An Evaluation on Two-Handed and One-Handed Control Methods for Positioning Object in Immersive Virtual Environments

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SUMMARY A two-handed distance control method is proposed for precisely and efficiently manipulating a virtual 3D object by hand in an immersive virtual reality environment. The proposed method enhances direct manipulation by hand and is used to precisely control and efficiently adjust the position of an object and the viewpoint using the distance between the two hands. The two-handed method is evaluated and compared with the previously proposed one-handed speed control method, which adjusts the position of an object in accordance with the speed of one hand. The results from experimental evaluation show that two-handed methods, which make position and viewpoint adjustments, are the best among six combinations of control and adjustment methods.

key words: hand manipulation, position adjustment, viewpoint adjustment

1. Introduction

Manipulation by hand which allows a user to grasp, move, place a virtual object by hand is referred to as direct manipulation in this paper. Direct manipulation could offer a casual user a more familiar and simpler way to manipulate a virtual object in an immersive virtual environment. For example, changing the position of a virtual object through hand manipulation in an immersive space is similar to manipulating an actual object in the real world, so less specialized knowledge and fewer technical skills are required of a user.

Suppose that we want students in a class to experience and understand a topic through interaction in an immersive virtual environment for hands-on learning. Most such students would be novice users of immersive virtual environments and unfamiliar with 3D pointing devices such as a cubic mouse [3]. Generally speaking, it takes time to master the use of any pointing device. This would make it difficult for many students to interact with the virtual environment, because the long training time would decrease their motivation and the time that could be used for hands-on learning within a fixed course period. If the students were unable to manipulate a virtual object or a virtual space as they like, the hands-on learning would be ineffective. For a broader acceptance and more effective use of immersive virtual environments, it is thus necessary for casual users to be able to precisely and efficiently manipulate virtual objects and virtual space, without a long training period.

Picking an object with a thumb and a finger, moving it and releasing is easy to understand, because this type of direct manipulation is more familiar to casual users in their real life. Such manipulation is easily used for approximate positioning. With simple direct manipulation, it is not easy for people to make precise adjustments efficiently because it is not easy to precisely hold their hand in mid-air without physical support, and it is also hard to release a virtual object in a precise position because it is difficult to fix the hand in mid-air when the object is released. Therefore some enhancements to direct manipulation are required to achieve precise and efficient manipulation by hand. We have been studying enhancements to direct manipulation by hand. In the following, it is assumed that the thumb and forefinger are used to pinch the virtual object although other fingers can be used similarly.

A handle bar metaphor interaction technique [16] had been proposed as a mid-air interaction technique using a camera-based motion capture device, and the technique is smart and effective. Mid-air interaction has recently attracted more research interest because camera-based motion capture systems like Microsoft Kinect have been popular and widely used. Although no currently available camera-based system can capture both hand and finger motions precisely in a large immersive space due to limitations in camera resolution and occlusion, technologies for motion capture will be improved to recognize finger motion as well as hand and body motion using multiple cameras, and affordable high-precision and wide-area motion capture systems will appear on the market in the near future. Moreover, “natural user interfaces” [5] and “perceptual user interfaces” [13], which utilize hand/finger movements and/or gesture/speech recognition, have been actively investigated and are important for future standards [8]. Therefore, it is important to utilize hands and fingers for manipulating a virtual object efficiently and precisely.

Our previous papers [10], [11] proposed and evaluated enhanced hand manipulation methods using only one hand in which speed of the hand controls adjustments. The results showed that the one-handed method with speed control is effective. However, it may sometimes be difficult to achieve a balance between hand movement for object positioning and hand speed control for precise adjustment. The proposed method in this paper enables a user to position an object by the hand which pinches it and to control an adjustment to

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precise manipulation by the other hand. An enhanced hand manipulation method is composed of adjustments and their control. This research studied enhanced control and adjustment methods to accomplish precise and efficient hand manipulation of an object. Section 3 describes briefly adjustment methods, which are release adjustment, position adjustment, viewpoint adjustment, and hand-size adjustment. Section 4 describes the one-handed and the two-handed control methods.

