DEVELOPEMENT OF THE VIRTUAL SHAPE MANIPULATING SYSTEM

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Abstract
In recent years, as the field of computer science highly developed, has become apparent the need for helpful devices for easier operation of computers. The visual image has a large recognition capability of and has been widely used. Although haptical information is useful for shape recognition and communication with other people, a device that provides external forces and haptical feedback is under investigation. The problem is what kind of device is suitable for human characteristics, and how to measure them. For these purposes, a Cartesian type manipulator as a force feedback device for human interface techniques has been developed. This paper reports the mechanism and control method of the manipulator.

1. Introduction

The virtual world and its manipulating method has received considerable attention from the improvement of human interface technology. One application of a human interface technology is a design process. The design process needs intelligence, experience for the objectives, kansei, representation skill and artistry. The design process consists of translation process an image object in a brain and a real object through trial & error process using a mock up model. This translation process requires experience and representation skill, and is difficult to master. However, human skills of manufacturing, sensing and manipulating seem to be very useful and have robustness. Our purpose is to replace this design process with the human interface techniques, whose key point is how to realize reality. Many researchers have approached the problem of how to realize reality concerned with the visual image's production, tactile and haptic feedback. Thus, the technology involved in realizing an adequate handling technique of virtual shapes in a computer, will be able to help the application of the human skill to the design process.

For this purpose, the virtual surface built in the computer world has to be translated in a form which man can easily recognize; that is a visual image and haptic or auditory information. However, the spatial handling feature is not homogeneous with highly non-linear somatic sensors. Such a feature has to be detected from the quantitative analysis, and adapted to a control technique of virtual form manipulating devices. From this requirement, we pay attention to use of the haptical feedback as an image of the virtual world, and develop force feedback device. This paper reports a device for measuring human characteristics. The device is a Cartesian manipulator with 6DOF, and a control method using impedance control.

2. Spatial Manipulation with arm

Movements of human spatial manipulation have many varieties depending on one's intention. In the case of a trace movement, one can smoothly travel on the objective shape as if one know what it is. In the case of precision and accuracy operation, the operator moves his/her arm slowly and stiffly and thus can manufacture and assemble intricate objects. Then the next problem is how to control a manipulator that traces arm trajectory with smoothly, quickly and with detail in real time. This problem involves various difficulties that have been pointed out from researchers in the robotics field who have developed the master and slave system. The main difficulty is generated by the operator. Namely, the stability of the systems including human characteristics in the feed back loop is hard to guarantee for quick movements. In order to guarantee system stability, operator dynamics becomes effective data. Then we measure a response of pointing operation that is a repeating manipulation on a spatial displacement. The objective features are maximum frequency, response, unstable and acceleration rate that probes the operator's arm's dynamics. In this section, we measured the maximum frequency of human hand.

3. Developed Device

3.1 Domain of objective device

The objective problem is development of a force feed back device that can detect the spatial handling features of human characteristics. For this purpose, the prerequisite conditions are as follows: the device has to reproduce as great a degree of freedom of the human arm as possible. The linear characteristic of actuators and mechanism is suitable for our purposes, because the singular point of device causes unstable action. The structure of the device must have sufficient toughness and stiffness to convey other measuring tools that detect more precise features of hand and finger. Actually, a simple mechanism satisfies the economic factors, therefor we employ a Cartesian type manipulator.

3.2. Mechanism of Manipulator

The developed manipulator is a Cartesian type that has 6 DOF at the end-effector position shown in Fig.5. To realize stiffness, toughness, linearity and economy, the manipulator uses bowl screws on parallel movement(X, Y, Z) and worm wheels on rotation(Mx, My, Mz) based on the prerequisite condition shown in section 2. The motor is an AC servo motor that moves the manipulator with high speed and precise pointing (0.01[mm/pulse]). The input device is a force sensor (6 DOF) which is set at the end-effector.

