AN EVALUATION OF 3-D OBJECT POINTING USING A FIELD SEQUENTIAL STEREOSCOPIC DISPLAY

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ABSTRACT

Experiments to measure user performance in 3-D object pointing using a field sequential stereoscopic display are described.

First, human performance in adjusting a random dot stereogram depth is measured to determine the possibility of pointing at a 3-D object. This experiment shows that the image displayed on the field sequential stereoscopic display can give enough depth information to its user who inputs 3-D coordinate with a mouse.

Next, user performance in pointing at 3-D objects using a mouse as an input device is measured. The target for 3-D pointing and an arrow shaped 3-D cursor are in the form of wire frames and displayed stereoscopically.

Finally, user performance using a 3-D magnetic tracking input device is tested.

These experiments show that it is possible to point at a 3-D object on a field sequential stereoscopic display with relatively high accuracy. However, pointing at objects in depth takes much more time than pointing at objects in a plane.

When a mouse is used, the required pointing time heavily depends on the direction of pointing. This tendency is due to the difficulties of depth detection using the field sequential stereoscopic display, and of manipulating a 3-D cursor with a 2-D input device. For the task tested, the 3-D magnetic tracking device was better in terms of the task completion time and error rate.

KEYWORDS: Input Devices, Stereoscopic Display, Human-computer Interaction

1 Introduction

The need for realistic image representation is increasing daily in various application fields. Much effort has been made to achieve this goal. Stereoscopic display using characteristics of binocular parallax is a familiar method to increase realism. The development of a high speed LCD(Liquid Crystal Device) shutter stereo viewer enabled stereoscopic images to be shown on one CRT display by switching the left-eye and right-eye image fields sequentially. Recently, CRT displays are used not only as simple output devices, but also as interactive devices in combination with an appropriate input device. Stereoscopic displays will provide other possibilities of interaction, such as 3-D direct modeling of real-world objects. How, one might ask, can stereoscopic displays be used as an a means of interaction?

There have been many studies of 2-D graphical interaction, especially in evaluating the performances of input devices, such as a mouse, a track ball, and so on.[1,2]. These studies have greatly contributed to designing better human-computer interaction. However, few studies have been made on combining input devices and stereoscopic displays for 3-D graphical interface.

Beaton et al. evaluated several input devices for a 3-D workstation[3]. They evaluated these devices on both a stereoscopic 3-D display and a conventional perspective display. For both types of display, "shadow lines" of the target were projected to help the subject locate the cursor in depth. Their study does not, therefore, show stereoscopic display user performance with only the binocular parallax depth cue. Moreover, such techniques cannot be used when there are many possible targets, as is the case with 3-D wire-frame direct manipulation.

Hirose et al. evaluated remote operation of a hand manipulator with remote camera stereoscopic visual feedback[4]. Their emphasis, however, was on remote control, and does not refer to other interaction possibilities.

Basic characteristics of 3-D interactive tasks need to be studied to discuss the possibilities of utilizing a stereoscopic display as an interactive device for 3-D design, coordinate input, or 3-D remote object manipulation, . For this reason, these two user skills were empirically tested: (1)basic capability of depth adjustment on a 3-D display, and (2)performance of 3-D cursor positioning using a 2-D mouse and a 3-D magnetic input device.

In section 2, a preliminary experiment using a random dot stereogram to measure human capability in adjusting the depth on a field sequential stereoscopic display is described.

In section 3, two experiments evaluating a 3-D coordinate input task and a 3-D object selection task using a mouse are described.

In section 4, an experiment similar to those of section 3, but insted using a 3-D magnetic tracking input device is described.

2 Depth Adjustment Capability

Depth cues from a stereoscopic display are mainly binocular parallax and the eye convergence angle. When observing a real object, eye focus also provides a depth cue. However, when observing a stereoscopic display, the eyes are focused insted on the display. It is quite natural, therefore, that this difference influences depth perception of CRT display stereoscopic images. If human depth perception of a stereoscopic display is vague and uncertain, then it is inefficient in determining depth or selecting a 3-D point on the display. Among the components of depth perception, relative depth comparison is important for the cursor locating task, because, depth adjustment requires relative comparison skills - to distinguish whether two objects are located at the same depth.

Experiment 1 evaluated basic depth adjusting performance using stereoscopic display.

