

PAPER

Virtual 3D Gearbox Widget Technique for Precise Adjustment by Hand Motion in Immersive VR

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SUMMARY Direct manipulation by hand is an intuitive and simple way of positioning objects in an immersive virtual environment. However, this technique is not suitable for making precise adjustments to virtual objects in an immersive environment because it is difficult to hold a hand unsupported in midair and to then release an object at a fixed point. We therefore propose an alternative technique using a virtual 3D gearbox widget that we have designed, which enables users to adjust values precisely. We tested the technique in a usability study along with the use of hand manipulation and a slider. The results showed that the gearbox was the best of the three techniques for precise adjustment of small targets, in terms of both performance data and subject preference.

key words: *immersive environment, gearbox, hand direct manipulation, user interface evaluation, precise position adjustment*

1. Introduction

Two-dimensional applications using graphical user interfaces (GUI) are used by many people, both professionals and amateurs. Three-dimensional immersive VR (virtual reality) applications, however, are still mainly used by professionals. This is partly because it is more difficult to do 3D authoring than 2D. It is usually necessary to use 2D GUI tools when authoring 3D animation content, even when authoring an immersive environment. However, it is difficult for novices to manipulate 3D objects and navigate freely in 3D space using 2D GUIs. Therefore, 3D manipulation using conventional tools requires familiarity with 2D GUI interfaces for 3D operations, although authors are unable to exploit immersive 3D space in authoring 3D contents.

We believe that an immersive virtual environment offers the 3D content author a familiar, simpler, and more efficient way of producing content, requiring less technical skill and specialized knowledge (e.g. of 2D GUI tools for 3D operations). It is easy to change the position of virtual objects in an immersive space by directly manipulating them by hand. This action is similar to the way we manipulate objects in real life, so authors do not need a lot of specialized knowledge and skill. This would put 3D authoring within the reach of amateurs as well as professionals. However, making fine adjustments by hand is difficult without physically supporting the hand because it is difficult to hold an unsupported hand still in midair and release an object at a

fixed position. A slider is often used in GUIs to control the coordinates, but this is unsuitable for precise adjustment in an immersive environment since it is also difficult for an unsupported hand to move a slider knob precisely.

We therefore developed a gearbox widget with multiple interconnected dials that enables us to make both large and fine adjustments to values. It was implemented as a gearbox widget in the “it3d” class library [12], which is a Java class library for 3D applications. In this widget, multiple gears are interconnected and the programmer can specify the ratio of outer gears to inner gears. The appearance of the gears reflects the specified gear ratio. Familiarity with gears in the real world enables users to easily understand how the gears change values based on the gear ratio. An immersive path editing application, using direct manipulation and the widgets, was implemented [13].

We believe that using the hands for interaction should be investigated as a way of developing intuitive interfaces. This paper does not discuss desktop VR systems using mice or large format screen systems without a stereoscopic view. We focus on using the hands to interact in an immersive virtual environment (see Sect. 4.1).

We conducted an experiment to compare the use of direct manipulation and the widgets in the developed application. The results showed that virtual objects could be positioned more efficiently and precisely using the gearbox widget than by using direct manipulation or a slider widget.

2. Related Work

There are numerous reports on developing and testing 3D interaction techniques [3], [6], [15], [16], [21]. Some studies have focused on 3D rotation [7], [17], and in others, techniques for manipulating grouped objects in a VR environment have been demonstrated [8], [9], [11], [20]. However, precise manipulation is more difficult in virtual spaces [10] and this description of a gearbox technique for precise manipulation adds to the literature.

This paper focuses on the precise adjustment of an object in immersive VR, which is one of the most fundamental interactions between humans and the 3D virtual environment in immersive VR.

Users can use physical input devices and gadgets, such as a cubic mouse [5], [19], to control values or coordinates. However, it is difficult for novice or casual users to use 3D pointing devices because some familiarity is needed to use them effectively. In addition, there are problems in using

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multiple devices to control multiple objects in 3D space because the correspondence between the devices and virtual 3D objects tends to be unclear. Multiple controls are required in applications such as our immersive path editing tool [13].

It is also possible to input numerical values for fine-tuning, but it is difficult to input numerical values in an immersive environment. Currently, devices such as wearable keyboards are used to input numerical values, but these are cumbersome and awkward to use. It is possible to input numbers using up/down keys, but this is tedious when inputting a large range of numbers. Even if the input devices themselves were not a problem, it would still be difficult for novices to understand which numbers to input.

