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Development of Telerobotic Surgery System with Single-Master Multi-Slave

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Abstract : Medical robotics and computer aided surgery in general, and robotic telesurgery in particular, are promising applications of robotics. In this paper, we shows a novel single-master (PHANToM based single-master multi-slave telerobotic system) multi-slave system using two parallel mechanism micromanipulators as a slave device. After a general introduction to the systems structure and configuration of telerobotic system, a manipulation control strategy to build the system that human and both manipulators perform the cooperative manipulation, is introduced, followed by its kinematic analysis, mapping method, and experimental results.

Keywords : teleoperation, haptic interface, internal force, kinematics, dual-manipulator

I. INTRODUCTION

Medical robotics and computer assisted surgery are ne w and promising fields of study that aim to augment the capabilities of surgeons by taking the best from robots a nd humans. Human being can master a dexetrous micro manipulation by the experience and the training for years. Since this ability is unfathomable, it is impossible to su bstitute completely the ability for the robot by the presen t technique. However, it is very important to develop eff ective and suitable methods that can easily execute the m icro manipulation and reduce the exhaustion. In the medi cal field many new potential uses of telerobotics and mas ter-slave technology have been explored.

Recently, a surgical teleoperator, known as daVinci system, has been designed to provide enhanced dexterity to doctors performing minimally invasive surgical procedures [l]. The doctor performs virtually the teleoperation from the surgeon's console. We know that haptic senses are fundamentally significant for the complex operations. Therefore, we believe that a force-reflecting teleoperation based on the bilateral control is well suited to the micro-operation. Further, the computer network may allow the teleoperation to expand and be popular. For the design of bilateral controller which is required for the performance specifications in the frequency region, the $H\infty$, control theory and p-synthesis/analysis are very effective. In micro-teleoperation, suck; as micro tele-surgery, scaling problem is one of the most important problems.

Colgate [2] has proposed an impedance shaping bilateral manipulation and derived the general condition based upon the approach using a structured singular value. Many researches tend to discuss a general design methodology or scheme. However, we know that there is an optimum diameter of grasping cylinder, such as the grip of tennis racket, for the arch formed by our fingers and palm. This is geometrical matching. In the same way, it is supposed that the dynamical or impedance matching is unconsciously done between the human and the scaled environment. In this study, the human-centered scaling in micro teleoperation [3-5] is examined.

In our research, single PHANToM haptic device as master device and dual 6 D.O.F parallel micromanipulators as a slave device are adopted. Using dual slave manipulators is expected to enhance the performance or dexterity of total system compared to our previous work which can be mentioned as having a single slave manipulator [9,10]. Fig. 1 shows overall configuration of telemicromanipulation system.

In our research, we consider the micromanipulation as an application of the teleoperation. In this case, the teleoperation is used to connect the micro-workspace with the human workspace. It will solve the scale difference problem existing when teleoperation is performed among human operator and micro objects. These systems aim to provide a more comfortable environment for task execution and work efficiency improvement.

This literature continues with the system structure of tele-

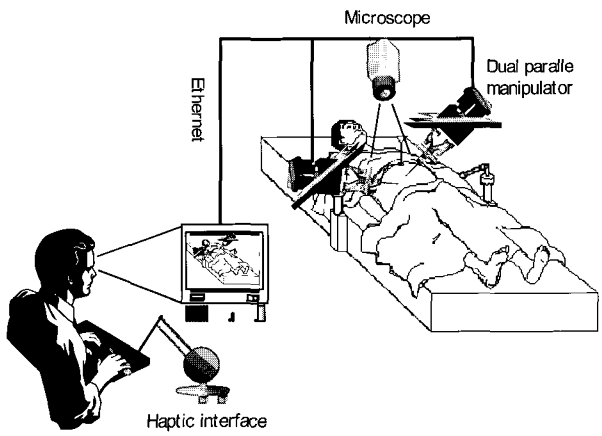

그림 1. 병렬형 마이크로 메니퓰레이터 원격수술시스템.

Fig. 1. Telerobotic surgical system based on dual 6 D.O.F parallel micromanipulators.

