DEVELOPMENT OF VIRTUAL TELEPHONE SYSTEM

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ABSTRACT

The virtual reality(VR) technology which is applicable not only in an image world but also in a audio and a tactile world is extremely useful. This paper deals with a newly developed telephone system applied the VR technology. For the sake of handling a receiver of virtual telephone(VT), five degrees-of-freedom serial link manipulator has been designed and manufactured. Also, in order to obtain a higher performance of operating the receiver of VT, the difference between the depth in the VR world and the depth recognized by human has been examined by the experiment. The proposed VT system would be applied to the other type of information terminal, such as a facsimile, a word processor and a personal computer.

Keywords:Virtual Reality,Telephone,Communication,CAD/CAM,Application
Topics:Artificial Reality/Virtual Reality

1.INTRODUCTION

As computer and communication technologies advance, information around human being increasingly diversified as well as complicated until terminal information equipment such as telephone, facsimile, word processor and personal computer are the part of our daily life today. Now, the growth of information by geometric progression and the deluge of terminals are eluding the command of an operator as they occupy large spaces, he find it difficult to master the controls of all those terminals which so differ from each other, and he has his limited working time.

The virtual reality technology is paid attention to an interface be-tween human being and machine [Sato et al.,1991],[Hirose et al.,1986],[Hirose,1991],[Nomura, 1991],[Loeffler,1993]. While the virtual reality technology has a variety of elements in it, one of them is to have the operator feel a virtual object as if it really existed before his eyes, and to use reactions operated to the virtual object by human as input data for a computer. The information terminals around us may be brought into a compact unification using this technology.

Now, we begin with the development of a <u>virtual telephone(VT)</u>. The telephone is an information terminal which is most simple and close to anyone in our contemporary life. First, we dug into devices necessary in operating a telephone, and next, we applied virtual reality technologies to these devices, and finally has developed a VT system.

2.DEVICES FOR VIRTUAL REALITY AND ITS CHARACTERISTICS

2.1 Input Device

As an input device of the developed VT system, a <u>5 degrees-of-freedom serial link(5L)</u> manipulator for left hand and a <u>3-dimensional magnetic(3M)</u> sensor for right hand are used.

Serial link manipulator

The 5L manipulator for measuring three dimensional left hand position of operator is adopted. Before manufacturing the 5L manipulator, the computer simulation is executed to evaluate the effective working area and the measuring positional error. Three type of manipulator named from Model-1 to Model-3 shown in Fig. 1 are assumed. Fig.2 shows both coordinates system and each parameter of 5L manipulator.

The 5L manipulator consists of three links and five joints. Each joint has a potentiometer, and rotational angle of each joints are θ, ϕ, α, β and η respectively. Using outputs from these potentiometers, the coordinate values of the center Cg of the grip at the tip of the manipulator are calculated. A push-button is mounted to the grip and it uses to control the gripping motion of the manipulator.

In calculating the positional error of the manipulator, the origin of the manipulator's coordinate system is set at its mounting center. The theoretical positioning errors are given by the equation from Eq.(1) to Eq.(9).

$$\Delta L = \frac{L_1 \cdot L_2 \cdot \sin\alpha}{L} \cdot \Delta\alpha \tag{1}$$

$$\Delta\omega = \frac{L_1 \cdot \cos\omega - L}{L_1 \cdot L \cdot \sin\omega} \cdot \Delta L \tag{2}$$

$$\Delta\psi = \Delta\phi + \Delta\omega \tag{3}$$

$$\Delta\xi = \Delta\alpha + \Delta\beta - \Delta\psi \tag{4}$$

$$\Delta\eta = \Delta\gamma + \Delta\theta \tag{5}$$

$$\begin{aligned} dXt = & \sin\psi \cdot \cos\theta \cdot \Delta L + L \cdot \cos\theta \cdot \cos\psi \cdot \Delta\psi \\ & - L \cdot \sin\psi \cdot \sin\theta \cdot \Delta\theta \\ & - L_3 \cdot (\sin\xi \cdot \cos\theta \cdot \Delta\xi + \cos\xi \cdot \sin\theta \cdot \Delta\theta) \end{aligned} \tag{6}$$