Direct manipulation by hand is simpler than using 3D pointing devices or numerical inputs. Users are familiar with the actions required and can manipulate virtual objects easily. These are important aspects of designing a user interface and many advances have been made in techniques for direct manipulation by hand, such as the silk cursor [24], body-relative interaction [10], go-go interaction [14], ray-casting interaction [2], and image plane interaction [18]. However, the problem of precise manipulation by hand is still unsolved because simple direct manipulation by hand is considered unsuitable for making fine adjustments to virtual objects. The underlying reason may be the influence of the larger muscle groups [22], [23].

There have been several reports on the use of widgets for interaction with virtual objects [4], [23] but not for precise adjustment of position.

3. Gearbox

This section describes our gearbox widget. A gearbox widget is a virtual and abstract imitation of a physical gearbox. Rotating the gears changes the values. In this widget, multiple gears can be interconnected. The appearance of the gears reflects the specified gear ratios, although the interconnection between the gears is not limited by their physical structure.

The gearbox widget shown in Fig. 1 has two dials. The larger back gear and the smaller front gear, which are concentric, constitute one dial for rotational manipulation. The front gear at the leftmost dial is omitted.

Any two adjacent dials are interconnected with an intermediate gear. The intermediate gear engages the back gear of the dial to its left and the front gear of the dial to its right. The intermediate gear is used to maintain the rotational direction of the dials for manipulation. Unless the intermediate gear is used, adjacent dials rotate in different directions. For example, when the right dial is rotated clockwise, the intermediate gear rotates counterclockwise and the left dial rotates clockwise. Thus, the rotational direction of the two dials is maintained. The intermediate gear helps users utilize their knowledge of the real world, although the intermediate gear does not prevent rotating the dials by hand. Rotating the dials changes the values. The size of the

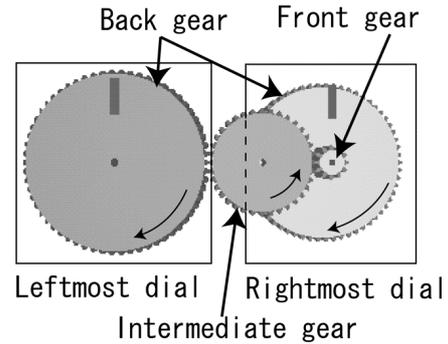


Fig. 1 Example of simple gearbox widget.

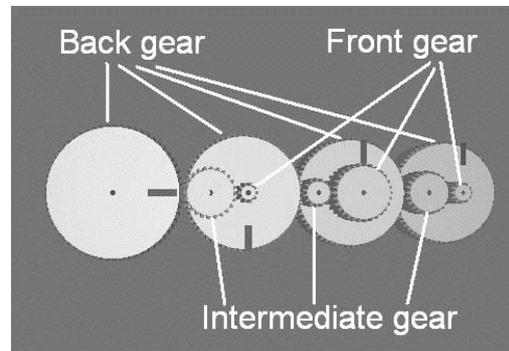


Fig. 2 Gearbox widget with four dials for rotational manipulation.

intermediate gear does not affect the ratios of the adjacent dials.

The leftmost dial is used for large changes in value, and the rightmost one for small changes. The value ratios of the dials in Fig. 1 are 5:1 for one revolution.

The gearbox in Fig. 2 has four dials for rotational manipulation. The programmer can specify the value ratio of a dial for one revolution. The back gears are all the same size in this example. Thus, the sizes of the front gears are appropriately determined by the gearbox widget based on the specified value ratio. For example, the value ratios of the dials in Fig. 2 are 60:10:5:1 for one revolution. In other words, the value ratio of the second dial from the right to the rightmost dial is 5:1. Therefore the size ratio of the back gear to the front gear of the rightmost dial is 5:1. Similarly, the value ratio of the third dial to the second dial from the right is 2:1, and that of the leftmost dial to the third dial from the right is 6:1. If the third dial from the right is rotated by one revolution, the leftmost dial, the second dial from the right, and the rightmost dial are rotated by 1/6, 2, and 10 revolutions, respectively.

4. Experiment

We conducted an experiment to evaluate the use of the gearbox widget and direct manipulation. We designed a simple experiment because we wanted to evaluate the basic features of the gearbox widget. Our hypothesis was that the gearbox would be better for making fine adjustments because it can

adjust the position of objects precisely, and the hand would be better for making approximate adjustments because it can easily move virtual objects and place them in an approximate position.