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논문접수 : 2006. 3. 3., 채택확정 : 2006. 6. 20.
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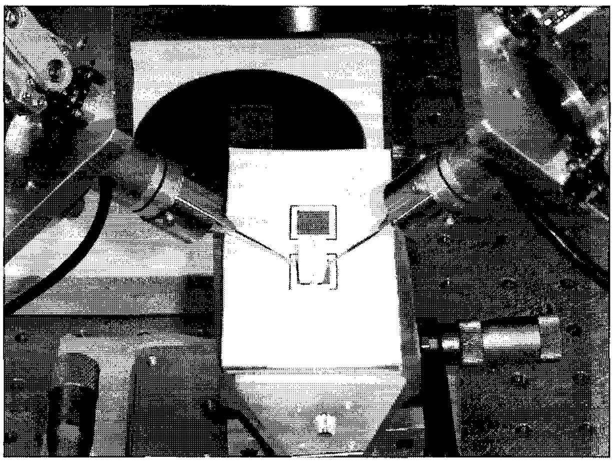
micromanipulation systems, and the parallel manipulator as slave device is briefly introduced. The configuration of single-master dual-slave system is introduced in section 3 and 4. Also, singular position problem that should be avoided to better manipulation performance is discussed and the manipulability of dual slave manipulator is analyzed. Then, mapping method between PHANToM master device and dual slave manipulators. Finally, several simulation results (e.g., manipulability, rectilinear movement error, master-slave mapping method) are to be shown. Every notation is based on the book "Robot Manipulator"[6].

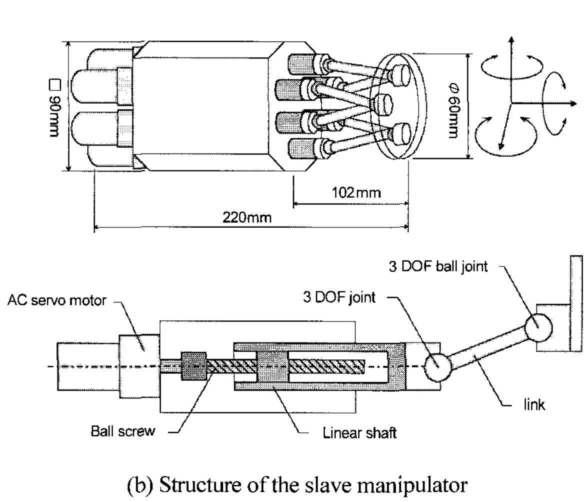
II. TELE-SURGERY SYSTEMS

Slave manipulator with parallel link mechanism shown in fig. 2 is used as a slave manipulator. Compared to th e serial mechanisms used in normal robot arms, parallel mechanisms has the following merits.

- High stiffness realized due to its truss structure,
- High-speed manipulation is possible, because of the non accumulation of links' weight in one of the actuators.
- High precision achieved, because of non accumulation axial positioning errors.



(a) Hardware architecture of dual slave micromanipulator system.



(b) Structure of the slave manipulator

그림 2. 듀얼 6자유도 병렬 마이크로 메니퓰레이터.

Fig. 2. Dual 6 D.O.F parallel micromanipulators.

Fig. 2(a) shows the hardware architecture of dual slave micromanipulator system. The structure of the slave manipulator is displayed in the fig. 2(b). Both manipulators are controlled by a PC (Pentium III 500MHz × 2). The Real Time Linux (ART-Linux) is used as the operating system to perform 1 KHz sampling time motion control. Extension bus connected to the machine performs Input,output of motors, rotary encoders and force sensors with AD, DA, Counter and DIO boards installed in it. As actuators, six similar AC servomotors are installed, and 1mm pitch ball screws are connected to each motor.

III. DUAL PARREL MANIPULATPR

In this section, tele-micromanipulation system is introduced Fig. 3 shows the configuration of our telemicromanipulation system. In these systems, the master input device used by the human operator is called haptic interface. The slave manipulators used directly to perform manipulation are called manipulators. The parallel manipulator having an original mechanism is used as slave manipulator in the teleoperation system. The slave manipulator and master system are connected using Ethernet and they are used to perform teleoperation through the network. Bilateral control system[11,12] was adopted to realize overall teleoperation system.

1. Slave micromanipulator

The main reason for using parallel mechanism manipulator as a slave in our research is that it has better positioning accuracy than the one of serial manipulator. High stiffness characteristics provided by its truss structure constitutes another reason. The high speed is achievable because of the not accumulation of link's weight in one of the actuators are also an another desirable characteristics. Fig. 3 shows the structure of the slave manipulator.

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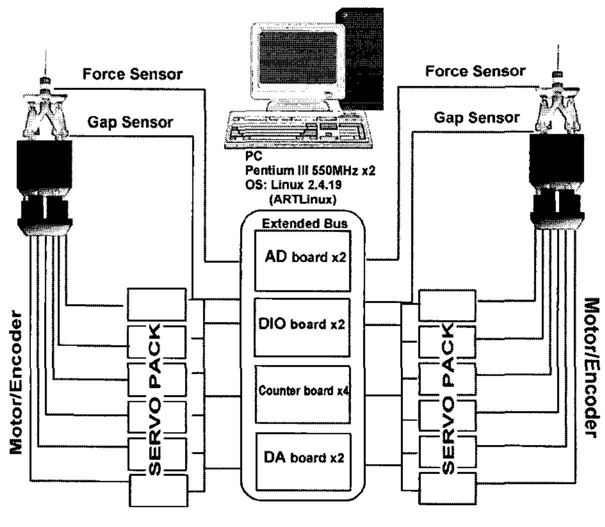


그림 3. 듀얼 마이크로 메니퓰레이터 시스템.