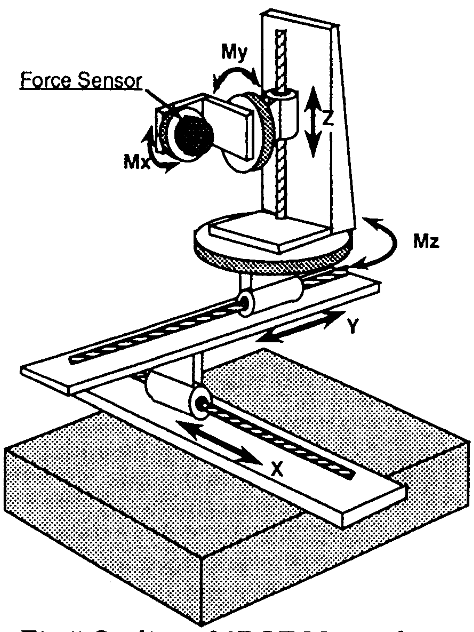


Fig.5 Outline of 6DOF Manipulator

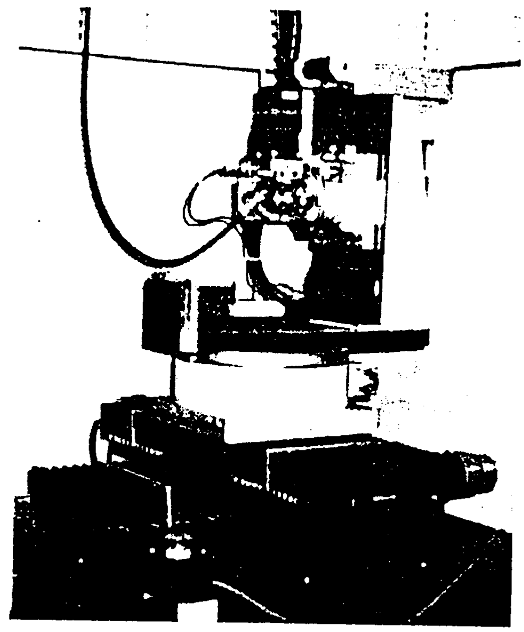


Fig.6 6DOF Cartesian Manipulator

4. Response of Manipulator

The developed manipulator behaves under both position to position (PTP) command and velocity command. This section describes the examination of responsibility of commands in the case of step input.

Examination: Maximum spent time for realizing the objective position or velocity.

Conditions : Pulse rate, acceleration rate and slowdown rate are the same for PTP command and velocity command. In order to remove an error caused by impinge shock, the servo motor is driven in lower gain mode. An external potentio-meter is used to measure the displacement of manipulator, to remove an error caused by a delay in the developed system.

Measuring system: The measuring system consists of potentio-meter, oscilloscope, controller (PC98) and manipulator. The potentio-meter is set parallel to an x direction on the manipulator. An output caused by a displacement of manipulator is recorded in the oscilloscope. Fig.7 and Fig.8 shows the outputs of the

Measurement 1. Maximum frequency with no limitation
The low data and spectrum's analysis data of Measurement 1 are shown in Fig.1 and Fig.2, where, the measured maximum frequency is 6.01Hz.