Guiard [4] presented a theoretical framework for the study of asymmetry of human bimanual action. The use of both hands could allow precise and efficient manipulation of virtual objects. This paper and a previous paper [12] propose two-handed control and adjustment methods in which the use of hands is asymmetric. The dominant hand is used for position and release adjustments, and the non-dominant hand is used for adjustment control. This paper comparatively evaluates the one-handed and two-handed methods. Experiments were conducted to evaluate important combinations of position and viewpoint adjustment methods and one-handed and two-handed control methods. The results from the evaluation showed that the methods including two-handed control for making position and viewpoint adjustments with hand-size adjustment and release adjustment were the best of all of the methods tested, and these methods were also the most preferred in a subjective evaluation. Our proposed method can enhance hand manipulation of a virtual object. The enhanced hand interaction techniques can provide intuitive and more effective interfaces for immersive virtual environments.

The rest of this paper is organized as follows. Related work is discussed in Sect. 2. Sections 3 and 4 describe the proposed adjustment and control methods based on our previous work [12] and show differences between this work on the two-handed control method and the previous work on the one-handed control method [10], [11]. Section 5 describes our experiments to evaluate proposed methods, and their results and statistical analysis are given in Sect. 6. Section 7 then discusses the results. Finally, Sect. 8 presents our conclusions.

2. Related Work

Many 3D interaction techniques supporting hand manipulation have been studied. For example, ray-casting interaction [6], the silk cursor [17], and go-go interaction [15] techniques are mainly used for selecting objects, not manipulating them. The HOMER techniques [11] use a combination of ray-casting and hand-centered manipulation, and can be used for grabbing and manipulating virtual objects. Although those techniques are useful for manipulating remote objects, their main purpose is not for supporting precise position of virtual objects. In contrast, our proposed method aims at accurately and efficiently placing a virtual object at a desired position.

Automatic scaling is used in one method of body-relative interaction [6] to manipulate objects outside the user’s reach, whereas the proposed methods use automatic scaling for precisely manipulating objects.

Image plane interaction [14] can be used for object selection, object manipulation, and user navigation, but the user needs to select a mode that is appropriate for his/her purpose. The mode selection complicates the use of these techniques for novice users.

PRISM [2] uses speed-dependent techniques and can be applied to control the position. In contrast, adjustment methods proposed in this paper use distance-dependent techniques with both hands for controlling position. Moreover, the adjustment model for PRISM which is based on a linear change model is different from a stage model proposed in this study.

Many existing studies used a handheld device, such as a stylus and a 3D mouse, to manipulate a virtual object. As explained in the introduction, research on mid-air interaction methods is required. The proposed methods enhance hand interaction without a handheld device for precise positioning by the use of both hands. The methods provide more effective and intuitive interfaces for novice users without the need for long training period. Furthermore, hand gestures including the fingers can easily be incorporated to give commands to a virtual reality system using the methods. Normally it is difficult to use such hand gestures including the fingers when holding a device.

Nickel and Stiefelhagen [7] presented a 3D vision system. The system enables robust tracking of a person’s head and hands and detects pointing gestures without a handheld device. Although the system can estimate the pointing direction, it is not intended for manipulating virtual objects.

3. Adjustment Methods

There are two difficulties when placing a virtual object in a desired position after it is picked by hand in an immersive virtual environment. One is the difficulty of fixing a virtual object to a precise position (precise positioning). The other is the difficulty of releasing it at a precise position (precise release).

We had proposed and evaluated automatic adjustment methods for precise positioning [10]. The proposed automatic adjustment methods include a position adjustment, viewpoint adjustment with virtual hand size change, and release adjustment. The position and viewpoint adjustments adjust the virtual hand position and the viewpoint, respectively, for precise positioning. These adjustments are controlled by scale factors, which are managed by control methods. The release adjustment adjusts the release timing for precise release. This section briefly describes the basic mechanisms of these adjustments, which are based on adjustment mechanisms in our previous work [12].