Fig. 3. Dual-micromanipulator system.

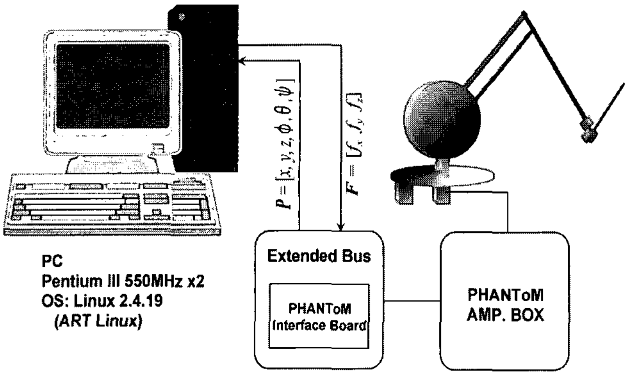


그림 4. 마스터 햅틱 인터페이스 시스템 셋업.

Fig. 4. Master haptic interface system setup.

Inputoutput of motors, rotary encoders and force sensors with AD, DA, Counter and DIO boards installed in it. As actuators, six similar AC servomotors are installed, and 1mm pitch ball screws are connected to each motor.

2. Haptic master device

A serial link mechanism PHANToM haptic device with 3 D.O.F are adopted as our master device. PC system configuration is shown in fig. 4. Real Time Linux was used as operating system to control the master with 1khz sampling frequency.

IV. KINEMATICS ANALYSIS OF SLAVE DEVICE

It is already mentioned in section 2 that there exist several characteristics of a novel parallel mechanism slave micromanipulator being used in this research. However, in the cooperative manipulation of multi-slave system, several problems of parallel manipulators such as singular position possibly become more serious than in the independent manipulation. As a previous work, kinematics analysis was already done [5]. Therefore, singular position, and manipulability of the parallel manipulator which is used in this research should be given in this section. The most feasible arrangement of both manipulators is also described in the latter part in this section.

1. Singular position analysis

There exists singular position in the manipulator workspace. The degree of freedom decreases around this position or point. Therefore it should be avoided to control manipulator. Here we need to analyze this singular position of our system by some calculations. First of all, Jacobian matrix can be mathematically defined as follows:

Assuming that an n D.O.F manipulator is working in an m-dimensional task space, where m<n, we have,

$$v = J_v(x)\dot{l} \tag{1}$$

where v and $\dot{l}$ indicate the Cartesian and joint velocity vectors defined in the task space $\Re^n$ and the joint space $\Re^m$, respectively, and J_v represents an $m \times n$ Jacobian matrix. J_v is also considered as a Jacobian matrix which contains ϕ as an Euler angle.

In the case that we put the column vector of J_v as $M_i(i=1\sim6)$, the relation between v and $\dot{l}$ can be described as,

$$v = \dot{l}_1M_1 + \dot{l}_2M_2 + \dot{l}_3M_3 + \dot{l}_4M_4 + \dot{l}_5M_5 + \dot{l}_6M_6 \tag{2}$$

Therefore, the singular position can be obtained by the calc ulation of determinant of Jacobian matrix J_v.

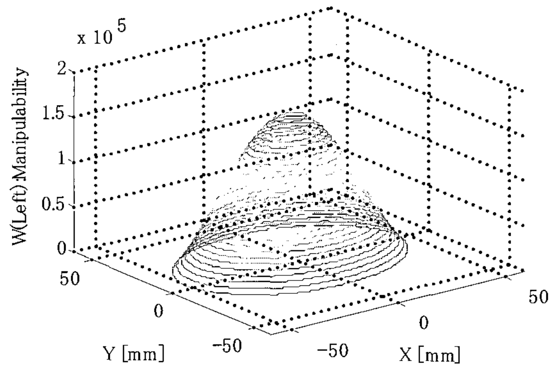
$$\det\ J_v = 0 \tag{3}$$

2. Manipulability measure

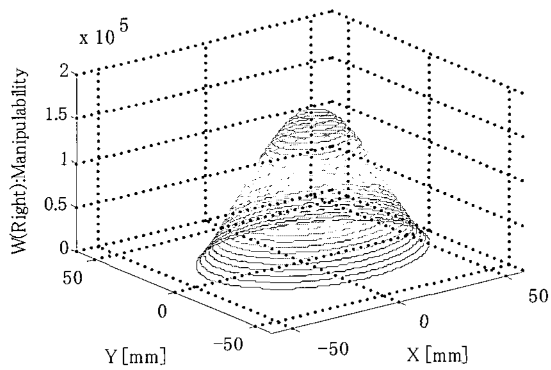
Manipulability measure w is proposed to measure quantitatively the ability to change the position and orientation of the end-effector from the view point of the kinematics [7]. There is also a trade-off between an accuracy and a manipulability. As the proposed parallel manipulator has no redundant degree-of-freedom, w is represented as follows:

$$w = |\det(J_v)| \tag{4}$$

The kinematical manipulability in the dual micromanipulator's workspace which is parallel to XY plane is shown in the fig. 5. It is easily verified that mapping the center position of both manipulators with the haptic reference position is giving the consistence of manipulability, because manipulability is plotted as symmetrical to the plane $x=0$,



(a) Case of left manipulator.



(b) Case of right manipulator.

그림 5. 듀얼 마이크로 메니퓰레이터의 조작성.

Fig. 5. Deal-Micromanipulator's Manipulability(w): upper and lower two respectively shows the cases of left and right manipulators.

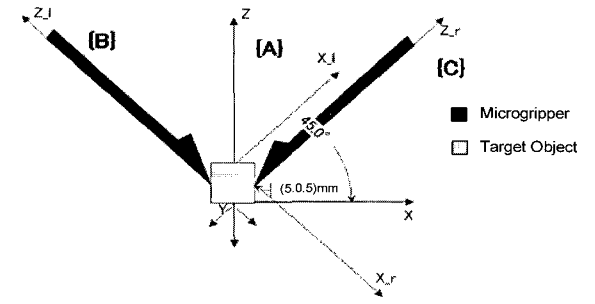


그림 6. 협조시스템의 기구학적 모델.

Fig. 6. Kinematical model of cooperative system: The universe, left and right manipulator's coordinate frames are respectively described as {A}, {B}, {C}.

3. Multi-micromanipulator analysis

In the case of dual-micromanipulator system, a proper coordinate system for each manipulator is needed to be analyzed. Fig. 6 shows the proposed model of the cooperative system. There are several advantages of this design which can be summarized as high flexibility to random target objects, high dexterity and etc. The angle between two manipulators is 90° and the initial points of end-effector is set as (5,0,5) mm and (-5,0,5) Eq. (5),(6) show the conversion matrix for arranging the coordinate system of each manipulator.

$$ {}^{A}_{B}C = Rot(y,45)\cdot Trans(5,0,-5) \tag{5}$$

$$ {}^{A}_{C}C = Rot(y,-45)\cdot Trans(-5,0,-5)\,. \tag{6}$$

V. CONTROL STRATEGY

Fig. 7 depicts the proposed mapping method in this paper. Reference position of haptic device is mapped in the centroid of both end-effectors' tip positions. At the same time, internal force generated by both end-effectors conflict with the target object is fed into user through the haptic device. In this section, A novel mapping method between single-master and multi-slave arranged as shown in the before section and a valid manipulation strategy are discussed.

1. Position mapping method

Basically, reference position of haptic device should be scaled to the center of both manipulator's tip positions during the free motion. The reference position to each slave manipulator is calculated from the current position and posture of the haptic device. Through using this method, same manipulability of both manipulators is possibly obtained on overall taskspace, because manipulability of both manipulators is symmetrically plotted to the plane x=0 as fig. 5. It can be the most feasible interface to human operator with only two-dimensional visual information. Several experimental results to verify the proposed mapping method are to be shown in the section 6.

2. Force decomposition

When multiple manipulators grasp an object, the force applied by multiple robots can be decomposed into motion-inducing force and internal force. Especially, the internal force should be kept in a certain range to assure the stable grasping

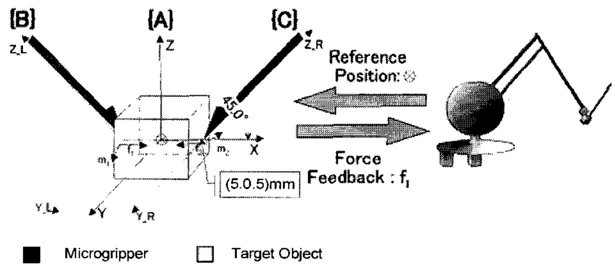


그림 7. 메니퓰레이터 매핑 방법.

Fig. 7. Mapping method.

and the safety of object. In the proposed cooperative master-slave manipulation system, the internal force to squeeze the grasped object is fed into the human operator through master haptic device.

