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Development of Tele-operation system Based on the Haptic Interface

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Abstract

In this paper, we investigate the issues for the design and implementation of tele-operation system based on the haptic interface. Here, the 3-DOF haptic device and the x-y-z stage are employed as master controller and slave system respectively. In this master-slave system, the force feedback algorithm, the modeling of virtual environments and the control method of x-y-z stage are proposed.

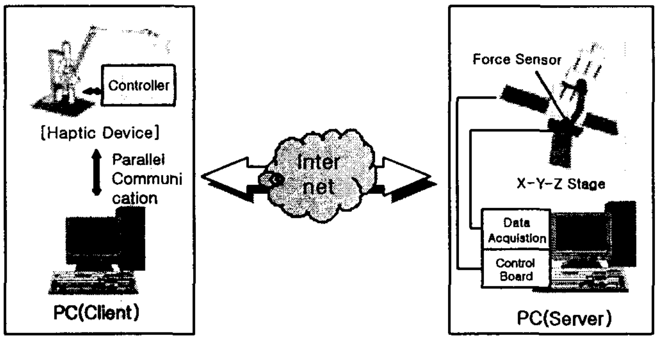
In this paper, inernet network is used for data communication between master and slave. We construct virtual environment of the real convex surface from the force-feedback in controlling the X-Y-Z stage and getting the force applied by the 3-DOF haptic device.

1. Introduction

Force-feedback technologies which can express gravity and sense of touch for an objecthave become increasingly important in the fields of tele-operation and virtual reality applications [1]. One of these applications is tele-medicine, where several successful experiments have been accomplished for the remote checkup and surgery, home care and physical therapy. Other applications of force feedback system may be the operations in hazard environments, hazard material manipulation and operations in the space and deep sea. In addition, there are e-services such as remote maintenance and monitoring of manufacturing processes, equipments and products [2].

However, for the applications of force-feedback technology via network to be widely accepted and used, some issues should be addressed and ensured. One of these is performance-guaranteed network for use. The role of the network in this system is the transfer of human sense (touch) to remote locations by feeding sensory formation back from the remote environment. In order to acquire a more realistic feeling of remote environments, the performance of it is very important and thus, warrantable performance should be given, which, in the sense of commercialization of the system, may result in cost and compatibility problems [4]. In this study, we use internet as network system with reliability, compatibility, and low price.

2. System Description



[Figure 2.1] System structure

Figure 2.1 shows the structure of our tele-operation system using haptic device. The overall system is composed of 3-DOF haptic device, controller of the device, X-Y-Z stage, control part of the stage and data acquisition part of force sensor.

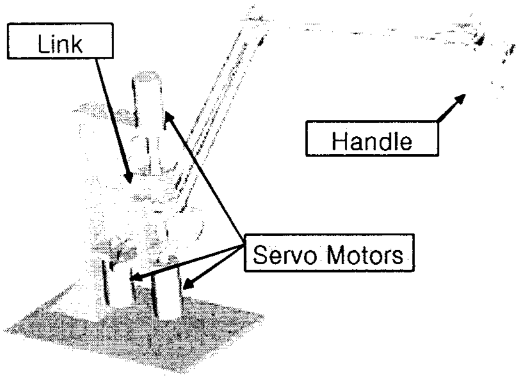
Haptic device is designed with 5 bar link structures and to control and drive it, we use C6711 DSP board for real time control. X-Y-Z stage consists of linear motors, lead screw and AC servo motor, and is controlled by PMAC controller of delta-tau company. PMAC, commonly used as a multi-axis controller, is interfaced through ISA bus of PC and can control up to 8 axes.

In this paper, we attach force sensor in the end part of X-Y-Z stage and obtain force data of each axis when end effector touch at the convex surface we made. The force data is transmitted to haptic device by network and we can feel the convex surface from the device at remote area. Also we design and implement TCP/IP socket program using Visual C++ 6.0 for data communication through internet.