3.1 Position Adjustment

As mentioned previously, the position adjustment method adjusts the position of the virtual hand to enable precise po-
positioning. The position adjustment method is designed to make movement of the virtual hand smaller than that of the actual hand. Figure 1 shows the relationships between the measured and adjusted positions. The adjusted position \( P_a \) is expressed by
\[
P_a = P'_a + F_r(P_m - P'_m) + F_d(P_m - P'_a),
\]
where \( P'_a \) is the adjusted position of the last calculation, \( P_m \) is the measured hand position, \( P'_m \) is the hand position of the last measurement. The position adjustment is controlled by two scale factors, a displacement scale factor (or offset recovery scale factor) \( F_d \) and a relative position scale factor \( F_r \). \( F_r \) is used to reduce the movement of the hand while the position adjustment is turned on. \( F_d \) is used to recover the offset between the adjusted and measured positions. The position adjustment with \( F_r \) generally makes the adjusted and measured positions differ. Therefore the offset recovery with \( F_d \) is needed to make the adjusted and measured positions the same after the position adjustment is turned off.

3.2 Viewpoint Adjustment

The viewpoint adjustment method is used for precise manipulation. Viewpoint adjustment enlarges the scene containing the virtual object. Enlargement is important and useful for precise manipulation when a user can precisely control his/her hand. We often use enlargement in the real world for precise manipulation. For example, people often use a magnifying glass to manipulate a precision machine such as a mechanical watch or to do delicate embroidery. Moreover, a surgeon uses a mesoscope for microscopic surgery. These are just examples to show that enlargement is useful and important for precise manipulation.

The viewpoint adjustment is illustrated in Fig. 2. The viewpoint scale factor \( F_v \) controls the adjustment. When the viewpoint is not adjusted, \( F_v \) equals one. As \( F_v \) is decreased, the viewpoint approaches the point where the virtual object is pinched (the pinching point). This viewpoint movement enlarges the scene containing the virtual object, or more precisely, containing the pinching point.

Virtual hand size is also controlled by the viewpoint scale factor \( F_v \) to maintain the apparent size of the hand. If only the viewpoint is changed, the apparent size of the hand is enlarged and the enlarged hand can prevent the user from seeing the virtual object. This is undesirable. Combining the viewpoint and size changes keeps the apparent hand size constant, and avoids the undesirable enlargement of the hand [11]. In this study, the virtual hand size adjustment is combined with the viewpoint adjustment to keep the apparent size of the virtual hand the same.

3.3 Release Adjustment

In the release adjustment, the virtual object is returned to the position that seems to be the intended release position when a virtual object is quickly released. The release adjustment control for precise releasing is based on the relative speed between the thumb and forefinger (or, pinching finger). When the relative speed is high, i.e., the thumb and fingers are quickly opened, the release adjustment is applied and the release position of the virtual object is adjusted. Our previous work [11] showed that, in terms of completion ratios and subjective evaluation, the release adjustment method was beneficial.

4. Control Methods

A user needs to control the application of adjustments. The control methods influence the usability of the adjustments and the performance of precise and efficient manipulation. In our previous studies [10], [11], a speed control method using only one hand was used for precise positioning. The position and viewpoint adjustments are based on hand speed. One assumption underlying the one-handed speed control method for precise positioning is that the hand moves slowly when the user wants to precisely manipulate a virtual object.

On the other hand, this study proposes a distance control method that uses both hands for precise positioning. The distance control method is also referred to as the two-handed method. In the two-handed control method, the distance between the right hand and the left hand controls the adjustments. When the distance between both hands is small, the adjustments are activated. In other words, bringing the controlling hand close to the pinching hand activates the adjustments. This can be considered to be analogous to stopping an object by moving a hand to the object.

The following subsections describe the proposed control methods, which are based on our previous work [12].
4.1 Stage Model Using Hysteresis

In our previous studies on speed control, the subjects disliked the linear change of viewpoint or scale factors, because the scene often changed or was constantly changing. Therefore, a stage model was used for the adjustments.

In the simplest case, there are two stages, precise and normal. In the precise stage, adjustments are activated, and in the normal stage, the adjustments are deactivated.