2.1 Experiment 1.

Equipment

Fig. 1 shows the experiment's environment. It includes a graphics workstation with a high resolution(1024×768) 19 inch color CRT display, having a display rate of 60Hz non-interace. The workstation has a display buffer for the left-eye image and another for the right-eye image. An LCD shuttered stereo viewer was used to switch the images. Synchronization was carried out optically with a trigger symbol displayed in each image frame. Photo pick-ups were positioned on the display to detect the trigger symbol. These in turn commanded the viewer drive unit to switch on either the left or the right LCD shutter. The frame buffer switching rate was 60Hz.

Method

Each subject was seated in front of the CRT display and wore a stereo viewer. On the CRT display, a random dots rectangle and a white rectangle were displayed as shown in Fig. 2. Ten different random dot patterns, each with different binocular parallax, were prepared. Applied parallax was from 5 to 50 dots in 5 dot increments. This parallax caused patterns to rise up 1 cm to 10 cm. The white rectangle could be manipulated with a mouse attached to the display. When subjects moved the mouse toward themselves, the amount of parallax applied to the white rectangle increased so that it moved toward them, and when the subjects moved the mouse away, the white rectangle also moved away. Each subject was asked to match the depth of the random dot rectangle and the white rectangle. When the subjects determined that the depth of both rectangles were the same, they were to press a button on the mouse to confirm it. Each pattern was displayed three times, and six subjects, male volunteers recruited from laboratory personnel, took part in the experiment.

The system recorded the amount of parallax applied to the white rectangle when subjects pressed the mouse button. Depth matching accuracy was measured by testing whether the subjects could match the same binocular parallax of the random dot rectangle to the white rectangle by moving the mouse.

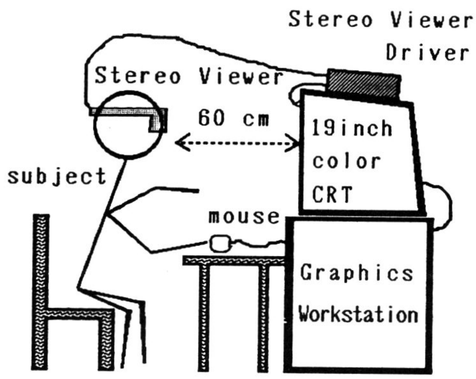

Figure 1: The Experiment's Environment

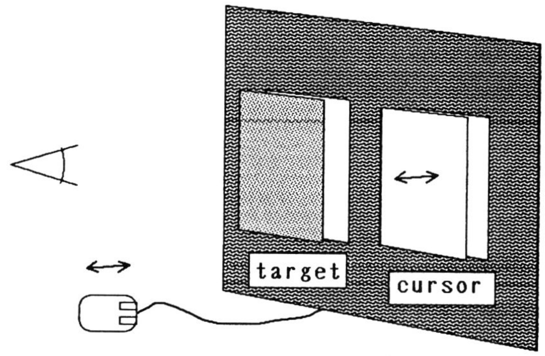

Figure 2: Experiment 1

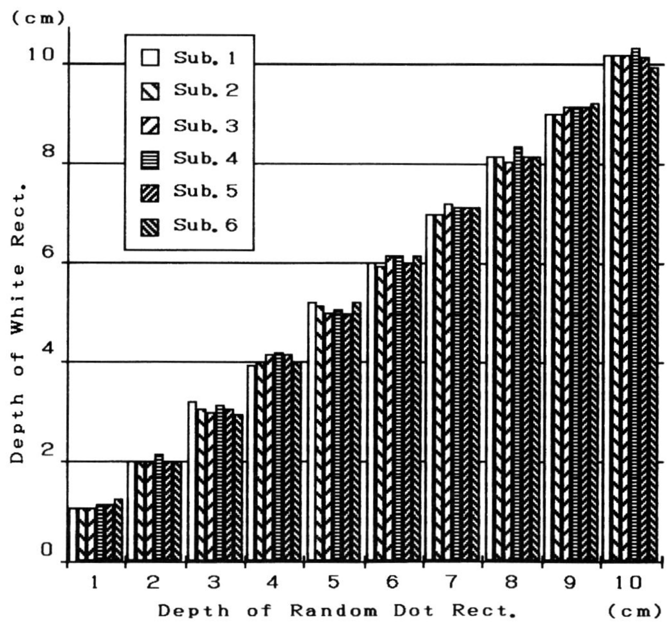

Figure 3: Results of Experiment 1

Results

The relationship between the random dot rectangle and the white rectangle parallax is shown in Fig. 3. In all depth ranges, the white rectangle was located within a 1 or 2 dot parallax error. The average adjusting error was 1.03 dot, which is approximately 2mm in depth. The result was stable for all subjects.

