International Journal of Fuzzy Logic and Intelligent Systems, vol. 3, no. 2, December 2003 pp. 161-165

Design and Implementation of Tele-operation system based on the Haptic Interface

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Abstract

In this paper, we investigate the issues on 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. For this master-slave system, the force feedback algorithm, the modeling of virtual environments and the control method of X-Y-Z stage are presented. In this paper, internet 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 measuring the force applied by the 3-DOF haptic device.

Key words : Tele-operation, Haptic Device, Force Control, Control thru Internet

1. Introduction

Force-feedback technologies, which can express gravity and sense of touch for an object have 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 or deep sea. In addition, E-services such as remote maintenance and monitoring of manufacturing processes, equipments and products are also fields of the application of force feedback system[2]. Also, the ability to use sophisticated and expensive manufacturing facilities by several users around the world is very cost effective[8]. Other applications relate to law enforcement. Government agencies are already using remotely operated machines in their operations to reduce human risk.

According to recent statistics, the internet has reached 100 million hosts around the world[3]. Moreover, its throughput is also constantly increasing to support multimedia sessions involving audio, video, and textual data. The internet is the preferred form of interactive communication, with new applications in multiplayer games, teleconferencing, and telerobotics being developed and tested everyday. Especially, web teleoperated games already exist where users can remotely login and operate a robot. This application will experience great advances in the next few years, once businesses realize its potential[4]-[6].

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 issues 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 information back from the remote environment. In order to acquire a more realistic feeling in remote environments, its 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[7]. In this paper, we use internet as network system for reliability, compatibility, and low price. We investigate the issues on the design and implementation of tele-operation system based on the haptic interface and present the force feedback algorithm, the modeling of virtual environments and the control method of X-Y-Z stage. And we construct virtual environment of the real convex surface from the force-feedback in controlling the X-Y-Z stage and measuring the force applied by the 3-DOF haptic device.

2. System Description

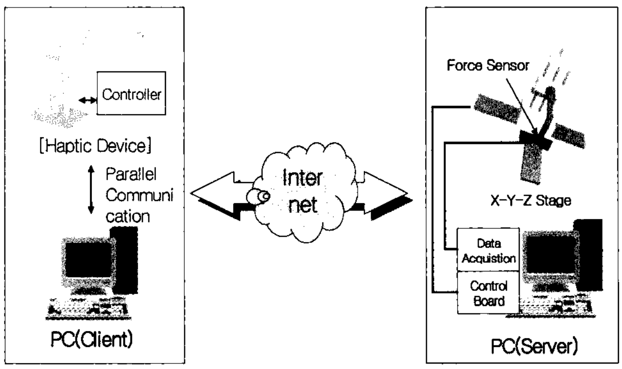

Figure 2.1 System structure

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 structure 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 the convex surface we made. For experiments 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 in the client system, control data is 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[8][9].

3. Client System

3.1 Haptic Device

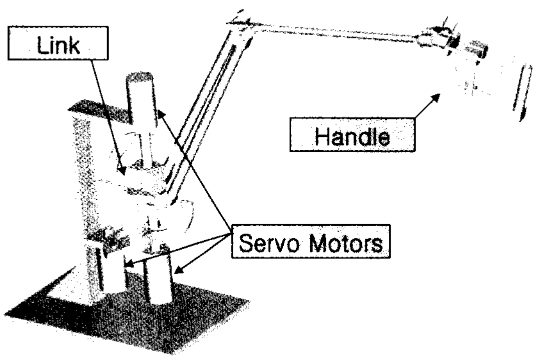

Figure 3.1 Structure of Haptic Device

The structure of haptic device we used is shown in figure 3.1. When we design our haptic system, it is considered to reduce backlash and friction force for 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.

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

$$P_{11}=\begin{bmatrix} d\cos\theta_1 \\ d\sin\theta_1 \\ 0 \end{bmatrix} \tag{1}$$

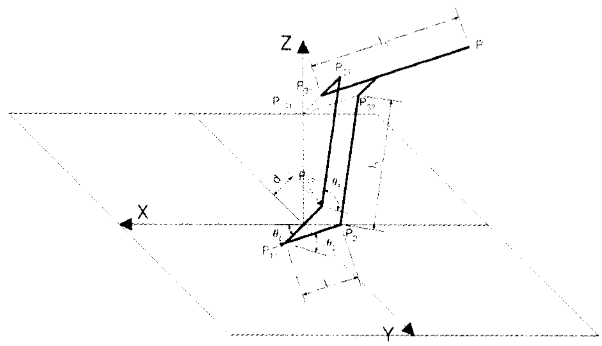

Figure 3.2 Schematic diagram of haptic device

$$P_{12}=\begin{bmatrix} -d\cos\theta_1 \\ -d\sin\theta_1 \\ 0 \end{bmatrix} \tag{2}$$

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

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

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

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

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

From the above equations, coordinate of end effector can be given as

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

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

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

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

$$[illegible]^T \tag{10}$$

where , , and denote the actuating torque from motor, the force applied to the end effector and the 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, detect position of haptic device and generates torque commands. Driving amplifier controls torque for the motor of haptic device using PWM control method.