A simple way to change the stage would be to use a threshold. Let us consider the speed control. When the speed exceeds a threshold, the stage is normal; otherwise, it is precise. This threshold method is simple but not desirable, because the stage could rapidly fluctuate if the speed is varied near the threshold. To avoid such rapid fluctuation, a form of hysteresis was introduced, which requires two thresholds. In this context, hysteresis means that the stage does not instantly follow the speed, but depends on its immediate history. When the speed is below the lower threshold, the precise stage is entered. This stage is then maintained until the speed exceeds the higher threshold, at which time the stage is reset to normal. A stage model with hysteresis is illustrated in Fig. 3.

The precise stage should be entered only when precise positioning is needed, and it should be maintained until canceling actions become apparent. Therefore the thresholds need to be chosen so as to control the stage as a user wants and to prevent frequent changes.

For a one-handed speed control, the lower ($S_p$) and higher ($S_n$) thresholds were set at 1.5 and 300 mm/s, respectively. The log records from our pilot study showed that about 60% of the movements during a precise positioning task were slower than 1.5 mm/s. When the speed was below the $S_p$, it was rare for precise positioning not to be needed. Therefore, 1.5 mm/s was chosen as $S_p$. Since the speed rarely exceeded 300 mm/s during precise positioning and the occasional movements for hand rests, 300 mm/s was chosen as $S_n$. The precise stage was turned off after the hand moved faster than $S_n$.

Similarly, for a two-handed distance control, the lower ($D_p$) and higher ($D_n$) thresholds were set at 300 and 400 mm, respectively. When the distance between both hands is nearer than the $D_p$, the precise stage is entered. If the distance between both hands is distant from the $D_n$, the stage is reset to normal. By using these values, small fluctuations in hand movement do not cause oscillation between two states and the stage stability is achieved with the hysteresis.

4.2 Scale Factors and Parameters

In the precise stage, the scale factor values were $F_r = 1/3$, $F_d = 0$, and $F_v = 1/3$ whereas the values of $F_r = 0$, $F_d = 1$, and $F_v = 1$ were used in the normal stage. Figure 4 shows viewpoint changes in two stages. A visual transition between two stages was needed to avoid the sudden changes that some subjects disliked when the stage was changed. Therefore, transition animation was used to show changes...
smoothly when viewpoint adjustment was turned on.

5. Experiments

We conducted experiments to evaluate the proposed two-handed control method based on various combinations of the control and adjustment methods for manipulating virtual objects in an immersive environment.

5.1 Environment and Settings

The experiments were conducted in a virtual environment that is a kind of surround-display system called TEELeX that uses immersive projection technology. It has a large cubic screen, each face of which is 3 by 3 m. It also has a passive stereo system, which employs circular polarization to provide a stereoscopic view to users. One stereoscopic face was used for display in the experiments to evaluate the adjustment methods in a simple and usual VR environment. A subject stood upright without physical support. Figure 5 shows the experimental settings.

A PC-based system was used in the experiments. The system ran on a PC workstation. The position and motion of the user’s body and hands were detected by a six-DoF position tracker (Polhemus Fastrak) and sensor gloves (Virtual Technologies CyberGlove). The experimental software was developed using the Java programming language, Java 3D class library, and the it3d class library for interactive 3D applications [9].

The sizes and positions were specified by a coordinate system in a position-tracker space, or a physical space. The origin (0, 0, 0) of the position-tracker space was 1200 mm above the center of the floor screen face.

To avoid motion sickness in the experiment, head tracking was not used in the experiments. A viewpoint camera was placed at a fixed position (0, 0, 400) (unit: mm) and along the −Z axis direction in the position-tracker space, where $F_v = 1$.

5.2 Subjects

Thirty-eight people (23 male, 15 female) took part in the experiments. They were all undergraduate students. They had no virtual reality experience of using sensor gloves in immersive virtual environments. In other words, they were all novice users. The subjects were paid for their participation in the experiments. They performed the task using the methods in different orders.