4.1 Experimental Environment

The experiment was performed in a virtual environment called TEELeX (Tele-Existence Environment for Learning eXploration) [1] at the National Institute of Multimedia Education in Japan. TEELeX is a surround display system that uses immersive projection technology. It has a large cubic screen, each face of which is 3 by 3 m. Circular polarization is used to provide users with a stereoscopic view. In other words, passive stereo is used. We used one stereoscopic face in the experiment. Head-tracking for viewpoint control was not used in the experiment.

The experiment used a PC-based system. The system runs on a PC workstation (Dell Precision 530 with dual 2-GHz Pentium 4 Xeon processors and a 3DLabs Wildcat II 5110 graphics board supporting dual displays). A six-DoF position tracker (Polhemus Fastrak) and a sensor glove (Virtual Technologies CyberGlove) were used to detect the position and motion of the user's body and hands. The experimental software was based on the immersive path editing tool that we developed [13]. The software was developed using the Java programming language, the Java 3D class library, and the it3d library [12], which is an interactive toolkit library for 3D applications with artificial reality (AR) technologies.

4.2 Subject

Eight participants (5 male, 3 female) took part in the experiment. They were university students, majoring in foreign language studies, engineering, or sociology. They were between 19 and 22 years old (mean age = 20.8 years) with little or no VR experience and were paid to participate in the experiment.

4.3 Design

We designed an experiment to test the use of direct manipulation by hand (hand, in short), the gearbox widget (gear), or a slider widget (slider). We used a within-subject design. Each interaction technique is briefly described below.

(1) Direct Manipulation by Hand

For direct manipulation by hand, the user moves the control point by pinching it between his/her thumb and forefinger and then moving it.

(2) Gearbox

For the virtual 3D gearbox, a property panel is used as the control point. The value of each axis is controlled by one 3D gearbox which includes multiple dials. Figure 3 shows

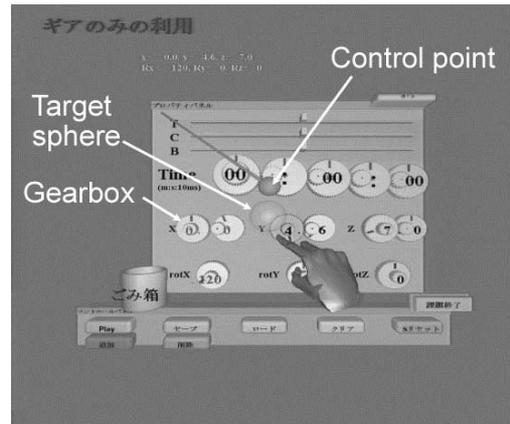


Fig. 3 Screenshot of test task using property panel with gearboxes.

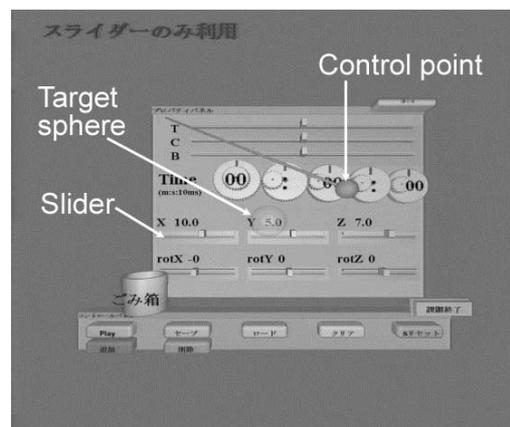


Fig. 4 Screenshot of test task using property panel with sliders.

a screenshot of a test task using a property panel with gearboxes. The value ratios of the dials for each axis are 10:1 for one revolution. The values of the left and right dials for each axis change by 10 and 1, respectively, for one revolution.

A line connected to the control point represents the correspondence between the control point and property panel. The property panel can be moved by selecting its title bar and moving it.

(3) Slider

A property panel with virtual 3D sliders is shown in Fig. 4. The value of each axis is controlled by one 3D slider. The width of each slider for position control is the same as that for position control using a gearbox. It is possible to lengthen the slider for easier and more precise control, but that would require more space. The experiment was designed to compare the gearbox and slider techniques under the condition that the property panel was the same size for both.

The value range of the slider for each axis is between -30 and 30, which corresponds to the size of the target space.

