The preliminary results of a force feedback control for Sensorized Medical Robotics

Duck Hee Lee
Medical Engineering R&D Center
Asan Institute for Life Sciences, Asan Medical Center
Seoul, South Korea

Seung Joon Song
Department of Convergence Biomedical Engineering
Daelim University College
Gyeonggi-do, South Korea

Reza Fazel-Rezai
Department of Electrical Engineering
University of North Dakota
Grand Forks, North Dakota, USA

Jaesoon Choi
Medical Engineering R&D Center,
Asan Institute for Life Sciences, Asan Medical Center and
University of Ulsan, College of Medicine
Seoul, South Korea

***Abstract*—A laparoscopic surgery system by using a robot holds many problems. Among these, its inability in delivering touching sensation to a surgeon is raised as the biggest problem. The current paper attempted to find a force feedback controlling method at the time of performing movement by using one-degree of freedom (DOF) arm of slave and master system that is used in the programming based system. The study was two methods experience force feedback control; In the first place used force sensors and otherwise, conducted for the force feedback control by using a force sensor and for the case when the sensor could not be used due to the spatial and systematic limitation. The realization of force feedback system was successful, and the experiment results of force feedback control and current based force feedback control mode based on the force sensors of one-DOF system indicates that it could be directly applied to the another multi-DOF surgical robot system that is currently under the development.**

***Keywords*—Laparoscopic surgery; force feedback control; degree of freedom (DOF).**

I. INTRODUCTION

Nowadays, the robot has been used in various fields for the development of industrial technology. In particular, it is utilization high for automotive and specialty industrial fields. Using a precision operation of robot is very good matching for required medical fields, because it is available details and accuracy surgical operations. Hence, the application of robot in medical field has been rapidly progressed in last decade. Based on its application, a medical robot is classified into surgical robots, human robots to help physically handicapped and aged people, and Bio robots to study biomechanisms [1]. While using a surgical robot, the sensing information delivery by using hand provides much information by surpassing visual and aural information. All of sensations felt by hand are called as haptic, and the haptic interface related researches have been initiated from remote operation or from a devise for handicapped person, and developed into telesurgery, remote control, and application in space & aeronautic fields [2-3]. Especially, Minimally Invasive Surgery (MIS) in the field of medicine operates a surgery without opening a lesion, but a surgeon operates a surgery by seeing a monitor after inserting surgical tools and camera through a hole in a lesion. Although the method's application scope is enlarged due to the advantages of shorter surgery time and shorter recuperation time of patients, but there is a three major disadvantage [4]; (a) As the surgeon does not have direct access to the operating field the tissue cannot be palpated any more. (b) Due to the friction in the trocar and due to the torque which are necessary to rotate the instrument around the entry point, the appearing contact forces between instrument and tissue can hardly be sensed. (c) As the instrument has to be moved around an invariant fulcrum point intuitive, direct hand-eye coordination is lost and due to the kinematic restrictions only four-DOF remains inside the body of the patient. Therefore, the surgeon could not feel the sensation when he directly operates a surgery [5-7]. Several robot surgical systems including Zeus and da-Vinci systems have been developed, but no report has been made yet for a haptic Interface providing system that could be applied onto an actual surgery. The current paper conducted a study for a force feedback control method that can be applied onto the currently developing surgical robot systems. The study was two type experiences for force feedback control; In the first place used force sensor and otherwise, conducted for the realization of force feedback control by using force/torque sensors and for the case when the sensors could not be used due to the spatial and systematic limitation.

II. MATERIALS AND METHODS

A. System Composition

In generally, surgical robot system is a consist of master and slave consoles. Therefore, many other researchers has been actively research of medical robot structure analysis and system developed the through after 1990s, but it is need to high cost and times. The development of haptic device that is used haptic interface for tactile transmission and control can be used to replace the master system. We used master system are PHANToM device that it have 6-DOFs functions for SensAble^{TM} [8]. This is characteristic as following; workspace of 381*276*191mm, nominal position resolution of 0.007mm, maximum executable force of 37.5N and stiffness of 3.5N/mm. The slave system used for Adept 550 industry robot (adept technology, Inc) [9]. This Adept 550 robot is a four-axis SCARA (Selective Compliance Assembly Robot Arm) robot. Among then, we used attached to the surgical instrument dummy tool on the one-axis. Accordingly, the study was conducted by using translational 1-DOF among total 4-DOFs of slave. Figure 1 illustrates the overall composition of the electrical current and force sensor base force feedback control system block diagram. The Slave were equipped with DC motors (Maxon Motor AG, Switzerland), and general controllers were used. The general controller design is based on a nonlinear system control approach. The implemented of control software was generated from the C/C++ with Pentium processor 2.5GHz CPU (Intel Co., Ltd.) and 2Gbyte of RAM. For the communication method between the control software and general controller that is connected to the master/slave, it used a performance proven, a well recognized serial bus type CAN (Controller Area Network) communication method. Through the minimum 3 lines of simple and small volume of communication lines, the serial communication up to 1Mbps was possible. Since the collision prevention and error control processing mechanisms were already well established on a standard phase, reliable communication was possible. The bus type allowed multiple controllers to share communication lines efficiently, which fitted the proposal of the current system. The motor used for the control was controlled by using 1000Hz cycle.