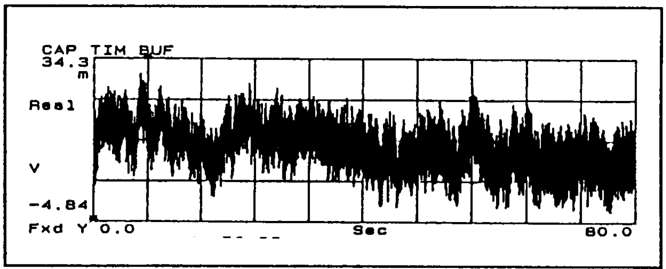


Fig.1 Low data of measurement 1

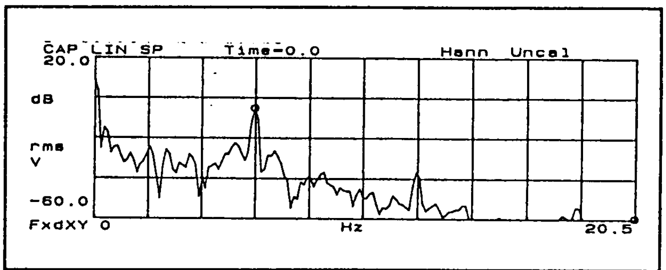


Fig.2 Spectrum's analysis data of Measurement 1

Measurement 2. Maximum frequency trying to maintain the constant amplitude (about 3cm)
The low data and spectrum's analysis data of Measurement 2 are shown in Fig.3 and Fig.4, where, the measured maximum frequency is 3.75Hz.

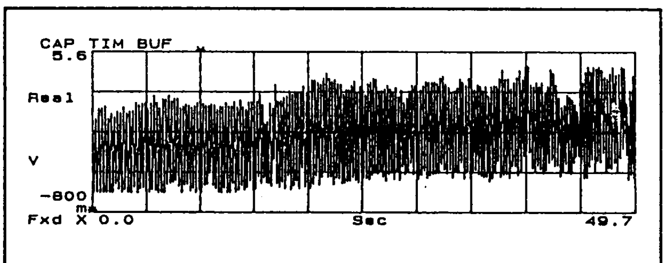


Fig.3 Low data of measurement 2

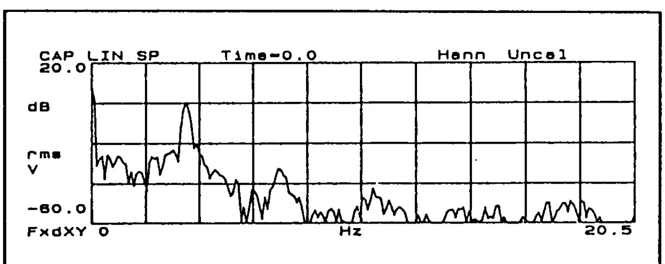


Fig.4 Spectrum's analysis data of Measurement 2

These measurements show responses of human's hand. Generally, in order to trace an oscillation by some mechanical device, the response of the device needs about 10 times of frequency of the objective oscillation. Therefore, The measurement 1 means that the response of the device needs over 70 Hz in order to trace the human's hand movement in free space. The condition of the measurement 2 is requirement to the operator processing some tasks and moving in his/her maximum frequency. Namely, such condition can be regarded as a drafting operation in a CAD environment (space). The measurement 2 means that the response of the device needs over 40 Hz to trace the human's hand movement still in the CAD space. Therefore, the desired response of the device needs less than 14[ms] in the free space and less than 25[ms] in the CAD space respectively.

potentio-meter where the trigger signal is sent from controller to the oscilloscope immediately before move command.

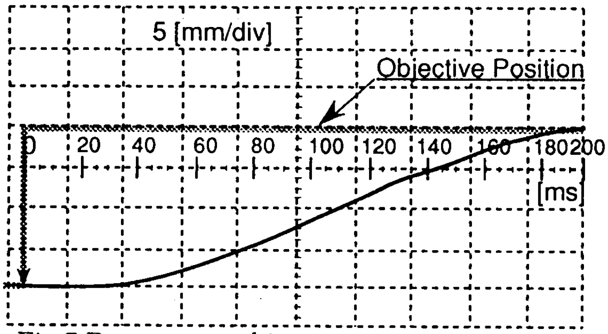


Fig.7 Response to objective position input

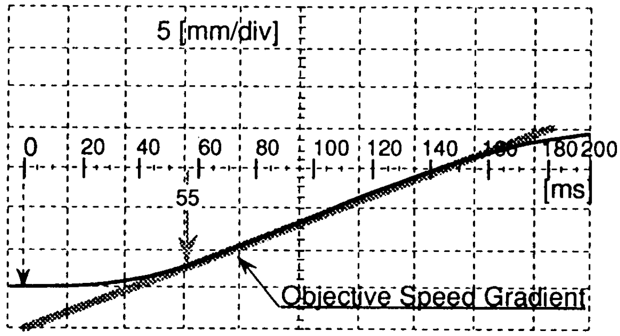


Fig.8 Response to objective velocity input

The results show that the PTP command requires 195[ms] and velocity command requires 55[ms] to achieve the objective displacement respectively. The vacant period until the motor starts are 30[ms] and 25[ms] respectively, then the response on velocity command is better than PTP command. Furthermore, since PTP command consists of start command and stop command repeatedly, the displacement is less smooth than velocity command control. For these reasons concerning response and smooth movement, velocity command for control variable was used.