Fig. 6 depicts two manipulators cooperate to grasp a single object. Therefore, force decomposition using the theory of metric spaces and generalized inverses [8] was adopted in this research. It is assumed that each manipulator grasp the object rigidly exerting both forces and moments on the object. The net force at the object frame is related to the forces applied by the manipulators by,

$$ f_{obj} = J_O^T f \tag{7}$$

where, $f_{obj} = \left[f_O^T \quad m_O^T \right]^T$ is the net force and moment at t he object frame.

$$ J_O^T = \left[J_{o1}^T \quad J_{o2}^T \right]. \tag{8}$$

J_{oi} is the Jacobian from the object frame to the i^{th} e nd-effector frame, $f = \left[f_1^T \quad m_1^T \quad f_2^T \quad m_2^T \right]^T$. f_i is the fo rce and m_i is the moment applied by the i^{th} end effect or. $p_i = \left[p_{ix} \quad p_{iy} \quad p_{iz} \right]^T$ is the vector from the i^{th} end ef fector to the object frame:

$$ J_{oi}^T = \begin{bmatrix} I_3 & O_3 \\ -P_i & I_3 \end{bmatrix} \tag{9}$$

The applied force f is decomposed into its motion-inducin g, f_M, and internal force, f_I, with

$$ f = f_M + f_I \tag{10}$$

$$ f_M = J_O^{T\#} J_O^T f \tag{11}$$

$$ f_I = (I - J_O^{T\#} J_O^T) f \tag{12}$$

where, $J_O^{T\#} J_O^T$ is a generalized inverse of J_O^T. The projections $P_M = J_o^{T\#} J_o^T$ and $P_I = I - J_O^{T\#} J_O^T$ project the applied force onto the motion inducing force subspace, F_M, and the internal force inducing force subspace, F_I, respectively.

If $rank(J_o^T M J_o) = rank(J_o^T)$, the weighting matrix

M can be used to compute a generalized inverse of J_o^T. Therefore,

$$J_o^{T\#} = MJ_o(J_o^T MJ_o)^{-1} = \frac{1}{2}\begin{bmatrix} I_3 & O_3 \\ P_1 & I_3 \\ I_3 & O_3 \\ P_2 & I_3 \end{bmatrix} \tag{13}$$

Using (11) and (12), the decomposition of f is,

$$f_I = \begin{bmatrix} f_1 - f_2 \\ m_1 + (P_2 - P_1)f_2 - m_2 \\ -(f_1 - f_2) \\ (P_1 - P_2)f_1 - m_1 + m_2 \end{bmatrix} \tag{14}$$

3. Force mapping method

When multiple manipulators grasp an object, the force applied by multiple robots can be decomposed into motioninducing force and internal force. In the proposed cooperative master-slave manipulation system, the internal force to squeeze the grasped object is fed into the human operator through master haptic device. Fig. 7 depicts two manipulators cooperate to grasp a single object. single force affecting on the object should be fed into the master haptic device.

4. Manipulation strategy

In Lots of previous master-slave manipulation research, whole task was done by only human operator. However, in the case of single-master and multi-slave system, there exist D.O.F differences between the master and the slave. Therefore, it is proper idea to build a whole process of manipulation with several task phases.

In this paper, human machine cooperative manipulation strategy is proposed as shown in the fig. 8. Human operator is assumed to monitor the target object under the 2-dimensional visual information on the task space. As a first phase, both slave manipulators are approached to the target object following the reference position scaled from the haptic device operated by human. Once one of both end-effectors is contacted with object, grasping phase is started. An automatized grasping algorithm leads to th stable grasp. Then, human operator make a movement of target object grasped between both end-effectors. To release object, operator needs to lead object to be touched on the ground.

The problem caused by the D.O.F difference between the master and the slave is overcomed through the proposed manipulation strategy which contains task-based phase shifting.