This overall system consists of server and client. The server is a controller for the stage using haptic device and the client is X-Y-Z stage equipped with force sensor. If the user moves the haptic device to x-y-z direction inthe client system, control datais transmitted to the server using internet and then, the motors are driven and the stage is moved to the appropriate position [2]. When the force data of each axis at convex surface is passed by client again, user feels force at each position in haptic device.

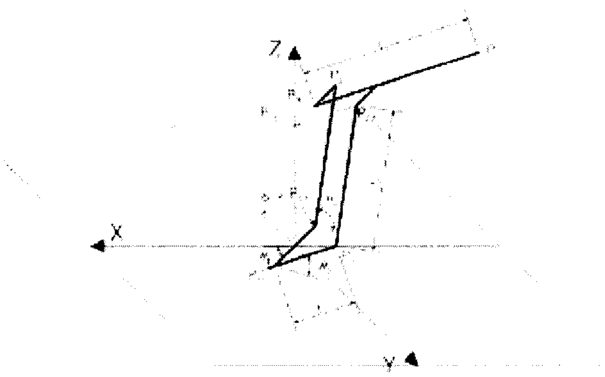
3. Client System

3.1 Haptic Device



[Figure 3.1] Structure of Haptic Device

Structure of haptic device we used is shown in figure 3.1. When we design our haptic, we consider to reduce backlash and friction force, to effect gravity compensation of the device, and to enlarge mechanical stiffness. We design five bar link structure for the haptic device and use 3 actuators for driving of x-y-z axis[5].



[Figure 3.2] Schematic diagram of haptic device

In the stage of designing haptic device, to calculate the position of the end effector, the kinematics analysis [6] is performed. When input angle of each joint is given, we calculate forward kinematics that get position of end effector. In figure 3.2, each position of the haptic device is given by

$$P_{11} = \begin{bmatrix} d\cos\theta_1 \\ d\sin\theta_1 \\ 0 \end{bmatrix} \quad (1) \qquad P_{12} = \begin{bmatrix} -d\cos\theta_1 \\ -d\sin\theta_1 \\ 0 \end{bmatrix} \quad (2)$$

$$P_2 = \begin{bmatrix} d\cos\theta_1 - l_2\sin\theta_1\cos\theta_2 \\ d\sin\theta_1 + l_2\cos\theta_1\cos\theta_2 \\ l_2\sin\theta_2 \end{bmatrix} \quad (3)$$

$$P_{31} = \begin{bmatrix} -d\cos\theta_1 - l_1\sin\theta_1\cos\theta_3 \\ -d\sin\theta_1 + l_1\cos\theta_1\cos\theta_3 \\ l_1\sin\theta_3 \end{bmatrix} \quad (4)$$

$$P'_{31} = \begin{bmatrix} d\cos\theta_1 - l_1\sin\theta_1\cos\theta_3 \\ d\sin\theta_1 + l_1\cos\theta_1\cos\theta_3 \\ l_1\sin\theta_3 \end{bmatrix} \quad (5)$$

$$P_{32} = P_2 + P_{31} - P_{12} = \begin{bmatrix} d\cos\theta_1 - l_1\sin\theta_1\cos\theta_3 - l_2\sin\theta_1\cos\theta_2 \\ d\sin\theta_1 + l_1\cos\theta_1\cos\theta_3 + l_2\cos\theta_1\cos\theta_2 \\ l_1\sin\theta_3 + l_2\sin\theta_2 \end{bmatrix} \quad (6)$$

$$P_{3c} = \begin{bmatrix} -l_1\sin\theta_1\cos\theta_3 \\ l_1\cos\theta_1\cos\theta_3 \\ l_1\sin\theta_3 \end{bmatrix} \quad (7)$$

From above equations, coordinate of end effector can be calculated as

$$P = P_{3c} + \frac{l_3}{l_2}(P_{32} - P'_{31}) = \begin{bmatrix} -l_1\sin\theta_1\cos\theta_3 - l_3\sin\theta_1\cos\theta_2 \\ l_1\cos\theta_1\cos\theta_3 + l_3\cos\theta_1\cos\theta_2 \\ l_1\sin\theta_3 + l_3\sin\theta_2 \end{bmatrix} \quad (8)$$