5. Control Method

The force sensor located in the end-effector informs the intention of the operator (which direction one wants to move), and the objective of the control method is gentle movement along to the information from force sensor. That is the system has to be designed as including operator. The feed back loop of the proposed system consists of operator, manipulator and controller, as shown in block diagram (Fig. 9). The commands for the manipulator are discharged from the controller as an objective increment of velocity, and controller calculates it from information F of force sensor.

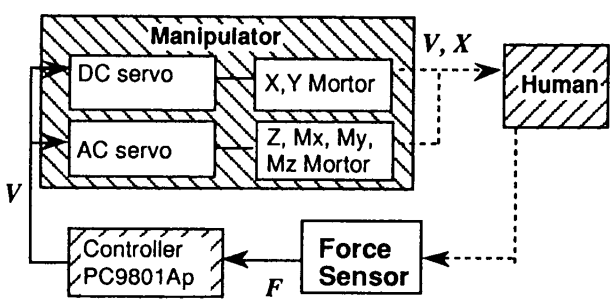


Fig.9 Block diagram of the system

The objective system needs to realize a programmable mechanical impedance control of the manipulator for the purpose that of finding a spatial manipulating feature of human characteristics. For this purpose, an impedance control based on dynamics of particles is applied. The position of the end-effector in a working space S including x, v moves with the forces those are external force F, virtual viscosity Cv and virtual restitution $K\delta x$. The standardized description of the system is eq.(1).

$$F(t)^T - G^T = M\frac{dv(t)^T}{dt} + Cv(t)^T + K\,\delta x(t)^T \qquad (1)$$

Where,

M : virtual mass.
C : viscosity coefficient.
K : restitution coefficient.
v : velocity of end-effector $v(t) = (vx, vy, vz, vMx, vMy, vMz)^T$.
δx : deviation $\delta x(t) = (\delta X, \delta Y, \delta Z, \delta Mx, \delta My, \delta Mz)^T$.
G : gravity.

$$M = \begin{pmatrix} m_x & & & & & 0 \\ & m_y & & & & \\ & & m_z & & & \\ & & & m_{Mx} & & \\ & & & & m_{My} & \\ 0 & & & & & m_{Mz} \end{pmatrix}, C = \begin{pmatrix} c_x & & & & & 0 \\ & c_y & & & & \\ & & c_z & & & \\ & & & c_{Mx} & & \\ & & & & c_{My} & \\ 0 & & & & & c_{Mz} \end{pmatrix}, K = \begin{pmatrix} k_x & & & & & 0 \\ & k_y & & & & \\ & & k_z & & & \\ & & & k_{Mx} & & \\ & & & & k_{My} & \\ 0 & & & & & k_{Mz} \end{pmatrix}$$

From eq.(1), command velocity $v(t+\Delta t)$ can be defined as eq.(2).

$$v(t+\Delta t)^T = M^{-1} \int_0^{\Delta t} \left\{F(t)^T - G^T - Cv(t)^T - K\,\delta x(t)^T\right\} dt + v(t)^T \quad (2)$$

The manipulator follows this v(t), and realizes smooth and gentle movement.

6. Application as a CAD Device

The developed system is applied as a 3D input device for a CAD environment. The used graphics terminal is a work station of silicon graphics, and the virtual surface is a 3DOF free form surface presented by Direct Deformation Method[7]. The process of the objective system including virtual surface (in the work station) is shown as a diagram in Fig.10. The work station processes position and velocity input, and it outputs collision information with virtual surface.