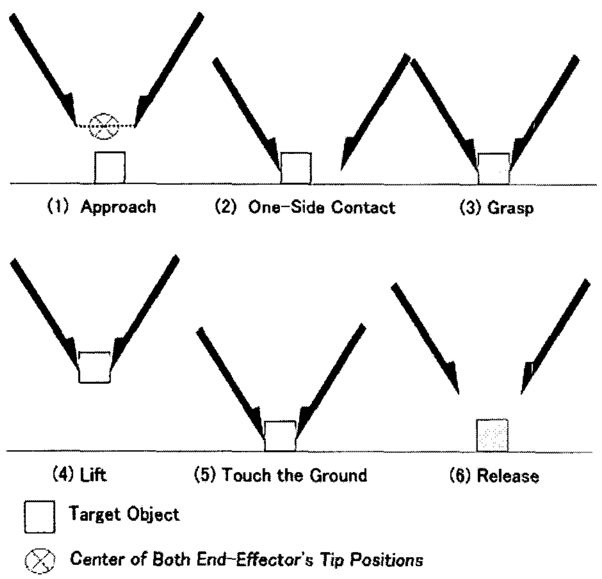


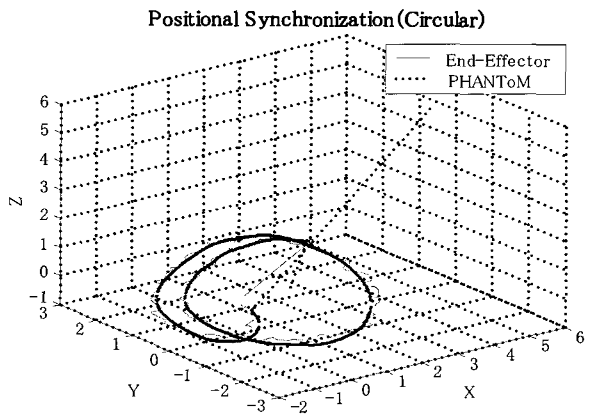
그림 8. 듀얼 메니퓰레이터의 협조방법.

Fig. 8. Manipulation strategy: (1)-(2) by haptic device, (2)-(3) autonomous, (3)-(5) by haptic device, (5)-(6) autonomous.

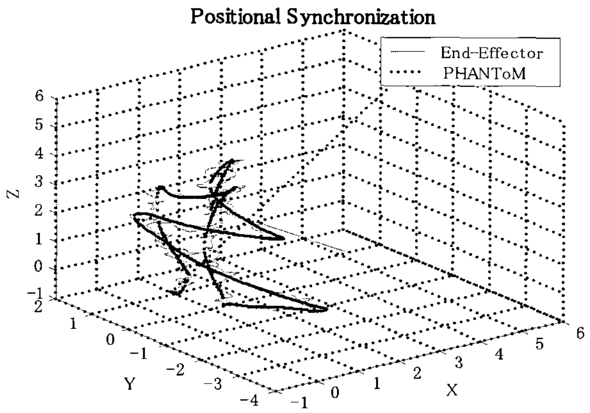
VI. EXPERIMENTAL RESULTS

1. Positioning accuracy experiment

An experiment on micro positional synchronization using our micromanipulation system was conducted. User operates PHANToM device with 3D random or circular trajectory. This PHANToM reference trajectory generated by the human operator is containing the scale factor between the master and the slave. The trajectory of the PHANToM ref and the result trajectory of both end-effector's center position is shown in the fig. 9.



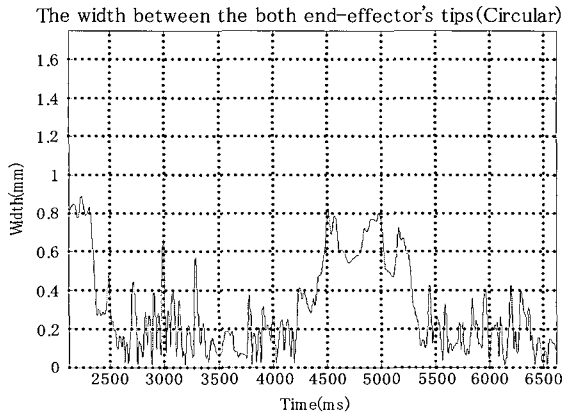
(a) Circular movement.



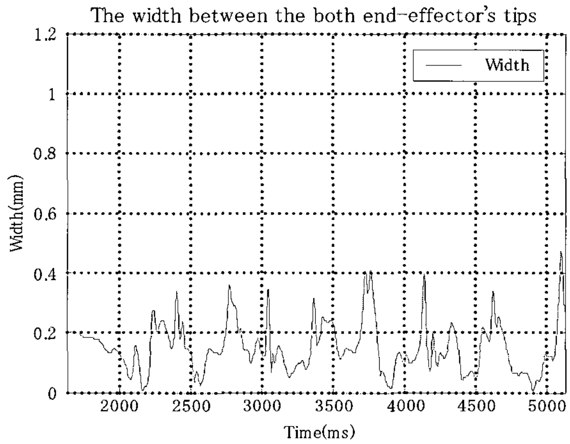
(b) Random movement.

그림 9. 위치 동기화 실험.

Fig. 9. Positional synchronization experiment.



(a) Circular movement.



(b) Random movement.

그림 10. 두 end-effector 팁 위치간의 폭.
Fig. 10. Width between both end-effector's tip position.

표 1. (A), (B), (C) 작업에 대한 평가.
Table 1. Succeed rate evaluation: (A),(B),(C) subjects.