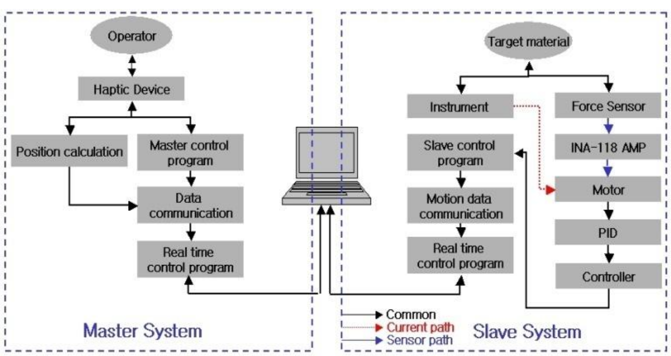

Fig. 1. Force feedback control block diagram

B. Control Method

The force feedback control scheme has an impedance control and admittance control about the haptic device [10]. Impedance controlled systems detect motion commanded by the operator and control the force applied by the haptic device. Admittance controlled systems detect the force commanded by the operator and control the velocity [11]. Also, The control methods for tele-manipulator systems used position to position control and position to force control. First case, controller torques applied to the master and slave are equal, but this is occur position and velocity error between the two device. Another case, It is similar to a position-position controller, except that the torque applied to the master system is based on a force sensor measurement on the slave system [12]. We system is a set the slave to follow the movement of the master haptic device and a controller was established based on the position of the master. From the movement position signals of the master device, displacement is detected to transmit the value to the operation for the position control command value of the slave. The tracking of the master command value used PID control method for the slave system. To feedback the amount of load received in the slave to the master side, an electric current based control and a sensor using control methods were used. The electric current based control method recognizes the force applied into the slave by using an electric current value of the slave and transmits the value to the master side for the control. The calculation and programming based control method was used for the electric current value input control of the master in Figure 2. For the Figure 2 illustration as follows: The controller is described by the transfer functions PF_{MX}, PF_{MY} and PF_{MZ} which are each position and force of master system. Theinverse Jacobian matrix JM^{-1} is computed by the estimated joint position θ . The delay time T_D dominates the delay of the communication network between master and slave that is a less than 1ms. For the force feedback control method by using sensors, the Load-Cell sensor was installed at the tool end of the slave as illustrated. The output of the Load-Cell sensor is approved as the input of control program through an amplification circuit. Such approved slave force could be felt at the master through the force and electric current control of the master haptic device.

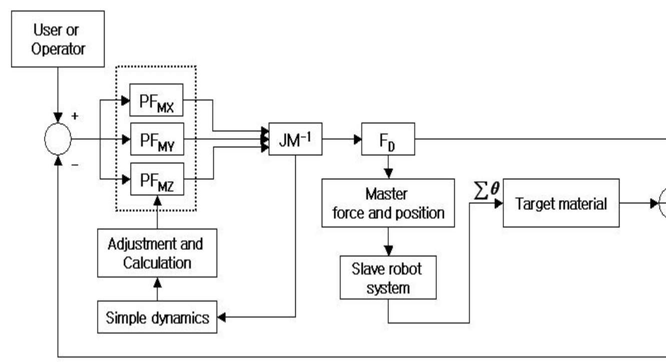

Fig. 2. Control system architecture for current and force sensor based force feedback

C. Current and force control function

In order to evaluate the interrelation of the electric current and force we compared current values according to the each condition after making the identical control condition to measure the current and force using no-load condition and soft-tissue.

For the no-load condition, the translation motor of the slave needs to be regular current to move the slave robot according to moving of master. Also when inflicting the load, it is received the position of translation movement and the force of reaching to the soft-tissue from the motor current. Therefore, in order to evaluate the interrelation of the current and force in this system, it is necessary to get information of the position as well as inflicting the force to the object. To examine the current and force, the following three equations are needed. For estimating the values of the force, three input variables, that is, position error (p_e) of the master and slave, the first variation ($\Delta p_e(n)$) of the error, and the second variation ($\Delta p^{'}$) of the error as follows:

$$p_e = P_{master}(n) - P_{slave}(n)$$
$$\Delta p_e(n) = p_e(n) - p_e(n-1)$$
$$\Delta p' = \Delta p_e(n) - \Delta p_e(n-1)$$

The interrelation equation of the current according to the force is a follows:

$$i_{current} = f(\Delta a)$$

Where Δa denotes the first and second variation of the position.