Also, by differentiating coordinates of equation (8) with respect to each θ, jacobian of our haptic device can be calculated as

$$J = \begin{bmatrix} -l_1\cos\theta_1\cos\theta_3 - l_3\cos\theta_1\cos\theta_2 & l_3\sin\theta_1\sin\theta_2 & l_1\sin\theta_1\sin\theta_3 \\ -l_1\sin\theta_1\cos\theta_3 - l_3\sin\theta_1\cos\theta_2 & -l_3\cos\theta_1\sin\theta_2 & -l_1\cos\theta_1\sin\theta_3 \\ 0 & l_3\cos\theta_2 & l_1\cos\theta_3 \end{bmatrix} \quad (9)$$

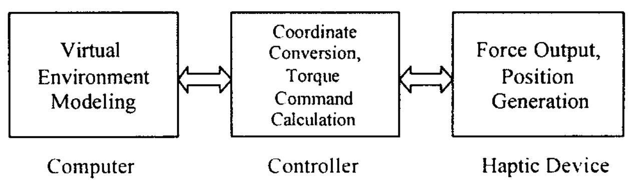
The relationship between the actuating torque from motor and the force applied to the end effector can be calculated as

$$\tau = J^T f \, , \quad (10)$$

where τ , f and J denote the actuating torque from motor, the force applied to the end effector and jacobian, respectively.

3.2 Control of Haptic Device

In order to drive and control the haptic device, we design and implement haptic controller. This controller is composed of main control board, input/output board and amplifier. We use TMS320C6711 DSP evaluation board for main control which perform control calculation and transmit output commands to I/O board. I/O board which is connected to encoder and amplifier by connector detect position of haptic device and output torque commands. Driving amplifier control torque for motor of haptic device using PWM control method.

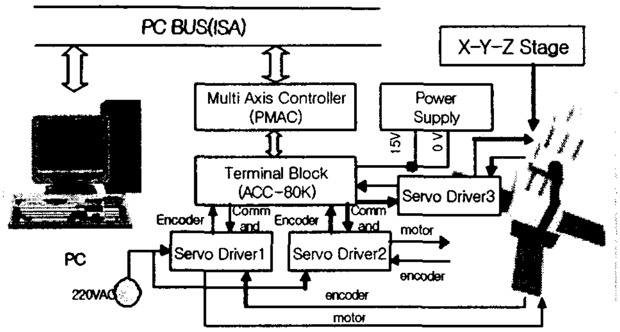


[Figure 3.3] Control block diagram of haptic device

4. Server System

4.1 X-Y-Z Stage

In this paper, to increase accuracy and decrease response time in x-y axis, we utilize a linear motor without power transfer equipment and, rotary servo motor and lead screw for z axis.

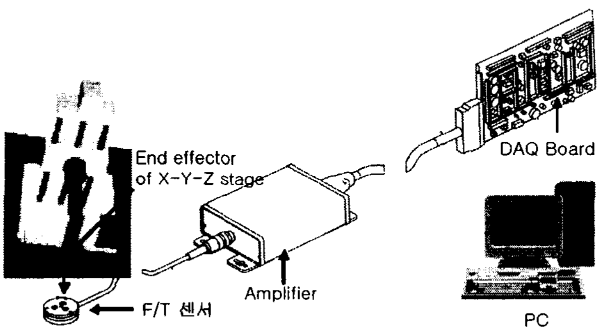


[Figure 4.1] Control system of X-Y stage

We use servo motion controller (Mini-PMAC, Delta Tau Data Systems, Inc.) which can control two axes. The configuration of the control system for X-Y-Z stage is shown in figure 4.1.

4.2 Force Sensor

We use force/torque sensor of ATI company to sense force in this server system but because are need to data in 3-axis, don't use torque data. This F/T sensor system consists of sensor, transducer, cable and DAQ board. This system is shown is figure 4.2.