	Proposal	Normal	Chopstick	Tweezer
(A)	3/7	3/9	3/5	3/3
(B)	3/6	3/8	3/3	3/3
(C)	3/7	3/9	3/5	3/4
(D)	9/20	9/27	9/13	9/10

We generated two different trajectories which are circular and random motion with single master device. Then the following trajectory of both slave end-effector's center position is depicted as red line. The validity of our proposed positional mapping method in real time operation is verified with this result. Through the result in the fig. 10, both slave end-effectors are kept in a certain width during the experiment. The reference trajectory by single master device is controlling two slave devices without coupling them. These results strengthen the feasibility toward the single-master controlled multi-slave system.

2. An experiment on force mapping method

Several experiments were made to verify how feasible for us to adopt the decomposed internal force derived in the section 4. Another purpose of this experimentation is to obtain

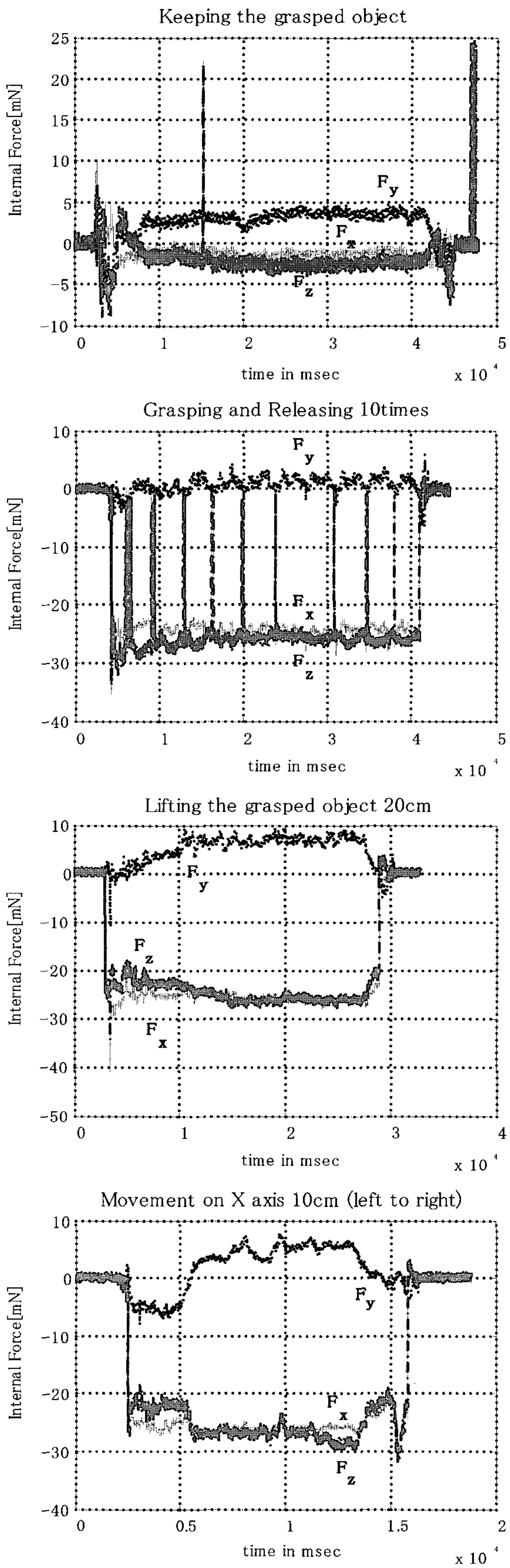


그림 11. 조작자에 의한 내부힘 패턴.
Fig. 11. Decomposed internal force pattern of human operator's grasping.

그림 12. Salmon roe의 픽-앤-플레이스 스크린(line 1-2), 트위징 주입(line 3-4) 실험.

Fig. 12. Screenshots of salmon roe pick-and-place(line 1-2) and tweezing injection(line 3-4) experiment: (from top left to bottom right: approach – grasping – pick – place – cell injection).

the desired internal force for stable grasping during several primitive tasks. A square styrofoam block which has ten mm in width, length, and height was used in this experiment. Fig. 11 shows the internal force plotted on several grasping phases such as keeping the grasped object, parallel movement, and 10 times iterative grasping/ releasing. Transferring force to the human operator gives the teleoperation more trasnparency strongly related with human operability and the task performance. It is known that the reasonable choice of the internal force during the grasp phase should be made around the 5mN on grasping direction(F_y). Fig. 11 shows the internal force distribution in these several cases conducted in this experiment.

- Keeping the grasped object
- Grasping and releasing 10 times
- Lifting the grasped object 20cm
- Movement on X axis 10cm

As shown in fig 11, F_y stays around the 5mN even though task experiences touching the ground which gives excessive force F_x and F_z. These force factors (F_x and F_z) can be ignored because they does not change the grasping stability. Also, the phase transition should be done by the event which is the change of internal force around the transition phase. Especially in the iterative grasping/releasing phase, it is possibly able to be used for compensating the deficiency of the master's D.O.F.