This experiment shows that a stereoscopic image display can give enough cues for detecting depth.

3 3-D Pointing with a Mouse

Graphical interfaces use target selection, coordinate input, and cursor locating for several applications. In conventional 2-D graphical interfaces, these tasks are called "pointing tasks." Even in 3-D graphical interfaces, such tasks are essential and can be used in many applications. These tasks will be referred to as "3-D pointing."

On 2-D displays, pointing is specifying the X and Y coordinates of a 2-D space. Evaluation of 2-D pointing is directly related to input device performance. In stereoscopic 3-D pointing, a 3-D space is mapped on a 2-D screen and depth(the Z coordinate) is encoded into a perspective view and into parallax. A 3-D pointing evaluation might have completely different results than a traditional 2-D pointing evaluation.

In this section, experiments to evaluate 3-D pointing performance using stereoscopic wireframe images and mouse are presented.

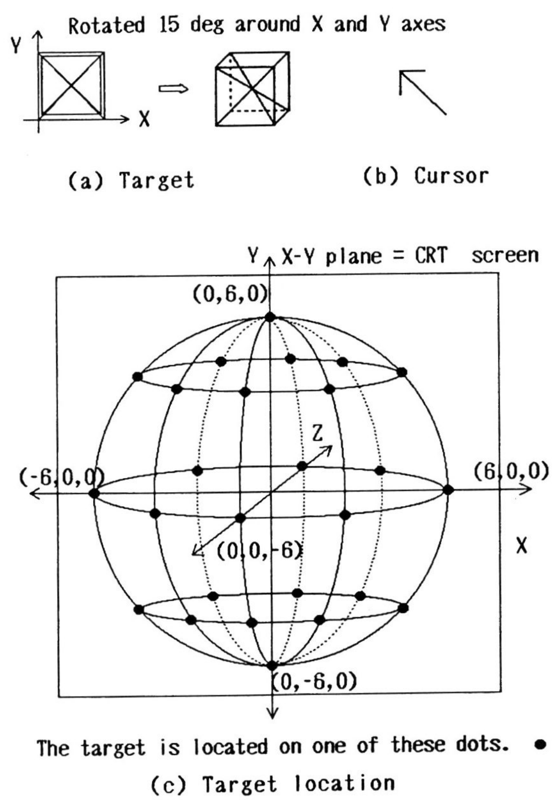

Figure 4: Target, Cursor and Target Location

3.1 Experiment 2

Target and Cursor

Two cubes, 2 cm and 1 cm, were used as targets for Experiment 2 (Fig . 4). Diagonals of the target were also displayed so that subjects could determine the center of the cube. Targets were rotated 15 degrees around the x and y axes as shown in Fig. 4. The target was located at one of 26 possible positions around the center of the display. The distance between the center of the display and the target was fixed at 6 cm.

The shape of the cursor is also shown in Fig. 4. This arrow-shaped cursor was selected among several candidates, such as a cross hair cursor and a small cube similar to the target, because the position the cursor is pointing at can be clearly understood.

Input device

There are few input devices suitable for 3-D pointing, and few evaluations of such devices have been reported. A mouse was used for the input device in this experiment because:

1. a mouse is a widely-used 2-D input device.
2. it has been evaluated as one of the best 2-D input devices for positioning and learning time[1].
3. the mouse buttons have a variety of uses.

The mouse used in the experiment is the so-called "optical mouse", which has three buttons. It is usually used to simultaneously specify 2 coordinate values. For 3-D input, the right-hand mouse button was used for controllable coordinate switching. That is, when the button is not pressed, back and forth movements of the mouse control the cursor's y coordinate values and it moves up and down on the screen. When the button is pressed, the same movement of the mouse controls the cursor's z coordinates and it moves back and forth on the screen. The left-hand button was used to confirm pointing. The subjects were requested to press it when they were pointing at the inside of the target. The center button was not used for this experiment.