[Figure 4.2] The force sensor system

5. Implementation

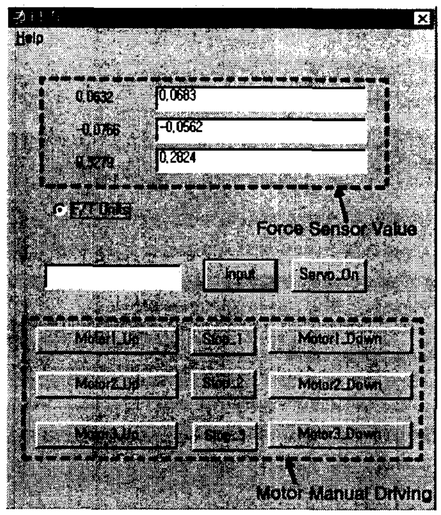
5.1 Internet and TCP/IP

In today 's world, the internet plays an important role in people's lives. It provides a convenient channel for receiving information, electronics communication and conducting business. Robotics researchers are now using the internet as a means to provide feedback for tele-operation[3]. Since TCP/IP (Transport Control Protocol/Interface Program) defines a communication protocol between different kinds of machines, it has been used widely and also become a standard protocol of Internet [7].

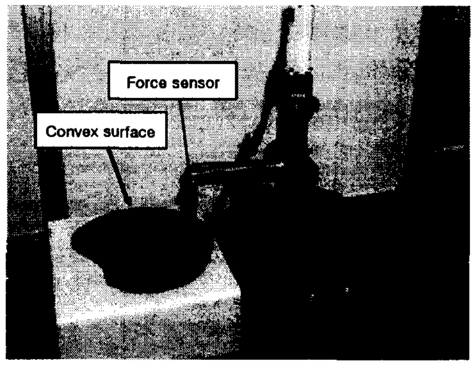
In this study, we use internet as network and selects TCP/IP as protocol. The system is compatible and can be reliable by using the open-shared network.

5.2 Server Program

The server system is connected through the internet using TCP/IP sockets and drives two linear motors into X-Y-Z directions by the commands transmitted by the client system via internet. The server program and system are shown in figures 5.3 and 5.4. We can see force sensor value and move the motor of each axis manually.



[Figure 5.3] Server program

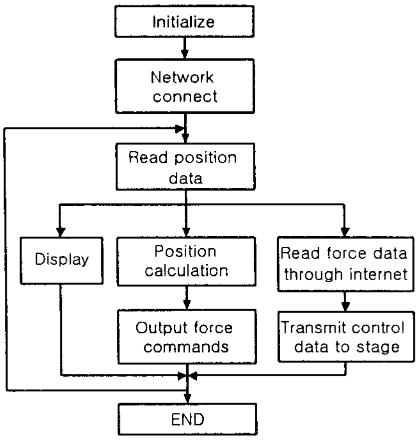


[Figure 5.4] Server system

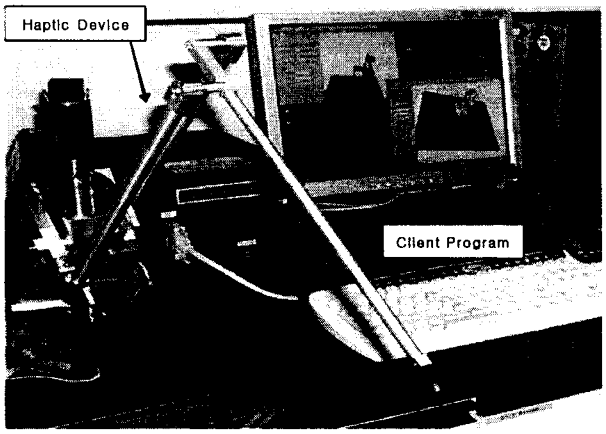
5.3 Client Program

The client program of the system is composed of three parts, *i.e.*, force calculating part of haptic device, graphic display part and TCP/IP socket part [2].

In force calculating part, using position data transferred from the controller and force data transmitted from server system through internet, force commands which we can feel at every state are calculated continuously. In graphic display part, we draw gesture of our haptic device and motion of X-Y-Z stage in remote area using encoder data transmitted through internet. In the TCP/IP socket part, we read the force data connected via internet when the force sensor of end effector touch at convex surface in client system, and send and send data for driving motors to the server via interrnet. Figure 5.5 shows the flow chart of client program.