4.4 Task

Subjects wore a CyberGlove on their right hands and were asked to move a control point sphere into a translucent target sphere. When the control point was moved into the target sphere, it turned red, indicating to the subject that the control point was within the target region. We measured the time taken to move the control point from the initial position into the target sphere.

To clarify the depth of the control point, an identically sized translucent sphere (reference sphere) was displayed inside the target sphere at (0, 0, 0). Two spheres were nested. The inner sphere was the reference sphere and the outer sphere was the target sphere. If the control point appeared to be smaller than the reference sphere, it was too far from the viewpoint. In other words, subjects were able to work out differences in the depth by comparing the size of the control point with that of the reference sphere. Subjects could also work out the depth of the control point from the occlusion of the spheres.

Figure 5 illustrates the target sphere, reference sphere (inside the target sphere), and control point (see Figs. 3 and 4 also). Since orientation was not considered in the experiment, a sphere was used as the shape of the control point.

The initial position of the control point was centered at coordinates (10, 10, 10) in the tasks. The center of the target position was (0, 0, 0). The radius of the control point was 1.5 cm. The radii of the target spheres' were 4.5, 3.0, 2.0, and 1.7 cm, respectively.

4.5 Procedure

First, we explained the functions of the system and the experimental task to the subjects. They were given practice tasks so they could learn to use the sensor glove and interaction techniques. These practice sessions were followed by data collection sessions. Each subject performed the task using each of the three techniques. Each subject used the techniques in a different order.

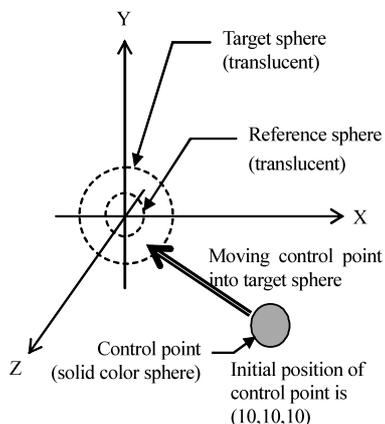


Fig. 5 Target sphere, reference sphere, and control point for experimental task.

The subjects were asked to complete the tasks as quickly and accurately as possible. However, some of them were unable to complete some of the tasks within the specified period (3 minutes). We established a cut-off time because it may have been impossible for some people to finish a task even with unlimited time and we did not want them to get too tired after one trial. We also consider that a technique that requires more than 3 minutes to move a virtual object to a target position is impractical.

After the subjects finished testing all three techniques, they were asked to complete a questionnaire. The basic question was: "How do you rate the technique tested in this experiment? Please rate each item on a scale of 0 to 9" (0 indicated the least preferred, while 9 indicated the most preferred). Questions were asked about six items: speed, accuracy, ease of use, fatigue, satisfaction, and desire to use the system.

5. Experiment Results

5.1 Incomplete Trials

Figure 6 shows the number of incomplete trials for each technique and the target size. An incomplete trial was a trial in which a subject did not complete the task within the time limit (3 minutes). There was a total of eight trials for each technique and target size.

The figure shows that single use of either sliders or direct manipulation by hand resulted in some incomplete trials when the target was small, whereas all subjects completed the task using the gearbox widget. This indicates that the gearbox widget is useful for fine adjustments. In real applications, the use of the interface techniques that resulted in incomplete trials would be less practical.

The difference in the number of incomplete trials between the gear and hand techniques was significant ($p < 0.01$) with Fisher's exact probability test using a two-sided test where the target size was 1.7. Similarly, the difference between the hand and slider techniques was significant ($p < 0.05$).

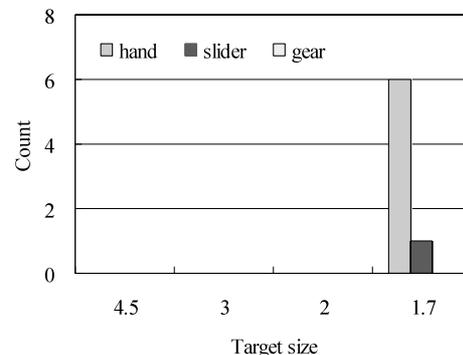


Fig. 6 Incomplete trials.