We can figure out the current when reaching to the soft tissue using the current value from equation:

$$i_{noload} = C_{noload}(n) - MA_{ChangeVacor}(n)$$
$$i_{load} = p_e(n) - MA_{ChangeVacor}(n)$$
$$i_{lcantact} = i_{noload} - i_{load}$$
$$MA_{ChangeVacor}(n) = Ax(n) + Ax(n-1) + Ax(n-s+1) + Ax(n-s)$$

Where $MA_{ChangeVactor}(n)$ is the value of the moving average in the interval where the value changes positive to negatives.

III. EXPERIMENT

The force sensor used for the experiment was composed as bridge circuit, and the tension/compression available UMN-K5 (DACELL Co., Ltd.) was used. The force sensor operates at DC 5V with input and output impedance of 352Ω, rated output of 0.9102mV/V, small size of 27*34mm and maximum measurement up to 49.03N is possible.

A. Design of a force sensor amplification circuit

To amplify few mill-voltages (mV/V) of output signal values outputted from a force sensor, an amplification circuit (INA118U), which enables 1000 times of amplification was designed.

The amplifier used at the current paper is precise, which can be operated under the low voltage and amplification coefficient was adjusted by using variable resistance. This amplify circuit board was a size of 76.2*53.5mm and 4-layer PCB (printed circuit board). In addition, a notch filter was used to remove 60Hz of power noise (Figure 3).

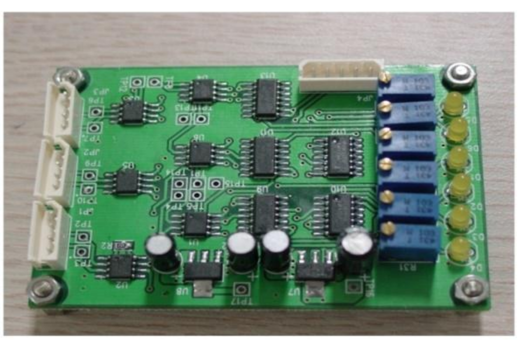

Fig. 3. Force sensor amplifier circuit board

B. Force sensor weight simulation

By using an experimental weight, the force sensor output at the 1-DOF translation movement was confirmed by the weight. The output experiment of the force sensor responding to 0.09N, 0.9N, 4.9N and 9.8N of weights was performed under the test condition of 10 seconds force application before 5-seconds of force removal (Figure 4).

C. Relationship of force with electric current on No-Load and test material

The electric current and force change was measured by actuating the master and slave system. As illustrated in Figure 5, it was possible to see the occurrence of motor current value under the No-Load state. It is also compared force sensor signals value. The motor current was developed by the interaction of equipment that holds a model tool in the slave robot arm at the time of Translation movement. To understand the relationship between electric current and force at the time of Translation movement on the test material, a laparoscopic surgery training use tissue suture pad was used to perform the test. The highest electric current was observed in test material model. However, the electric current under the No-Load state was observed in ±500mA range. It revealed that relatively large amount of electric current was flowing even under the No-Load state. It is a movement current following the master command to slave system.

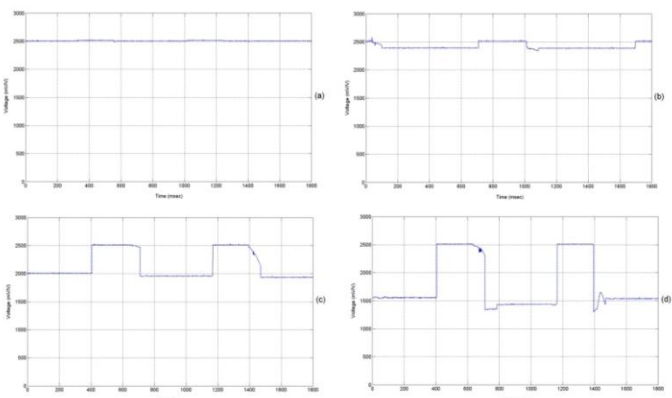

Fig. 4. Test of sensor weight simulation: (a) 0.09N; (b) 0.9N; (c) 4.9N; (d) 9.8N (X-axis is time(msec) and Y- axis is voltage(mV/V)

