrated micro force sensor LPM 562. This force sensor provides precise, reliable force sensing performance in a compact commercial grade package. The force sensor operates on the principle that the resistance of silicon implanted piezo resistors will increase when the resistors flex under an applied force. The load is applied to a stainless steel plunger transmitting force to the silicon sensing element. The sensor packaging incorporates a modular construction and use of innovative elastomeric technology and engineered molded plastics which allow for load capacities of 4500 grams overload.

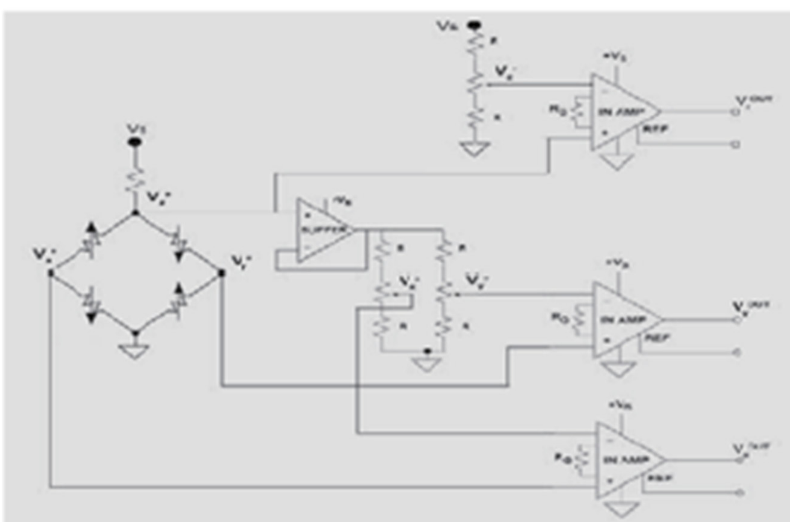

Fig. 3. Circuit diagram of force sensor and amplification Circuit

The device consists of three strain sensitive thick-film resistors. A force applied to the interface stick produces a change of resistivity. Proper arrangement of the resistors in three Wheatstone bridges, and a simple decoupling amplifier, allow obtaining three voltages proportional to the applied force components. Digital potentiometers are used for self-calibration of the bridges and three instrument amplifiers provide appropriate signal conditioning before sampling.

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V Tactile Sensor

A. Tactile Sensor Transducer

The tactile transducer is a matrix of 64 electrodes covered by a layer of pressure sensitive conductive rubber (PCR Co. Ltd.). The electrodes are etched on a flexible PCB substrate in order to conform to a cylindrical surface. A thin elastic sheet covers the whole sensor and provides a mild preload useful to reduce noise. Pressure due to contacts produces changes of resistance among the electrodes. The geometry of the electrodes has been defined with the goal of limiting the spurious currents that may occur across the various electrodes, and interfere with measurement.

B. Tactile Data Processing

Tactile data are sampled by the on-board MCU, with 10 bit resolution. Preliminary tests show an actual sensor resolution of 8 bit/taxel. Each tactile image consists of 64 taxels. During contact; a number of adjacent taxels are subject to pressure. The analog output of the tactile sensor allows to measure the distribution of pressure over all the transducer. Therefore, we propose to compute the contact centroid as where C is the computed contact centroid, xij is the coordinate of the taxel and p (xij) the weight of this. As a matter of fact further geometric information about the distribution of the pressure during contact could be useful, although not directly relevant to point contact model solution. To this aim the pressure distribution is approximated as an ellipsoid as follows:

$$c = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} x_{ij} \cdot p(x_{ij})}{\sum_{i=1}^{N}\sum_{j=1}^{N} p(x_{ij})} \qquad (2)$$

Where E is a symmetric matrix who represent the ellipsoid. The approach used to compute and the associated approximate ellipsoid is strongly based on the availability of an analog tactile sensor.

Conclusion

The flexible robotic arm was proposed and developed to evaluate the flexibility, reliability and accessibility towards hospital environments. This tele-surgery flexible robotic arm increases the working envelope when it is gradually extended and the accessibility of the robotic arm increases with variation in arm length. This enables more flexible articulation of the arm and video projection can be done from many angles on the patient. The yaw and pitch movement of the video camera allows more accurate video projection to be obtained.

An integrated force and tactile sensor with embedded electronics has been presented in a light weight flexible hand with 13 D.O.F, and the associated visual feedback control. The sensor consists of a three components commercial force sensor and of a custom matrix tactile sensor based pressure sensitive conductive rubber. The joint used of both tactile and force information allows the direct solution of the point contact problem. A technique to compute the contact centroid and a quadratic approximation of the pressure distribution during contact has been proposed.

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