$$\begin{aligned} dYt = & \sin\psi \cdot \sin\theta \cdot \Delta L + L \cdot \sin\theta \cdot \cos\psi \cdot \Delta\psi \\ & - L \cdot \sin\psi \cdot \cos\theta \cdot \Delta\theta \\ & - L_3 \cdot (\sin\xi \cdot \sin\theta \cdot \Delta\xi + \cos\xi \cdot \cos\theta \cdot \Delta\theta) \end{aligned} \tag{7}$$

$$dZt = \cos\psi \cdot \Delta L - L \cdot \sin\psi \cdot \Delta\psi \tag{8}$$

$$d = \sqrt{dXt^2 + dYt^2 + dZt^2} \tag{9}$$

To evaluate the effective working area and positioning accuracy of the manipulator, three different types of manipulator before mentioned were examined. The condition of numerical calculation is that the link length is determined as L_1=200mm, L_2=400mm and L_3=100mm. The errors of the potentiometers mounted to each joints that is $\Delta\theta$, $\Delta\phi$, $\Delta\alpha$, $\Delta\beta$ and $\Delta\eta$ are all less than 0.1 degree.

The effective working area of three type of manipulator is shown in Fig.3. Fig.4 shows resultant maximum positioning errors obtained by the Eq.(9). In this case, the Model 2 manipulator is superior. In both figures, the Yt=500 axis of abscissas means the X-Z plane shown that Y-axis value is equal to 500mm, and both X and Z value changes from zero to 500mm respectively.

To verify the positioning accuracy of the designed manipulator, we made a jig, which can fix the manipulator at 225 positions in total intervals of 50mm in every axial direction within ranges X=-200mm to 200mm, Y=-50mm to 150mm and Z=0mm to 200mm. Here, the coordinates system is shown in Fig.9. The mounting accuracy of the manipulator connected to the jig is verified in advance at each position using a three-dimensional position measuring instrument. Fig.5 shows the angular error $\Delta\theta$. Here, L means the distance shown in Fig.2. The positioning accuracy of the manipulator designed for this system is less than

2mm, equal to the calculated value using the Eq.(9) shown in Fig.6. In this figure, symbol x shows the measured data, and real line is the result of calculation used the errors of the potentiometers from $\Delta\theta$ to $\Delta\eta$ are all 0.2 degree. This 5L manipulator is also used as a positioning device in the depth cognitive experiment.

Three-dimensional magnetic sensor

A 3M sensor called polhemus sensor was used to detect the motion of the operator while pushing the push-button on the VT system. The source is fixed at a position in the coordinates (0,320,300) as shown in Fig.9. For examining the output near the CRT, a jig used to fix the receiver at 455 positions in 50mm intervals in three axial directions within ranges X=-300mm to 300mm, Y=-50mm to 150mm and Z=50mm to 300mm was prepared, and the outputs from the sensor are measured as its fixing position is changed in sequence. A non-magnetic resin was selected as the material of the receiver fixing jig to have it not disturb the magnetic field.

The positioning accuracy of the jig was measured beforehand using a height gauge. The outputs from the 3M sensor on an Y-Z plane at X=0mm are shown in Fig.7 For the sake of comparison, the outputs when the CRT is turned on are also shown in an broken line. It is evident that within the range of Z<150mm, outputs from the sensor change widely when the CRT is turned on from when it is turned off. This is considered attributable to the sensor output disturbed by the strong magnetic field of the CRT in its vicinity.

2.2 Output Device

We employed a dual-lens stereoscopic display(SD) device to give a depth to the computer display of the VT so that it will have a stereoscopic image. The SD device displays picture images for the left and right eyes produced by a graphic display's picture images for the left and right eyes produced by a graphic work station at a speed of 120 frames per second and enabled the operator putting on a pair of liquid crystal shutter glasses synchronized with the speed to see left-eye images with his left eye and right-eye ones with his right eye, making him fell as if they had a depth.

Depth recognition with both eyes fixed

There are three factors that make a man recognize the depth of a solid [Igoshi,1988],[Ohzu,1988],[Nagata,1989].