3. Salmon roe tweezing experiment

Fig. 12 shows the salmon roe handling experiment to verify the proposal system as the surgery of soft membrane or tissue using modeled one(salmon roe). The detailed proposed control is omitted in this literature. Table 1 shows the summarized succeed rate for 3 subjects which are compared with the normal internal force feedback or chopstick manipulation (steel,ideal case) by each subject. The results show that salmon roe grasping is hard task even with the chopstick so the simple information delivered to human helps to increase the human's manipulation capability and dexterity. Human operator is considered to be not sensitive to high frequency internal force feedback which is continuous but more sensitive to classified force feedback such as "almost dropping", "stable", "excessive force" and etc. In the last, we've found that the proposed force feedback strategy let human operator to know about the information on robot's intervention to control. Therefore, this strategy improves human's operability during the human-robot shared control with SMMS system environment. An hypothesis of Ikura grasping experiment is proved by showing the adaptivity to different human's skill levels.

VII. CONCLUSIONS

This study addressed various aspects of telerobotics system. We first introduced the single-master multi-slave micromanipulation system for telerobotic surgery system whi ch can be representative as micro robot, a master-slave telerobotic system designed considering the special requirements of minimally invasive telesurgery, followed by its kinematic analysis, evaluations of singular position, and manipulability of multi slave system. Also, one of the most serious problems such as mapping method between the master and the slave was discussed. A novel micromanipulation strategy which is the most feasible for single master and multi slave system was dealt. Several experimental results were shown to verify the feasibility of the proposed method.

In the near future, more detailed experimental results to verify this manipulation strategy or mapping method will be shown. Also, the low-level controller integrating the multi robots with human will be discussed. Haptic guidance from the viewpoint of human operability and task performance should be challenging research.

REFERENCES

[1] S. S. Sastry, M. Cohn, and F. Tendick, "Milli-robotics for remote, minimally invasive surgery," *J. Robot. Auton. Syst.*, vol. 21, no. 3, pp. 305-316, Sept. 1997.

[2] J. E. Colgate, "Robust Impedance Shaping Telemanipulation," *IEEE Trans. on Robotics and Automation,* vol. 9, no. 4, pp. 374-384, 1993.

[3] T. Tanikawa and T. Arai "Development of a nicro-manipulation system having a two-fingered micro-hand," *IEEE Trans. on Robotics and Automation*, vol. 15, no.1, pp. 152-162, Feb 1999.

[4] J. A. Thompson and R. S. Fearing, "Automating microassembly with ortho-tweezers and force sensing," in *Proc. IEEE/RSJ Int. Conf. Intelligent Robots Systems*, Maui, HI, pp. 1327-1334, 2001.

[5] N. Ando, M. Ohta, K. Gonda, and H. Hashimoto, "Micro teleoperation with parallel manipulator," *2001 IEEE/SME International Conference on Advanced Intelligent Mechtronics Proc.*, pp. 63-68, July 2001.

[6] Richard P. Paul "Robot manipulators: Mathematics, programing, and control," *Cambridge*, MA: The MIT Press, 1981.

[7] T. Yoshikawa "Manipulability of robotic mechanisms," *The International Journal of Robotics Research*, vol. 4, no. 1, pp. 3-9, Dec 1985.

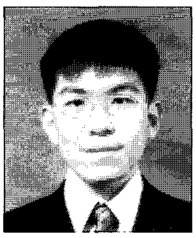
[8] R. Bonitz and T. Hsia, "Force decomposition in cooperating manipulators using theory of metric spaces and generalized inverses," in *Proc. of the IEEE International Conference on Robotics and Automation*, vol. 2, pp. 1521-1527, May 1994.

[9] E. F. Fichter, "A stewart platform-based manipulator: General theory and practical construction," *The International journal of Robotics Research*, vol. 5-2, pp. 157-182, 1986.

[10] K. Cleary and T. Arai, "A prototype parallel manipulator: Kinematics, construction, software, workspace results, and singularity analysis," *Proc. of the 1991 IEEE International Conference on Robotics and Automation*, pp. 566-571, 1991.

[11] K. Kosuge, T. Itoh, Toshio Fukuda, and Manabu Otsuka, "Telemanipularion system based on task-oriented virtual tool," *IEEE International Conference on Robot and Automation*, pp. 351-356, 1995.

[12] B. Hannoford and R. Anderson, "Experimental and simulation studies of hard contact in force reflecting teleoperation," *Proc. of 1988 IEEE International Conference on Robotics and Automation*, pp. 584-589, 1988.



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