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Haptic and Tactile Sensing Methods for Master-Slave System in Medical Robotics

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Abstract

Sensors for robots have been a widely discussed and researched topic. Various industry-accepted sensors based upon diverse principles include optical sensors, acoustic sensors, inductive sensors, capacitive sensors, resistive sensors, piezoelectric sensors, magnetic sensors, thermal sensors, etc. All these are used to perform different types of sensing functions in the robot, like force sensing, position sensing, shape sensing, collision prevention, and smart-sensing. In this paper, we have discussed the various tactile, vibrotactile and haptics based sensing methods. The sensors, associated components, software and hardware issues, constraints, requirements, development, and research issues have been discussed, in particular related to Master-slave system in medical robotics. An experimental implementation in the context has also been briefed in the paper.

Keywords: *Haptic, Tactile sensing, Vibrotactile sensing.*

I. INTRODUCTION

Sensors in robots may be internal or external. Whereas the internal ones take care of the position of moving parts with reference to a home position, the external sensors have to deal with the outside environment and workplace. Whatever be the job assigned to a sensor inside or outside a robot, the purpose is to increase independence from the human operator. Choosing a sensor for a particular application requires the consideration of various aspects like measurement range, temperature, rigidity, sensitivity, response time, cost, shape, size, etc. Keeping in view our requirement of sensors for medical robots, the most commonly used and researched-upon tactile, vibrotactile and haptic sensors have been focussed on in the subsequent section, followed by a briefed laboratory implementation and conclusion.

II. SENSING METHODS

In this section, we have elaborated upon three types of sensing methods employed in medical robotics. These are tactile sensing, vibrotactile sensing and haptics.

Tactile Sensing: A contact sensor equipped device can be used for grasping or holding the objects. A good grasp may be a power grip that gives high holding force or it may give an object maximum mobility, so it depends upon the task to be accomplished to define an effective grasp. A numerous types of tactile sensors have been reported in literature, like Conductive elastomers, which are based on the principle of change in resistance; ferroelectric polymers, optical devices, VLSI designs, etc. While the conductive polymers suffer from high hysteresis and low sensitivity, the ferroelectric materials lack static response and the optical devices are bulky. In this category, the most promising has been the capacitance based tactile sensing which measures applied force by calculating the gap between two parallel plates of a small capacitor. The dielectric material is the most important component in such devices. The dielectric material is sandwiched between two parallel layers of capacitive cells. The dielectric layer translates force into positional changes as well as creates a dielectric distance between the capacitor plates. The overall sensitivity of a device can be derived by conducting the force test several times and computing the statistics of the response. The spatial resolution of the sensor is controlled by the properties of the dielectric and the distance between the capacitive layers [1, 18]. Another piece of work from the point of view of sensor design explains the significance of tactile sensing in medical robotics. Infact, it is force sensing because the objects to be handled in this case are usually fragile and delicate. Tactile sensors has many feedback advantages too in addition to better shape perception of object and measuring impact forces [2]. Force measurement can be done by using force sensors in direct touch with the patient, of course, keeping sterlizability and electromagnetic compatability in consideration. A force feedback control loop structure allows the precise force measurement [3]. Tactile sensors have been developed which encase a sequential arrangement of semiconductor based pressure sensors inside an elastic body consisting of varying density elastic materials. An important feature of these sensors is that they have the ability to sense tangential stress, fit into curved surfaces, and work over a range of depth and resolution. The use of diodes and switches reduces the number of complexity of cables and wires in the tactile sensor. The layered arrangement of the sensor mimics the human skin structure, the layers act as amplifiers and the total thickness is determined by performing appropriate simulations [4]. Another wonderful work is based upon the change in the hydrodynamic state of our fingertip due to physical interactions of the nail and the bone beneath the finger nail. We observe various patterns of blood volume due to varying forces in different dimensions. A filter predicts the forces based upon this photoplethysmographic nail sensor. To ensure good contact, the surface area of the sensor is kept high and to observe bending angles, optical sensors may be used. The array of photodetectors on the sensor in an indoor, temperature and pressure-controlled environment avoids the effect of these physical parameters on the working of the sensor [5].

Vibrotactile Sensing: Human Vibro-tactile sensitivity is another domain to study techniques to analyse speech and visual information through neurophysiology. An equivalent model of human sensory system when includes the effects of mechanosensory receptors is a case of non-linear and stochastic behaviour of cell membrane. Infact, the Pacinian corpuscles (PCs) and the ion channels in the cell membrane determine the action potential of the membrane. In addition, environment induced and physical set-up factors also contribute to simulate neural response to touch and vibration thereof. The biomechanical models here consist of skin layers (dermis and hypodermis) and PCs (embedded between dermis and hypodermis) along with the approximations. The compression observed at the pressure sensors (PCs) further affects the Transfer Functions (Neural Activity). The Ion channels, which are sensitive to both positive and negative pressure gradients with increasing sensitivity in the low and high threshold channels. Considering the different types of mechanical and neural noises, and spike rate and amplitude at input stages of the model, the morphological details of receptors have been utilized for sensing purpose [6, 17].