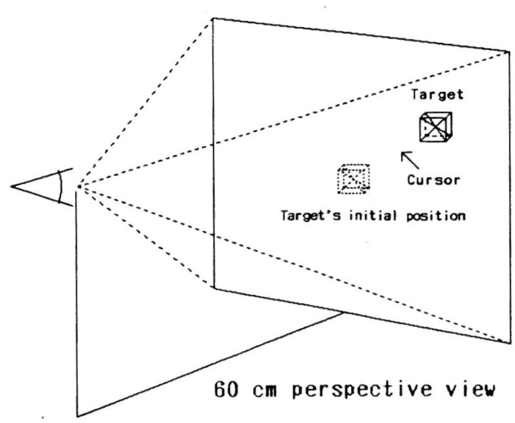

Figure 5: Experiment 2

3-D perspective view

The stereoscopic view was designed to exactly match the view of the target and cursor from a distance of 60 cm (Fig. 5). The binocular parallax was designed for an eye distance of 6 cm. The origin of 3-D space (x=y=z=0) was located at the center of the display.

Seven male volunteers from the laboratory personnel took part in this experiment. Five of these subjects also took part in experiment 1. None had prior experience with this type of experiment or 3-D pointing. However, all of them were familiar with computer equipment such as CRT displays and mouses.

The experiment was carried out using the following procedure, taking about 20 minutes for each subject.

1. The experiment was explained, and the subjects were allowed to practice moving the 3-D cursor with a mouse.
2. A 2 cm target was located at the center of the CRT screen (x=y=z=0 mm).
3. Subjects located the cursor inside the target and pressed the left-hand mouse button to confirm the cursor's location, indicating the start of a pointing task.
4. When the button was pressed, the target changed its location to one of the target positions in Fig. 4.
5. Subjects pointed at a new target, as in step 3, and pressed the left-hand mouse button to indicate the completion of the task. Thus, the task is locating cursor initially on the center to the target.
6. Steps 2 to 5 were repeated ten times.
7. Subjects were allowed to rest to avoid experiment fatigue.
8. Steps 2 to 7 were repeated ten times, for a total of 100 trials for each subject using the 2cm target. The system recorded the 3-D cursor track, the time required for each positioning, and the 3-D cursor location when the subject pressed the confirmation button. These data were then analyzed.

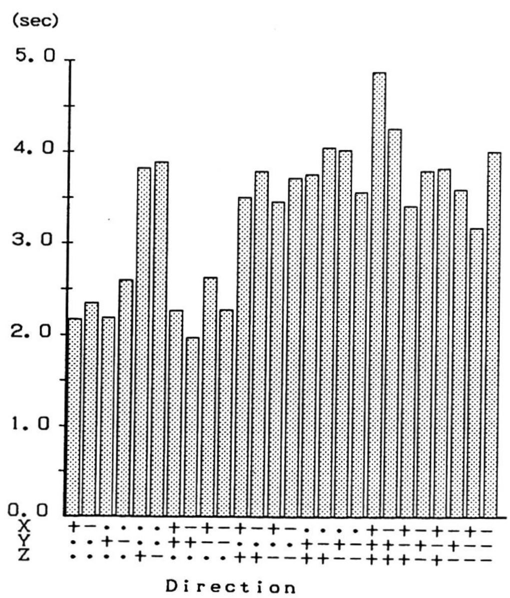

Figure 6: Mean Pointing Times for 26 Different Directions (experiment 2)

Several days later, all of the subjects repeated this experiment using a 1 cm size target.

Results

Mean pointing time for all directions is 3.20 sec (3.0 sec for a 1 cm target, 3.4 sec for a 2 cm target). Pointing at 2cm targets took slightly longer than at 1cm targets. This is because the centers of the 2 cm target were clearly designated by a diagonal line, and subjects tended to locate the cursor exactly at the center of the target rather than inside the target. Mean pointing time for all subjects and for each pointing direction is shown in Fig. 6.