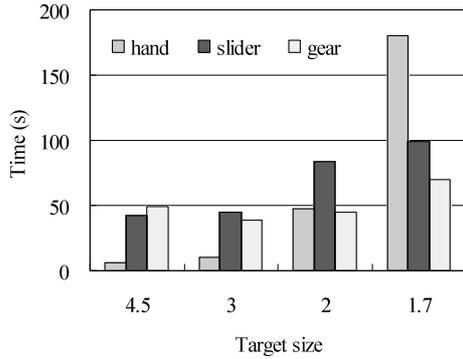


Fig. 7 Median trial time.

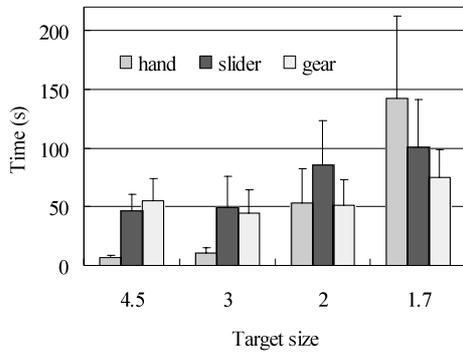


Fig. 8 Average trial time (with standard deviation error bars).

5.2 Target Size and Performance

This subsection describes the relationship between target size and performance. As mentioned in the previous subsection, some experimental trials were incomplete. Therefore, a simple calculation of the mean of the completion time is impossible. Hence, we first show the median for trial times, which should provide a robust index of tendency when some tasks are incomplete.

The median of the trials is shown in Fig. 7. In this figure, the trial time for uncompleted tasks is counted as 3 minutes. The figure shows that the hand technique was better than techniques using 3D widgets when the target was large; however, the hand technique was worse than other techniques when the target size was 1.7. The figure also shows that the gear technique was best when the target size was 1.7.

Tukey analysis shows that the difference between the hand and 3D widget techniques was significant when the target size was 4.5 or 3.0 ($p < 0.05$), and the difference between the hand and gear techniques was significant when it was 1.7 ($p < 0.05$).

The average trial time is shown in Fig. 8. In calculating the average time, the completion time for incomplete trials was counted as 180 seconds, which would be the lower bound of the completion time even if the cut-off time was longer.

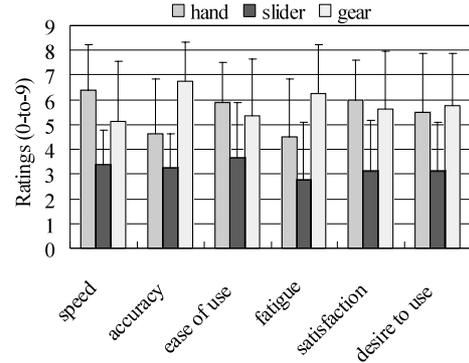


Fig. 9 Subjects' rating of three techniques on scale of 0-to-9 (0 = least preferred, 9 = most preferred).

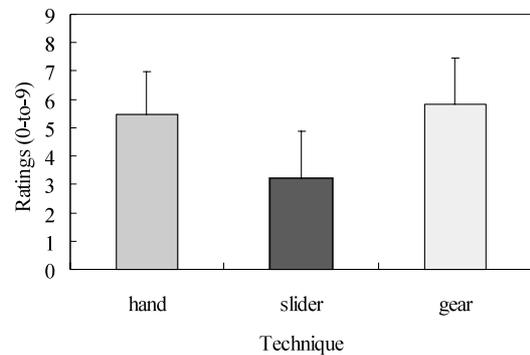


Fig. 10 Overall rating according to subjects' preferences.

Although the average time was not the mean of all trials, ANOVA analysis was applied to the data in Fig. 8. The analysis shows that there was a significant difference between the three techniques when the target size was 1.7 (mean = 74.5, $SD = 22.9$), $F(2, 21) = 3.94$, $p < 0.05$. The gear technique was the best of the three.

5.3 Preferences

Figure 9 shows the subjects' rating of each technique. The gear technique was most preferred in answer to some questions. The least preferred for every question was the slider technique.

Figure 10 shows the overall ratings, which were based on the mean value of the answers given by the subjects to the six questions. Significant differences can be seen between the three techniques, $F(2, 21) = 6.30$, $p < 0.01$. The gear technique was most preferred (mean = 5.81). There was also a significant difference between the gear and slider techniques, $F(1, 14) = 10.05$, $p < 0.01$. The hand and gear techniques rated better than the slider technique.