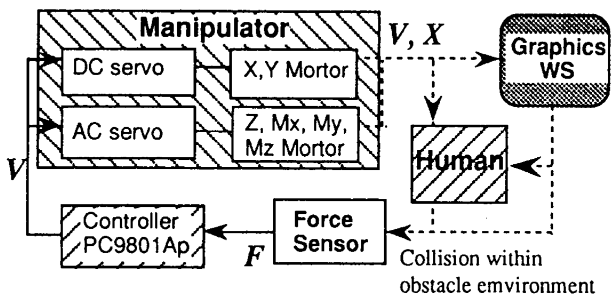


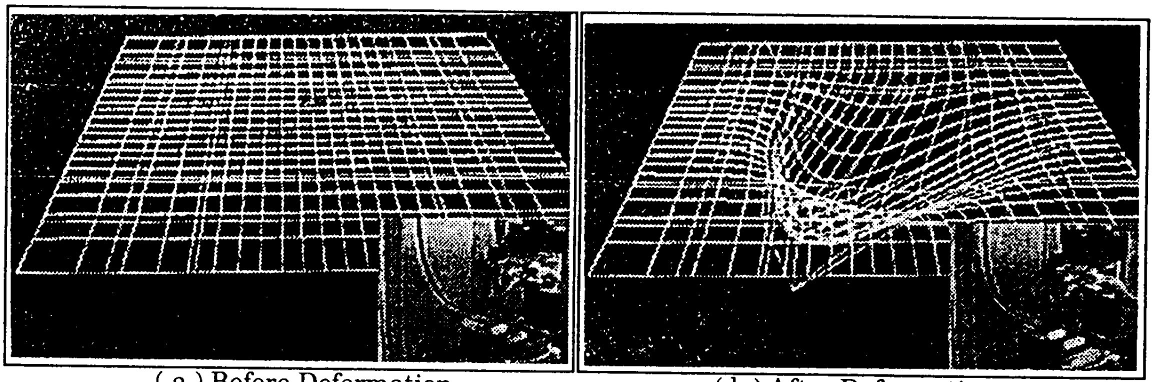
Fig.10 Block diagram of 3D CAD device system

The experiment shows a deforming process of the plan surface with pushing operation. The used manipulator is shown in Fig.6, and an example of deformed virtual surfaces is shown in Fig.11. The deforming process is shown in Fig.11 a) and b). During pushing operation, the operator feels force feed back (reaction force) through the end-effector to the operator's hand according to pushing strength. The reaction force is derived from normal vector n(t) at the point of touch on the surface and an output F(t) of force sensor. Using n(t) and F(t), the system can be written as eq.(3).

$$F(t)^T - G^T - |F(t)\cdot n(t)|\, n(t)^T = M\frac{dv(t)^T}{dt} + Cv(t)^T + K\,\delta x(t)^T \quad (3)$$

In the experiment, the velocity derived from eq.(3) realizes the deforming manipulation of virtual surface with force feedback.

However, a quick and sensitive operation causes one problem. Namely unstable movement of the manipulator is the result of discontinuous and shaking movements with resonance. This problem may be caused by the response of servo motor, non sensitive area of force sensor and feed back loop including operator. As a countermeasure, we have to detect the operator's intention and consider how to use the detected data in the control method. Then we have to tune the dynamics of the system according to the velocity of end-effector. Further research is being carried out on how to avoid such unstable behavior.



(a) Before Deformation (b) After Deformation
Fig.11 Manipulation of 3DOF Surface by Proposed System

7. Conclusion

This paper reported virtual surface manipulation system with force feed back. The developed system is a Cartesian manipulator with stiffness, toughness, linearity and economy. The proposed manipulator lets the operator spatially manipulate the virtual space with 6DOF, using a force sensor. The control system of manipulator realizes smooth movement using velocity control. As an application of the system, the deforming operation of virtual surface is shown in an experiment. This application shows the possibility of using this device as a CAD device. In the future, we plan to improve the system's response so that quicker and more sensitive operation is achieved.

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