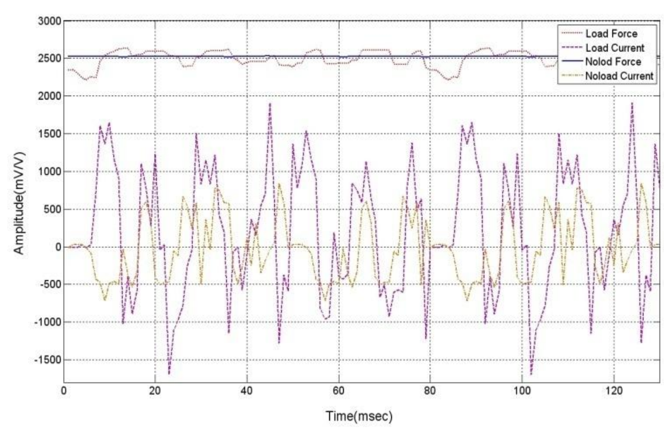

Fig. 5. Relationship of each No-Load and Load force with electric current

IV. RESULTS

To control the force feedback in this paper, we use electrical current values of the motor instead of sensor value, because of restriction of the space and structure in the laparoscopic surgery robot system that is in the process of the development.

Figure 6 shows the results of using the 5-point moving average algorithm for the current values that are obtained when no-load condition and pressing the test material object. That it is obtained from subtracting current values between no-load condition and pressing the test material. This means that the actual current values when pressing the soft-tissue object. Figure 7 shows position following performance of the slave. It shows good performance. The master and slave system of correction (r=0.93) for each position has an positive linear relation.

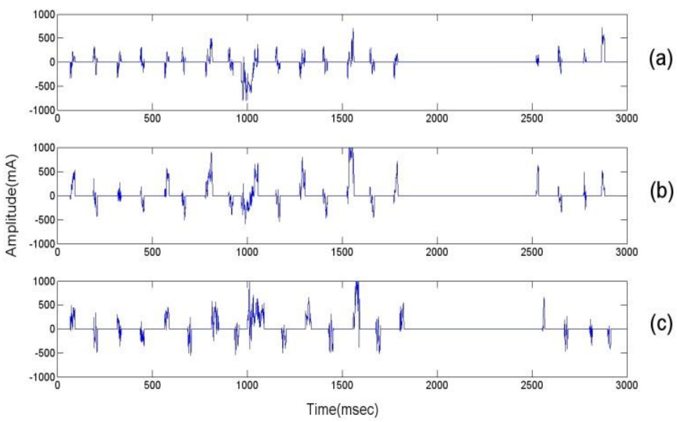

Fig. 6. Results of moving average feedback current value; (a) No-load current; (b) Load current; (c) Load and No-load current subtract

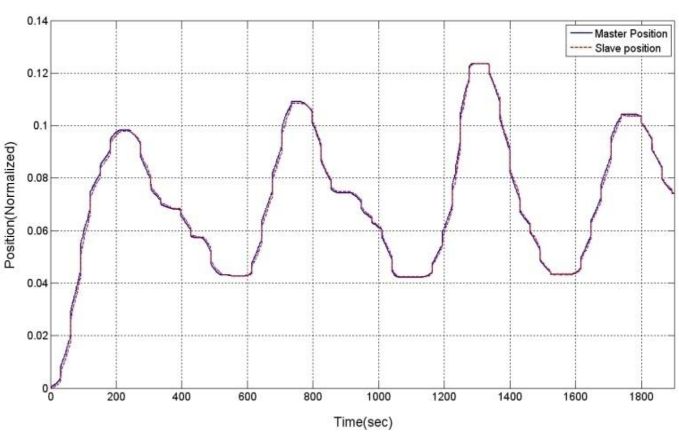

Fig. 7. Results of from master system to slave system position tracking

V. CONCLUSION

The surgical robot systems have been used on the surgery method for various diseases through the MIS. Therefore, the transit of haptic information to the surgeon's are such an environment as open surgery which it is appropriate microsurgery and bad location the affected part of surgery. The current paper describes a force feedback controlling method by using a force sensor or motor current in a laparoscopic surgery robot system. As it has been tested in the current study, the application of the force feedback control method by using a force sensor onto a surgery robot tends to require use of more sensitive force sensor than the one currently used, and the problem of vibration at the slave robot arm has to be improved at the time of translation movement. In addition, the application of force sensor has to be applied onto the actuation, rotation, pitch, and yaw DOF other than the translation movement suggested in the current study, and reviews and studies have to be progressed on the force feedback control method by using motor current along with the force feedback control method on position.

Based on the above result, future studies have to be made on the method of using force/torque at the whole many other DOF of the slave and to realize force feedback system by using more various algorithms. We also should be study to development of component and small size sensor for medical robotics fields.

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