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Haptics: Haptics based sensing is a tactile feedback technology which combines the tactile and Vibro-tactile technologies towards a better perception, however, this should not be confused with both of them [16, 19]. Haptic device is a manipulator, haptic interface is device along with associated softwares, haptic perception and rendering are the processes and telehaptics is the science. The collaborative haptic audio, visual environment creates a structure which is user and feedback controlled, may be simulation based and force reflecting too. In a virtual environment, haptics enables richer media content due to coupling of touch sensing along with other body senses [7]. However, new ISO standards and prospective guidelines may be required for potential usage of haptics such as appropriate interaction styles, efficient movement controls, flexibility of movement controls, seamless integration of task and output, task display conflict, reliable interaction, minimizing system fatigue, multi-modal sensing and so on [8]. Haptic devices are mechanical devices while haptic interfaces are relatively sophisticated devices. General purpose haptic interfaces may be ground-based or body-based. The body-based, that is, human sensory systems exhibit faster haptic feedback rates than individual visual or auditory or tactile sensing. However, the system requires a dedicated controller and processor, making it a expensive, but computation costs are reduced. Alternatively, motors can be used to create tension in wires, which result in applied force at the end-effector [9]. Some of the low-cost haptic devices include paddles, knobs, Novint Falcon, Gaming Joysticks and phantom. These have diverse applications in the fields of visual rehabilitation, automation, virtual education, medicine, e-commerce and research [10]. The principle of haptics is under research for application in medical robotics using master-slave machine system. The principle is being used to transfer motion at the two ends. Though perfect coordination between the two is the main challenge, the technique has been proven to be more accurate, efficient, safe and superior in performance. The implementation of this sensing method should make the robotic surgeon feel that he is operating directly on the patient [11]. The teleoperator may have two robots, equipped with robotic instruments, encoders and motors. The communication between the operator and teleoperator may be established via Ehernet. Weber Fechner’s law specifies that the intensity of force sensation at human end is directly proportional to the logarithm of the physical force causing it. The essential characteristics for exploiting such sensing requires a perfect eye-hand coordination, the force feedback should be close to threshold, and so quite trained professionals are required [12, 20]. The sensing tool may be a force sensor integrated to a grasper providing dual axial force measurement capability, 3-axis pull and 1-axis grasp force. The working principle here is to analytically differentiate between responses of various pressure sensors in case of contact between tissue and superficial layer of sensor. Haptic sensing system placed at the instrument tip measures the contact forces directly without friction and other disturbing forces. Secondly, the simple structure, the dimensions and significance of grasper can be retained. A capacitive-type sensor exhibits promising characteristics for high sensitivity and reliability in addition to being cost-effective. This sensor consists of two sensing electrodes and an elastomer of dielectric properties.. Hook’s law governs the relationship between applied force and capacitance. Researchers have been able to measure various contact forces in different dimensions which is important to prevent tissue damage [13, 21].

The knowledge gathered by studying many such touch and feedback sensors and systems, we chose to work on haptic feedback technology in medical sensing [14].

III. HAPTICS IN MEDICAL ROBOTICS

A master and slave set up has been used to establish the principle of haptics in our laboratory set-up. The transfer of motion from master handle to slave robot arm has been successfully achieved.

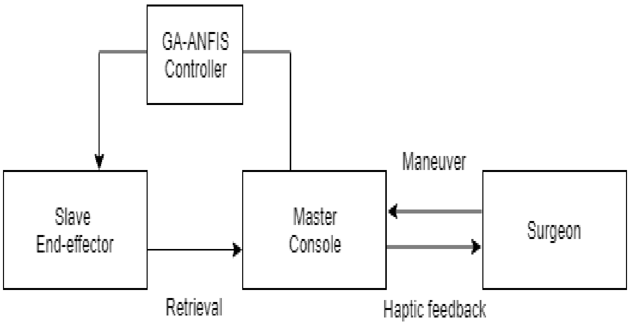

Figure 1: Basic Block Diagrammatic

The synchronization between the two ends had been achieved on an experimental pulley arrangement using two dc motors of same configuration at both ends. Later, the slave-end dc motor was replaced by a gear motor. The same set-up was then established between a dc motor at the master end and a gear motor at the slave end arrangement, along with the calculation of degrees of motion transfer (using a circular scale and pointer) as well as the reduction ratio calculation at the gear end. This controlled transfer of motion has been achieved by designing the circuit using ARDUINO motor shield, a dc motor, a gear motor and other associated electronic components. Gear motor is required to provide higher torque at the slave end for smooth tool movement. Diodes have been used throughout the circuitry to prevent reverse current. To nullify the constant leakage voltage, a variable pot has also been inserted. Relays and transistors are being used as switches for controlled transfer of reverse force in different directions. Whenever a force is experienced at the slave side, the current drawn by the slave motor surpasses its normal value in a directly proportional manner. As soon as the current drawn by the slave motor increases its normal operating value, the PWM value for rotation of master motor, corresponding to the slave current is fedback to the master motor. This generates a resulting force on the master side. The reverse effect is studied in terms of voltage/ current readings. Reverse force applied while the motors are in motion generates voltage/ current and correspondingly a reverse force is felt at the master's end. This forms the basis of haptics technology [14, 15]. We have identified some mechanical parameters, like, displacement, angular displacement, force and torque to study transfer across the two ends, keeping the constraints to be high sensitivity, ideally zero error and precise scaling. The aim further is to model/ simulate the principle in medical robots. The actual circuit diagram and videos of the working principle may be requested by those interested to work in the domain.

IV. CONCLUSION

We have been able to establish the principle of Haptics using Master Slave Configuration. The two-way force transfer has been successfully demonstrated. This paves way for plethora of applications in various domains including Medical Robotics. Future prospects include working in higher degrees of freedom and incorporation of the principle in medical applications including medical robotics.

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