6. Discussion and Future Work

6.1 Gearboxes and Sliders

The results of the experiment show that the gearbox was better than the use of either the hand or the slider, in terms of

manipulation time required for small targets and overall subjective evaluation. The results support our hypothesis that our technique, i.e. the gearbox, is effective for fine tuning.

First, the gearbox does not have a fixed value range so that there is no limit on the changes that can be made by turning the dial. In contrast, the slider has a fixed range of values. The user can make large or small value changes using the same rotation of dials as when he/she chooses the appropriate gearbox dial. This choice does not require any change in mode or special equipment. This feature of the gearbox is useful for both coarse and precise value adjustments, although coarse adjustments can also be made by direct hand manipulation. The slider has a minimum and maximum value. Therefore, it does not support precise adjustments that are small with respect to the fixed range of the slider. If the slider has a large range, it can easily be used to control large values, but it then becomes difficult to control small values. It is possible to make the value range of the slider changeable; however, this would require more space for setting the value range and would complicate value-change operations.

Secondly, the gearbox has multiple dials, which minimizes the effect of the instability of the hand in midair, and provides the user with the ability to make sure of a value, enabling fast and precise adjustments to values. However, when using the slider, the position where the user wants to precisely fix the value often slips a little when the user releases his/her hand from the position. This problem occurs particularly when the target is small.

The results of the experiment showed that the gearbox widget was better than the other methods. We now need to analyze the features of gearbox widgets in more detail to establish appropriate design guidelines.

6.2 Depth Perception

Even in an immersive environment that uses stereoscopic vision, perception of depth seems to be difficult for some people [3]. Although we showed a reference sphere at the target point that was the same size as the control point, some participants could only position the control point using trial and error. They often positioned the control point backwards because it was occluded by the target sphere with the control point appearing to be included in the target. Moving a virtual object in a depth direction by direct manipulation (using the hand) was easy, but 3D depth perception is still a problem even in an immersive environment. To solve this, we designed a color technique, i.e., when a control point reaches the target sphere, then the control point changes color. Further study of suitable techniques for 3D depth perception is required.

6.3 Release of Virtual Objects

It is easy to move a control point to the approximate position of a specified target point using direct manipulation. However, the position often slips a little on release and this is a

problem. Although we provided a gearbox interface for fine tuning, we should probably also consider enhanced direct manipulation techniques.

Our observations during the experiment showed that some subjects opened their hands quickly to release the object at a position. We think that this behavior should be supported in the immersive virtual environment. For example, when a user releases an object quickly, the object should stay at the position where the release starts. This technique would require information on the velocity of the hand or fingers. We need to study this issue further, and to implement enhanced direct manipulation techniques as used in intelligent 3D widgets.

6.4 Dial Rotation

Some participants kept manipulating the first gear they used in a trial even when other gears were more suitable for adjusting a value. Typically, the subject used a dial for the most significant digit (left dial) in a gearbox and then kept using the same dial when making fine adjustments. This inappropriate use of the gearbox caused some difficulties in adjusting the value properly and efficiently.

It is not clear whether this was due to insufficient training or human nature, that is, whether the inappropriate use of the gearbox depended on the circumstances or on human factors. This requires further investigation.

6.5 Combination of Techniques

The proposed 3D gearbox widget is suitable for fine-tuning, while direct manipulation is suitable for approximate positioning. Therefore we should investigate combining direct manipulation by hand with the use of 3D widgets for fast and precise positioning.

We plan to evaluate the effectiveness of a combination of direct hand manipulation and gearbox widgets. We believe that this combination will enable novice users to manipulate virtual objects in 3D space more easily. We will also investigate appropriate gear ratios, which may be dependent on specific applications or objectives.

7. Conclusions

Direct manipulation by hand is intuitive and easy to use for approximate positioning. However, it is not suitable for precise adjustment of virtual objects in a virtual environment because it is difficult to hold the hand at a fixed point in midair without support. We therefore proposed an alternative technique using a virtual 3D gearbox widget that we designed and tested the approach in a usability study.

The experimental results showed that the gearbox was the best of the three techniques tested for small targets, in terms of both performance data and overall subject preference. This study shows that the new 3D gearbox widget can improve user satisfaction and interactive efficiency in making precise adjustments in immersive virtual environments.

Although the experimental task was established on a 3D interface in an immersive VR system, the implications of this study go beyond this specific interface. We believe that the technique proposed here may benefit the design of precise adjustment techniques in other VR systems.

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