The results clearly show that there was a tendency to take longer to point in the depth direction. While there was not much differences in mean pointing time between 1cm and 2cm targets, analyses of variance for each direction show that there are statistically significant differences in pointing time between pointing directions($p= 8.3 \times 10^{-17}$). These differences can easily be divided into two groups - the group where Z axis (depth) direction moves and the group without Z axis movement. The former group needed more time than the latter. Actually, the group with and without depth direction positioning needed 3.8 sec and 2.3 sec respectively.

Mean error rates for 2cm and 1cm size targets are 5.70% and 12.8% respectively. The high error rate for the 1cm size target is due to one subject who had an error rate of 27%.

3.2 Experiment 3

One of the reason depth positioning takes longer is the need to press the mouse button to select Z direction movement. Is this the only cause of the phenomena? Experiment 3 was carried out to identify why depth direction pointing required more time.

Method

The location of the target and cursor was fixed either on the X-Y plane or on the X-Z plane. The cursor only moved on the target's plane as the subjects moved the mouse in the usual 2-D pointing manner. Thus, only the left-hand mouse button was used for selection confirmation and the other buttons were not used. Subjects pointed to 100 targets on the X-Y plane as in experiment 2, then pointed to 100 targets on the X-Z plane.

Results

Fig. 7 and 8 show the mean pointing times of the X-Y and Y-Z planes respectively. The average pointing time on the X-Y plane was 1.43 sec, and 2.21 sec for the X-Z plane. On each plane, there are no significant pointing time differences between directions. The average error rate was 2.6% for the X-Y plane and 17.8% for the X-Z plane. The high error rate of the X-Z plane was due to one subject having a 34% error rate. If this subject's data is subtracted, the error rate becomes 15.0%.

4 3-D Pointing Using a 3-D Tracker

In the previous experiments, it was shown that using a 2-D pointing device requires more pointing. Can this extra pointing time be reduced by using a 3-D direct input device? In this section, a 3-D magnetic tracking device is used to control the cursor position on the CRT screen.

This tracking device consists of three magnetic field generating coils packed into one module(magnetic source), three orthogonal magnetic field detecting coils also in one module(magnetic sensor), and a control unit[5]. The control unit drives source coils sequentially and simultaneously measures the signal strength detected by the sensor. The unit calculates the position of the sensor relative to the source 60 times per a second.

The starting point is set at a certain position. When the sensor is located at this position, the 3-D cursor located at the center of the display. Any movement of the sensor is mapped by the movement of the 3-D cursor, and the user of the system can directly locate the cursor by moving the sensor to the desired position. A 1cm movement of the sensor causes the cursor to move exactly 1 cm.

4.1 Experiment 4

Method

Six subjects followed the same procedure as in experiment 2. Again, 1cm and 2cm targets were tested. The subjects were asked to attach the sensor to their index finger. They were allowed enough practice to get accustomed to this unfamiliar input device. To confirm the selection, they were to press a button with their left hand. The other conditions of the experiment remained the same.

Results

Mean pointing times over all subjects were 2.0 sec for 2 cm targets and 2.4 sec for 1cm targets. Mean error rates over all subjects for 1cm and 2cm target were 3.5% and 6.17% respectively. Fig. 9 shows mean pointing times for 1cm and 2cm targets for each of the 26 directions. There were no significant differences found between the pointing times of these directions, though X direction moves were slightly faster than the others.

5 Discussion

The results of experiment 1 show that it is possible to use stereoscopic 3-D display as a method of 3-D interaction with computers. The results of experiments 2, 3 and 4 are now discussed.

Comparison with 2-D pointing

The average pointing time in experiment 2 (3.2 sec) is about twice as long as 2-D pointing time using a mouse (approximately 1.4 sec as reported in [1]). The results of the 3-D tracker is better and about 1.6 times faster than 2-D pointing. Whether the pointing times evaluated in these experiments are fast enough depends on the 3-D application. If we point to a 3-D coordinate with orthogonal displays, as are used in many CAD/CAM applications, at least two 2-D pointings (eg. pointings in the front and side views) are required. Therefore, the performance measured here indicates that it is reasonable to use 3-D pointing, even when using a mouse as the input device. Using a 3-D input device such as the 3-D tracker will improve the user performance of such tasks.