(1)Recognition by the movement of eye-balls as they bring themselves into focus(eye-ball accommodation)

(2)Recognition by the movement of eye-ball as they rotate to make the central vision of an object being seen with both eyes(convergence)

(3)Recognition by binocular parallax S between retinal images of left and right eyes due to the difference in distances to an object from both eyes(binocular parallax)

While human see a solid, these three factors interact with each other to give you a stereoscopic image of the object. The VT system employs a method to have two-dimensional images displayed separately for the left eye and the right eye. With this method, of the above-mentioned three factors, binocular convergence(2) and binocular parallax(3) are satisfied, but the factor of eye-ball accommodation(1) may give a somewhat wrong feeling because the focus is always fixed on the CRT, that causes a gap between eye-ball accommodation to a position where a virtual object is to exist. Fig.8 shows relationship between parallax, convergence and depth recognition. The distance between the CRT and the virtual object is shown by depth Dv and is expressed by the following equation.

$$Dv = S \cdot De/(Be+S) \qquad (10)$$

$$D = Dr - Dv \qquad (11)$$

To ascertain the relationship between the theoretical depth given by the Eq.(10) and the depth a man actually recognizes, we conducted a depth measurement using the afore-mentioned 5L manipulator arranged in Fig.9. In this experiment, a pair of liquid crystal shutter glasses is set at a position where distances from the both eyes of the subject to the CRT become identical, and where the subject's visual point comes at the center of the CRT.
For measuring the depth D, the subject watches a virtual object displayed with an arbitrary parallax S on the CRT through the liquid crystal shutter glasses, moves the manipulator, and pushes the button switch at the grip at the tip of the manipulator as he feels that the grip coincides with the virtual object. The difference between the depth Dr the operator recognizes and the depth Dv given by the Eq.(10) is made a recognizing error D(=Dr-Dv). Because the structural characteristic of human eyes makes the recognizing error in lateral and longitudinal directions far accurate than the depth recognizing error, the examination was devoted to the latter.
The depth recognizing error was measured against the 18 displays of a virtual object with random S values at each point of six positions in 20mm intervals in the range of depth Dv from 100mm to 200mm. The results are shown in Fig.10. Six male adults were tested. For this experiment, the distance between pupils Be was made 60mm which is the pupil-to-pupil distance of an average Japanese male adult. The result shows that recognizing error D versus depth Dv falls within a range of 40mm. This error is considered permissible in view of the accuracy required in the depth-wise push-button operation of the VT system.
Furthermore, in this experiment, some subjects failed to recognize the virtual object as a stereoscopic image when depth Dv was over 200mm making the value of difference due to parallax S too large. This calls for the necessity not to have the image pop out too much in designing the VT system. For this experiment, the CRT display of the VT was set at the position z=100mm.

3.VIRTUAL TELEPHONE SYSTEM

3.1 Configuration of the System

The block diagram and overview of the VT system are shown in Fig.11. The configuration of this system is a personal computer(PC-9801) connected with a 5L manipulator, a 3M sensor, a telephone control circuit and a graphic work station IRIS 4D/Crimson VGX. The work station governs the overall control of the system, the 5L manipulator and the 3M sensor measure the motion of the operator, the telephone control circuit is connected to three telephones through an experimental telephone switchboard, and connects or disconnects between the system and the telephone line, and the work station produces three-dimensional picture images at a high speed.
Based on the motion of the operator measured by the manipulator and the sensor, the personal computer judges the state that is holding a receiver, or pressing the push button, and so on. Judging the motion of the operator, the personal computer sends a command to the telephone control circuit to connect or disconnect the telephone line, or the speaker, or the microphone, and at the same time, sends the basic information of the image such as the coordinate data of the telephone to the graphic work station through a RS-232C interface channel, which, based on these data, produces a left-eye image and a right-eye image.
As for the depth-wise display of a virtual object, three methods, that is how to fix head's position, how to measure eye's position and how to calibrate the distance between pupils are discussed. However, these methods were not used with the VT system that does not demand a highly accurate recognition in the depth-wise direction, i.e. whoever the operator is and wherever he sits, distance between pupils Be is always 60mm and distance between CRT and eye De is 400mm.
This convenience had no problem with the VT system that demands a less-accurate depth-wise recognition. The telephone image is displayed at a depth position

Z=100mm on the CRT. This depth position has been selected taking into consideration that somebody may fail to have the stereoscopic image of the VT at Z>200mm, that the sphere in which the receiver is operated is limited if Z is made around 150mm, and that while being operated, the manipulator may hit the CRT when Z is made smaller.
With this VT system, the mere 100mm distance between the CRT and the operating position of the 3M sensor attached to the finger tip of the operator puts the sensor under the influence of the magnetic field, and therefore, makes it impossible to raise the accuracy of the sensor in its reading the push-button operation of the operator. An error of about 50mm takes place in the measuring accuracy of the sensor at Z=100mm. Therefore, this VT system is designed so that it can judge the operation of two push buttons corresponding to the furthest position alone. Since the ordinary telephone has 10 push buttons to be judged, we have to improve the performance of the sensor in measuring the finger-tip position of the operator.