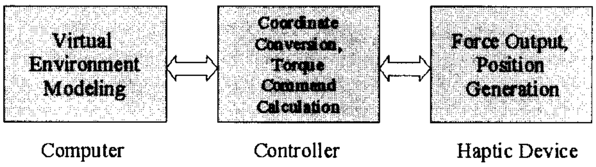

Figure 3.3 Control block diagram of haptic device

Specifications of evaluation board we use for control is as follow.

Table 3.1 Specifications of evaluation board

Item	Specifications
CPU	TMS320C6711 DSP, 150MHz
Memory	16MB on-board memory, 128KB Flash ROM
Peripheral	TLC320AD535 16-bit Data converter
Interface	JTAG1149.1 Emulator connector, Parallel port interface
Expansion	2 slot for daughter card interface
Environment	Code Composer Studio

4. Server System

4.1 X-Y-Z Stage

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

We use servo motion controller (Mini-PMAC, Delta Tau Data Systems, Inc.) which can control three 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 (F/T) sensor of ATI company to sense force in the server system. This F/T sensor system consists of sensor, transducer, cable and DAQ board. This system is shown is figure 4.2.

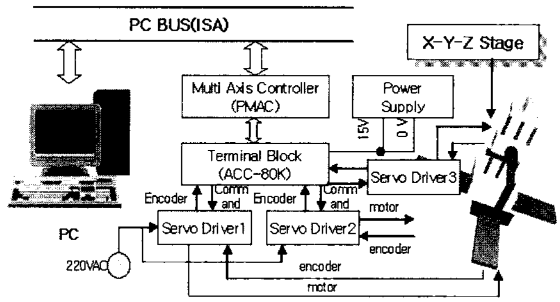

Figure 4.1 Control system of X-Y stage

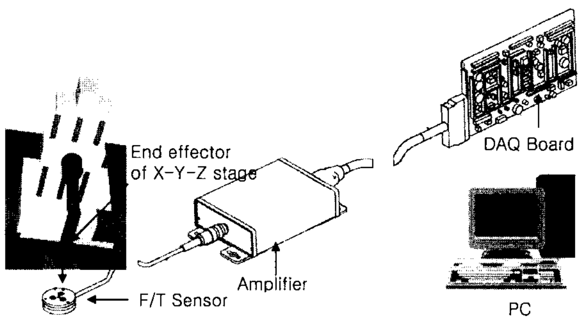

Figure 4.2 The force sensor system

5. Implementation

5.1 Internet and TCP/IP

Today, the internet plays an important role in people's life. It provides a convenient channel for receiving information, electronic communication and conducting business. Robotics researchers are now using the internet as a means to provide feedback for tele-operation[10]. Since TCP/IP (Transport Control Protocol/Interface Program) defines a communication protocol between different kinds of machines, it has been widely used and also become a standard protocol of Internet[11][12].

In this paper, we use internet as network and select TCP/IP as the protocol. Then, the system can be compatible and reliable due to the open-shared network.

5.2 Server Program

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

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.

In force calculating part, by using position data transferred from the controller and force data transmitted from server system through internet, force commands which we can feel at