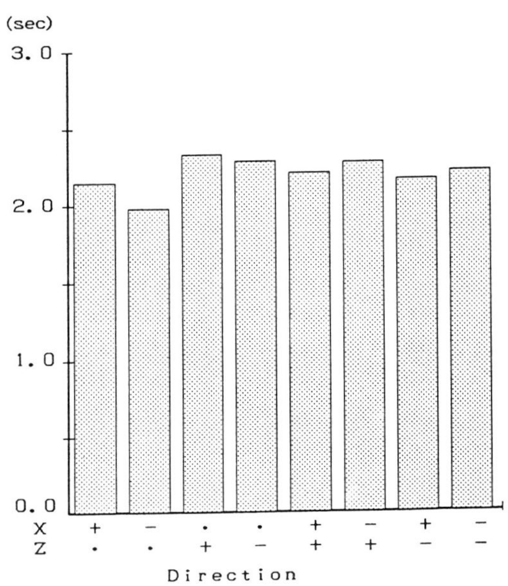

Figure 7: Mean Pointing Time of Experiment 3 on the X-Z Plane

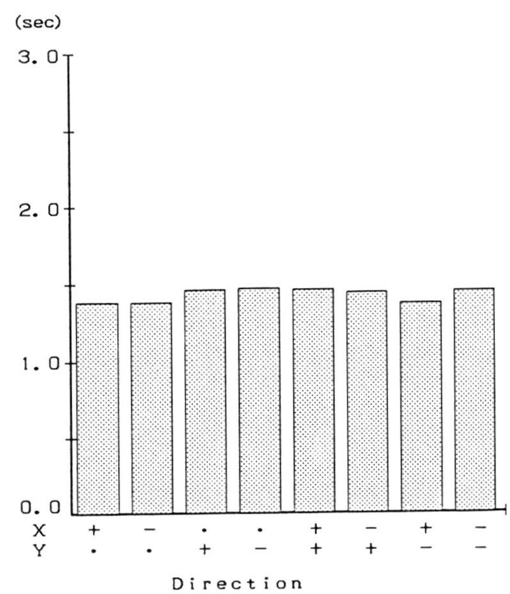

Figure 8: Mean Pointing Time of Experiment 3 on the X-Y Plane

Directional dependency

The results of experiment 2 show that pointing in the depth direction takes more time than in other directions. There is a statistically significant difference between the pointing times when the Z coordinate value is zero and not zero. The following two hypotheses could be reasons for this tendency:

1. A mouse button was assigned for coordinate selection - an operation that is more complicated than 2-D pointing.

2. It is difficult to adjust depth direction with a stereoscopic display.

If this tendency is due only to hypothesis 1, the results of experiment 3 would not differ between the X-Y and the X-Z planes. If only hypothesis 2 is true, the results of experiment 3 would not differ from these of experiment 2 for each direction. However, the actual results of experiment 3 show that:

(a) The X-Y and the X-Z planes recorded different performances.

(b) The performance is better than that of experiment 2 on both planes and in every direction.

Therefore, these results support both hypotheses. Moreover, the fact that there was a subject who had a high error rate shows that depth adjusting difficulties vary between individuals.

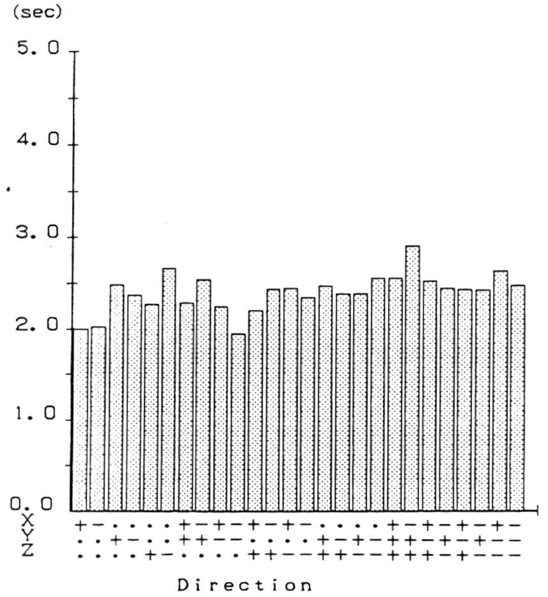

Figure 9: Mean Pointing Time of Experiment 4(1cm target)

3-D tracker vs. Mouse

The results of experiment 4 show that the device with 3 degree of freedom can reduce pointing time and error. In experiment 4, there were no significant differences between performances for each pointing direction. The readers may think that the pointing on the X-Y plane should be faster than the other directions, as it was in experiment 2. Actually, it isn't because the input device has 3 degree of freedom and the subjects had to adjust cursor depth, even when pointing at objects on the X-Y plane where no Z movements are required. Fig. 10 shows typical cursor trails recorded by the system using a mouse and a 3-D tracker. This figure clearly shows that the subject controled the X-Y axis and depth separately when using the 2-D mouse. On the other hand, he moved the three axes simultaneously when using the 3-D tracker. This considerably reduces the directional dependency of the performance.