3.2 Operation of the System

When you make a call using the VT, you begin with operating its manipulator held in your left hand to pick up its receiver. You push the button at the grip of the manipulator, and you will be successful in picking up the virtual receiver if the grip center Cg is within a 40mm radius sphere of the position of coordinate (-100,50,100) where the receiver is situated, and otherwise unsuccessful. This 40mm radius has stemmed from the 40mm error in the depth-wise recognition when the VT system has its distance between pupils Be set at 60mm. You are successful in picking up the virtual receiver, then its image moves along as the coordinates of the manipulator move and you change your position, and the system is ready to accept telephone numbers you are calling.
Next, you operate the 3M sensor attached to your right-hand index-finger tip and dial the telephone numbers as you want. Due to the afore-mentioned accuracy related limitations of the 3M sensor, this VT system has only two dialing operation of either number is successful when the sensor receiver is within a 50mm sphere of its dialing coordinates. The 50mm radius margin has been decided considering that the positioning error of the 3M sensor is plus 50mm at Z=100mm, and that the depth-wise accuracy is not important because normally the operator conducts the dialing operation by moving his finger linearly in the depth-wise direction.
With the receiver coming into the 50mm radius sphere of the dial-1 coordinates, the VT system assumes that the number 1 is dialed, and its button flashes blue notifying that the number has been accepted, and the telephone No.1 that is connected through the experimental telephone switchboard is called up. Similarly, the number 2 of the telephone is dialed to call up the telephone No.2. As the line is connected, the telephone control circuit enables the microphone and speaker.
At the end of telephone conversation, you want to hang the receiver of the VT. You will be successful in it as you release the grip button of the manipulator only when the grip center Cg is within 40mm radius sphere of the position (-100, 50,100) where the virtual receiver is situated. Otherwise, you will never success. As the virtual receiver is successfully hung, the telephone control circuit disconnects the telephone line, and turns off the microphone and the speaker.
In opposition, you receive a telephone call from outside, and you will note the push button of the VT flashes red. In the same way as done in calling, you operate the manipulator and pick up the virtual receiver to connect the line.

3.3 Applications in Other Fields

As mentioned above, we have developed a VT system by applying the virtual reality technology to the telephone, an information terminal simplest and closest to our daily activity among others and familiar to everybody in the contemporary world. You can use the VT system as you do the real telephone. Moreover, one VT system can accommodate a variety of telephones in color and shape by simply changing its image.

Similarly, it may be possible to apply the virtual reality technology to other modern information terminals including word processor, facsimile and personal computer by using the input/output devices of the VT system we have developed, and further modifying the image and system control program used with the system. Now, we dare to predict that a variety of information terminals could be unified into a VT system, which would dissipate the current flood of information terminals surrounding us by taking over all of their individual jobs.

With the unified system, an approach may be possible to select a type of terminal the operator wants to use out of a variety of terminals displayed in the CRT's stereoscopic imaging space. This process could be also used for the initial calibration in obtaining the distance between pupils Be. As such, the VT system will find its expanding application to various virtual information terminals that require smooth and highly accurate depth recognition.

4.CONCLUSIONS

We summarize this research as follows. Firstly, We made a prototype 5L manipulator and conducted experiments to examine its accuracy, and have verified that the manipulator is usable as an input/output device in realizing the virtual reality. Secondly, We examined the accuracy of the commonly used 3M sensor placed in the vicinity of a CRT. We have found that the sensor loses its accuracy near the CRT.

Thirdly, We examined the usability of a SD device in displaying a virtual object, and have proposed a simple method to raise the depth-wise recognition accuracy. also, we have suggested the possibility of using this device with virtual reality systems that require a high accuracy in depth-wise recognition. Finally, We have developed a VT system using the above input/output devices, and further suggested the possibility of applying the virtual reality technology to various information terminals.