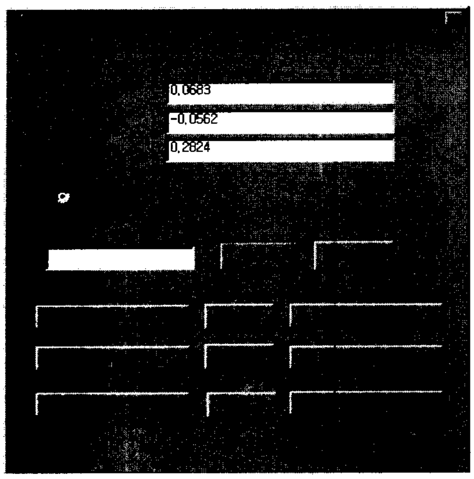

Figure 5.3 Server program

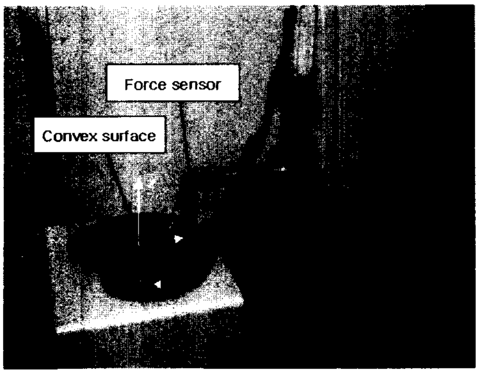

Figure 5.4 Server system

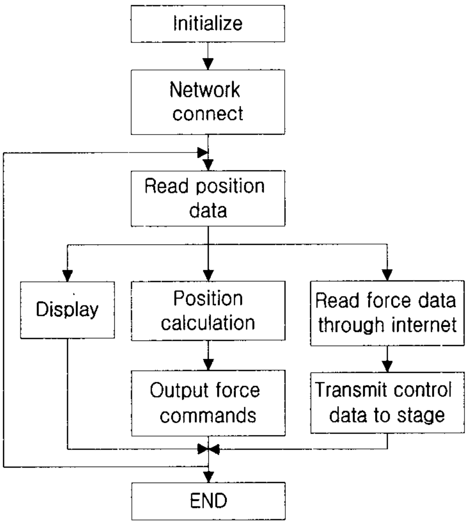

Figure 5.5 Flow chart of client program

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 the encoder data transmitted through internet. In the TCP/IP socket part, it reads the force data connected via internet when the force sensor of end effector touch the convex surface in client system and sends commands for driving motors to the server via interrnet. Figure 5.5 shows the flow chart of client program.

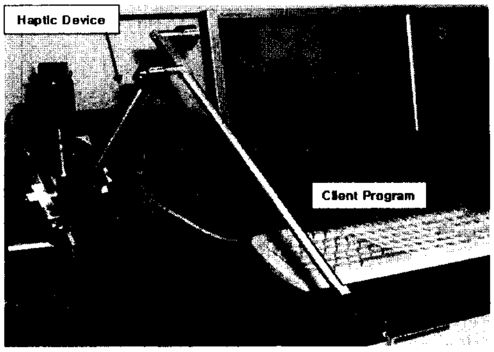

Figure 5.6 Client system

5.5 Experimental results

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

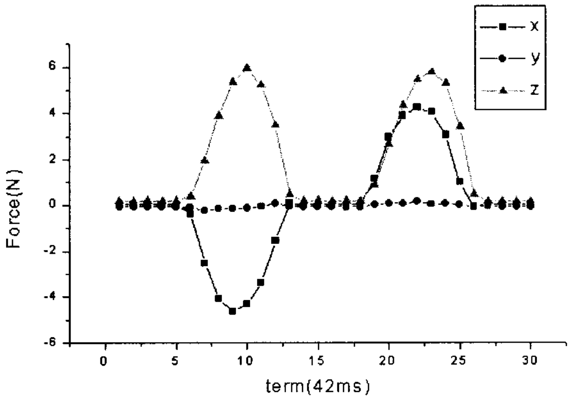

Figure 5.7 The data of force sensor

The end effector is moving alternately on convex surface toward +X direction for the first 16 seconds and X direction after 16 second. The force sensor data in each X, Y and X axis is shown in figure 5.7.

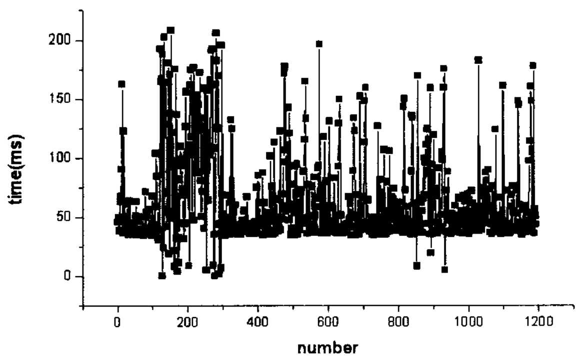

Figure 5.8 The delay time through internet.

We measure time delay while force data is transmitted from server to client system through internet. This time graph is shown in figure 5.8 and it is shown that the mean time delay 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-axes. Generally, control system through internet can be unstable because of time delay and data collision etc. In our future study, the performance evaluation according to the time delay will be performed.

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