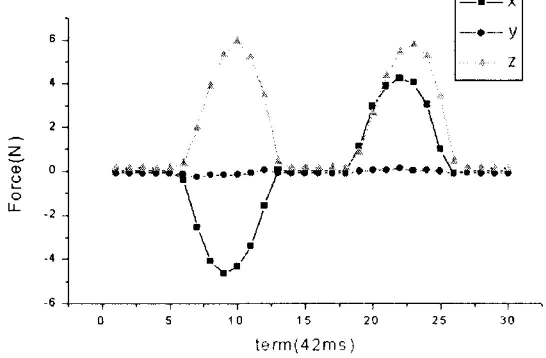
[Figure 5.5] Flow chart of client program



[Figure 5.6] Client system

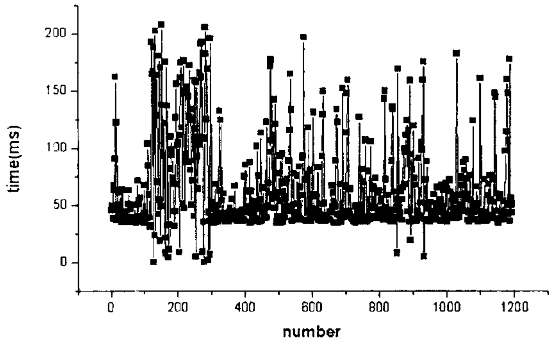
5.5 Experimental result

In this section, the experiments on the force while force sensor is moving on convex surface and the transmitting time of force data from server to client system are presented.



[Figure 5.7] The data of force sensor

The data of force sensor while end effector is moving alternately on convex surface to x direction is shown in figure 5.7. In this experiment, maximum force is 4 N in x axis and 6N in z axis. Because sensor does not receive force almost to y direction, force data is about zero in y axis.



[Figure 5.8] The delay time through internet.

And we measure time while force data is transmitted from server to client system through internet. This time graph is shown in figure 5.8 and the mean time is about 100 ms.

6. Conclusion

In this paper, we designed tele-operation system based on the haptic interface. Also, we controlled X-Y-Z stage in remote location through the internet and implemented force feedback system for the user to be able to feel elastic touch of the convex surface in local area. We proposed and implemented force feedback system using force sensor which can measure force in 3-axis.

Generally, control system through internet can be unstable because of time delay and data collision etc. In our future study, the method of the performance evaluation will be made.

References

[1] Navarro, S.F.; Ballester, E.," Operating a Robotized System Through an Ethernet Network Factory Communication Systems, 1997. Proceedings.1997 IEEE International Workshop on, pp. 267 -273, Oct. 1997

[2] Noriaki Ando, Hideki Hashimoto, evelopment of Micromanipulator and Haptic Interface for Networked Micromanipulation IEEE/ASME Trans. on Mechatronics, Vol. 6, No.4, pp. 417-427, Dec. 2001

[3] Teresa T. Ho and Hong Zhang, "Internet-Based Tele-Manipulation", Proceedings of the 1999 IEEE Canadian Conference On Electrical and Computer Engineering, pp.1425-1430

[4] Grigore C. Burdea, "Force and Touch Feedback for Virtual Reality", John Wiley & Sons, Inc., pp. 199-224, 1996

[5] D.S.Kwon, K.Y.Woo, S.K.Song, W.S.Kim, H.S.Cho,H.S.Cho," Microsurgical telerobot system Intelligent Robots and Systems, 1998. Proceedings. 1998, IEEE/RSJ International Conference on , Vol. 2, pp. 945 -950, Oct. 1998

[6] Leo J. Stocco, Septimiu E. Salcudean, Farrokh Sasani, "Optimal Kinematic Design of a Haptic Pen", IEEE/ASME Trans. on Mechatronics, Vol. 6, No. 3, pp. 210-220, Sep. 2001

[7] Dong kyu Shin, etwork Programming Van Press, pp.17-43, 2002