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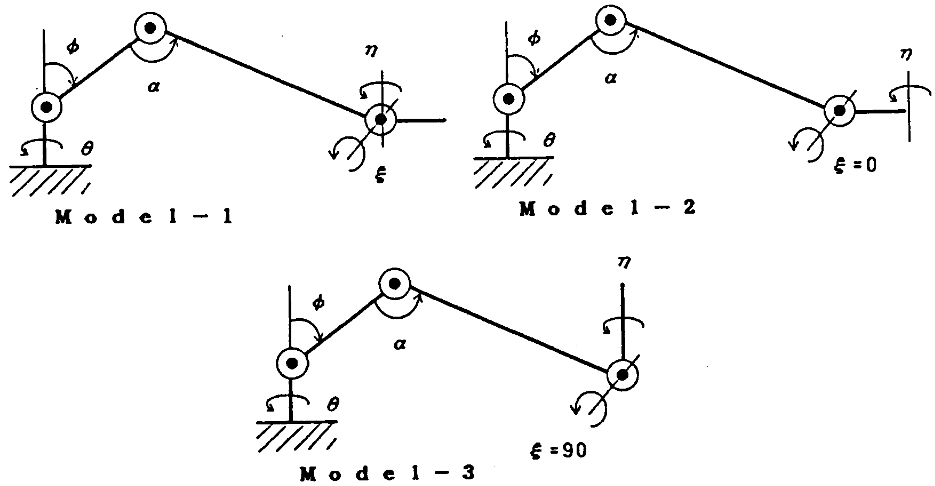