Other considerations

In our experiments, no feedback was given to help the user locate the cursor. With appropriate feedback, such as changing the cursor color when it goes inside the target, pointing performance would be improved. Although the 3-D tracker was superior to a mouse in these experiments, it requires the user to hold it's sensor in the air. Some subjects complained of this unusual arm positioning. A better way to hold the sensor is necessary to effectively use this type of input device. Some trigger input like mouse buttons will also improve the usability of the device.

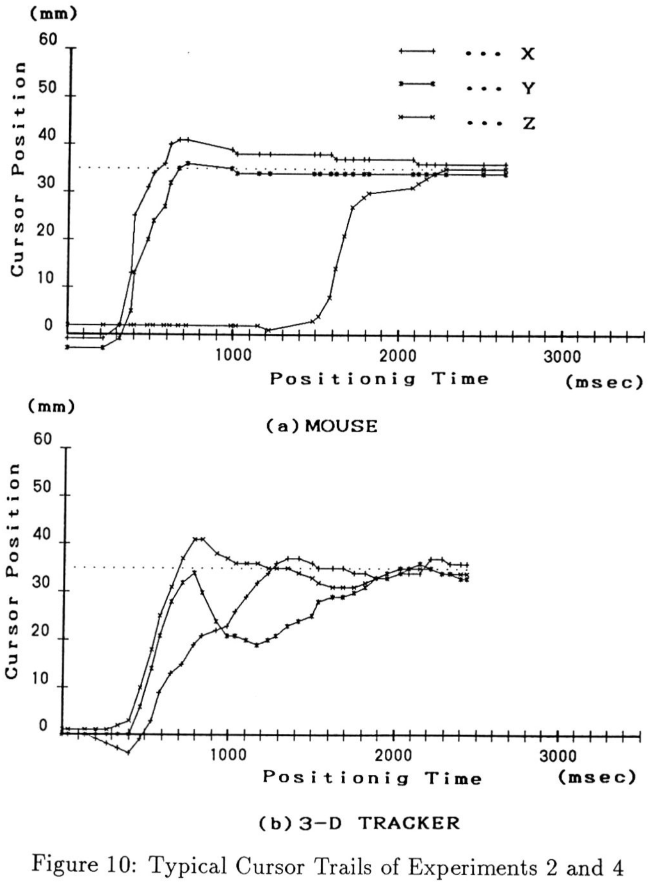

Figure 10: Typical Cursor Trails of Experiments 2 and 4

6 Conclusions

We have evaluated human performance of 3-D pointing using a field sequential stereoscopic display as an output device, and a mouse and a 3-D magnetic tracker as an input device.

The results of our experiments show that:

1. A field sequential stereoscopic display gives enough depth cues to match a certain depth within a 1 or 2 CRT dot accuracy.
2. Although 3-D pointing on a stereoscopic display takes longer than conventional 2-D pointing, the measured difference is not so large as to preclude its use in other applications.
3. There are substantial difficulties in depth adjusting, and pointing in depth direction takes longer than in other directions.
4. Coordinate selection using a mouse button also increases pointing time.
5. For the experiment's tasks, using a 3-D tracking device improved pointing efficiency.

Therefore, to improve the performance of 3-D pointing, further studies should be made toward the development of a method that reduces the depth pointing difficulties and toward the development of better 3-D input devices.

Acknowledgments

The authors wish to thank Mr. Koichi Yamashita - president of ATR Communication Systems Laboratories, and Dr. Kohei Habara - executive vice president of ATR International (chairman of the board of ATR Communication Systems Laboratories), for their thoughtful advice and encouragement on this research also, the authors wish to thank those who voluntarily took part in the experiments.

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