Fig.1 Skeleton of 3 kind of 5L manipulator

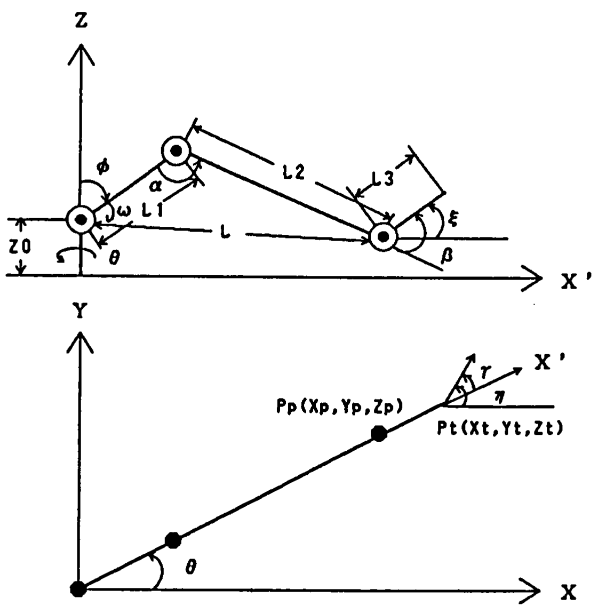

Fig.2 Parameter and coordinates system of 5L manipulator

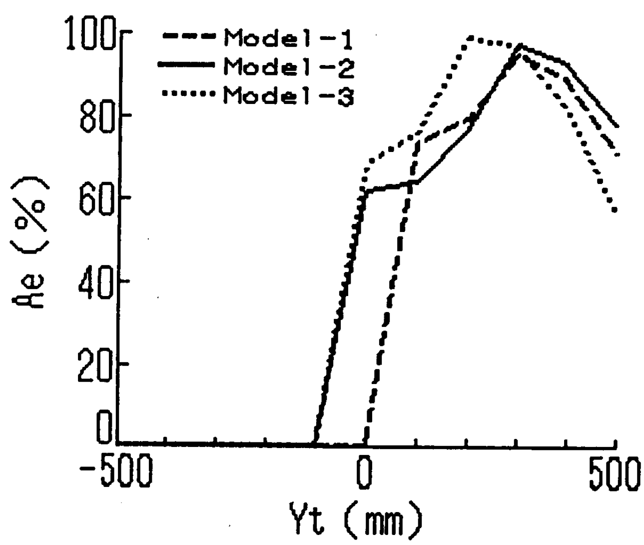

Fig.3 Calculated effective working area of 5L manipulator

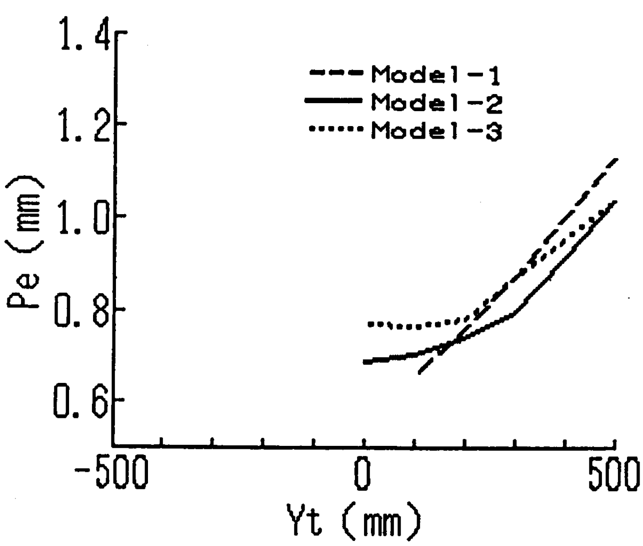

Fig.4 Calculated positioning error of 5L manipulator

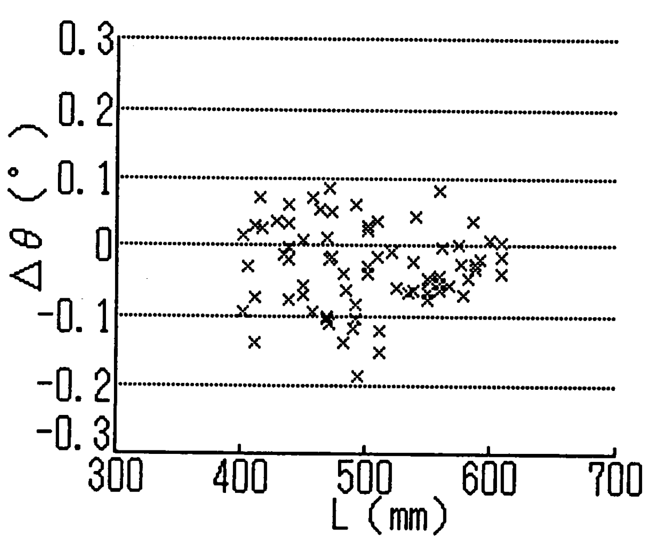

Fig.5 Measuring error of postural angle θ

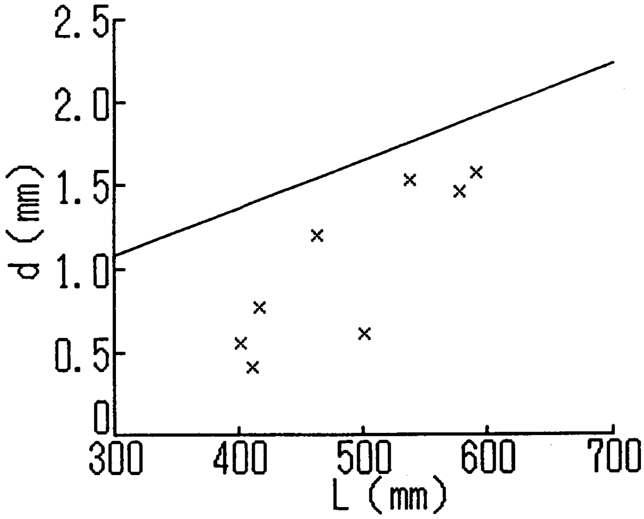

Fig.6 Comparison of experimental and calculated positioning

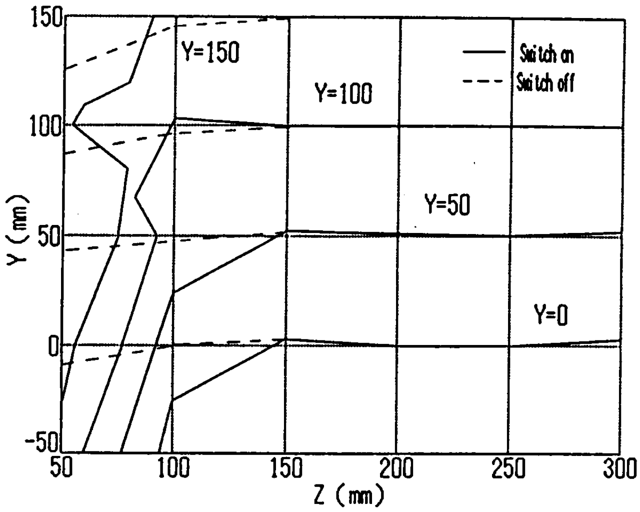

Fig.7 Outputs from the magnetic sensor error

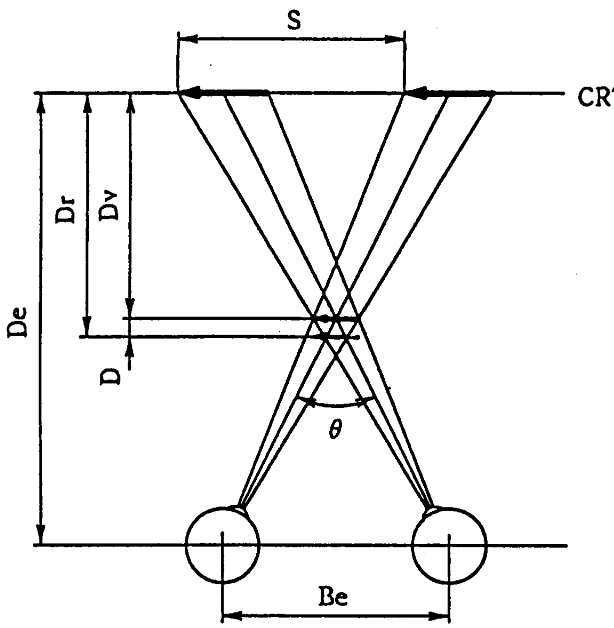

Fig.8 Comparison of theoretical and recognized depth

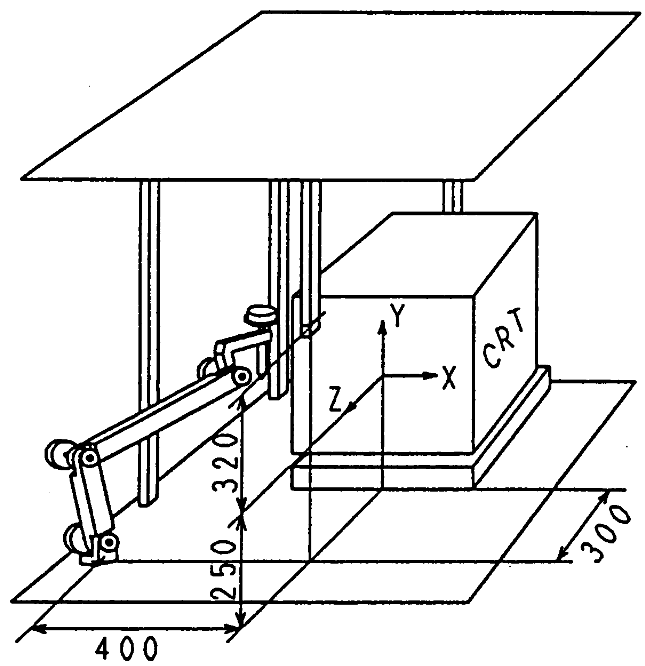

Fig.9 Experimental unit

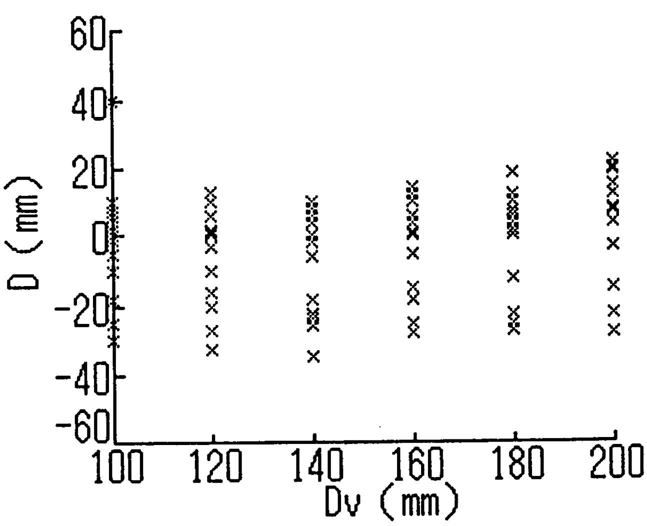

Fig.10 Recognizing error obtained from experiment

Fig.11 Overview of the VT system