5.3 Task

The basic task in the experiments is illustrated in Fig. 6. The subjects were asked to place a control sphere inside a translucent target sphere repeatedly within a specific period. These experiments measured the number of completions within the specific period. The period of each trial was one minute. The period during which the virtual object was grasped was counted as part of the trial period. The thumb and forefinger were used to pinch the virtual object; no other fingers were used.

The initial positions of the control and target spheres were randomly generated within a cubical space whose diagonal vertexes were at (−150, −150, −150) and (150, 150, 150) (unit: mm). When the control sphere was released inside the target sphere and one task was completed, the positions of the control and target spheres were changed for a new task. Figure 7 shows a screenshot of the task settings.

When adjustment for precise positioning was applied, the virtual hand was colored light sea green or light slate blue, respectively, for the speed control and distance control. When precise positioning by both control methods was applied, the hand was colored light steel blue. This coloring was intended to help the subjects understand the adjustment status.

When the control sphere was placed inside the target sphere, the control sphere turned aqua blue, indicating to the subject that the control sphere was within the target region.
The radius of the control sphere was 15 mm. The target sphere had a radius of 17 mm (Size M), or 16 mm (Size S). Our previous studies showed that with sizes larger than 17 mm, adjustments are not usually needed to complete the task. A sphere was chosen as the shape of the control and target objects because orientation was not considered in the task. A sphere was chosen as the shape of the control and target objects because orientation was not considered in the experiment.

5.4 Combination of Control and Adjustment Methods

The control methods used for the evaluation were the one-handed (or speed) control method (referred to as one) and the two-handed (or distance) control method (referred to as two). Both of the control methods could simultaneously be used in the experiments. This was referred to as one+two.

As stated before, since our previous work showed that the release adjustment method was beneficial, release adjustment was used for all combinations in this study. A method using only release adjustment is referred to as base. Position adjustment and viewpoint adjustment are respectively referred to as pos and view. A method using both position and view adjustments is referred to as pos+view.

Important combinations of control and adjustment methods were chosen for a comparative evaluation. Selection of the combinations was based on the results from previous experiments. The following six combinations were used in the experiments: (0) base, (1) one:pos, (2) one:pos+view, (3) two:pos, (4) two:pos+view, and (5) one+two:pos+view. These combinations are summarized in Table 1.

5.5 Procedure

The functions of the system and the task to be done were explained to the subjects, and each subject was given practice tasks in order to learn how to use the sensor gloves and the control and adjustment methods. These practice sessions were followed by data collection sessions. Using the six methods, the subjects performed the tasks first with a target of Size M once and then with a target of Size S twice.

The subjects were also asked to rate that method on a scale of 1 to 5 (where a 1 indicated the lowest preference and 5 indicated highest preference) after they had finished testing all methods. Moreover, they rated the adjustment methods and the control methods separately and commented about their experience.

6. Results

6.1 Performance

Figure 8 shows the average number of completions with standard deviation bars within the trial period. An analysis of variance (ANOVA) was used to analyze the number of completions for each method. The ANOVA showed that there were significant differences among the performances of the methods: for Size M, F(5,222) = 16.8, p < 0.00001; for Size S, F(5,440) = 17.1, p < 0.00001.

The least significant difference (LSD) multiple comparison test showed that the differences were significant between group means of group pairs (0) base and other methods, all p < 0.01, group pair (2) one:pos+view and (5) one+two:pos+view, p < 0.05, and group pair (3) two:pos and (5) one+two:pos+view, p < 0.05, for Size M. Moreover, group pair (1) one:pos+view and (5) one+two:pos+view showed a tendency, p < 0.1.

Similarly, for Size S, the differences were significant between group means of group pairs (0) base and other methods, all p < 0.01. Group pair (1) one:pos+view and (4) two:pos+view, group pair (1) one:pos+view and (5) one+two:pos+view, group pair (3) two:pos and (4) two:pos+view, and group pair (3) two:pos and (5) one+two:pos+view showed tendencies for Size S, all p < 0.1.

Table 2 summarizes the above results. The upper right parts show the results for Size M and the lower left parts show the results for Size S. ‘****’, ‘***’, and ‘*’ show respectively p < 0.01, p < 0.05, and p < 0.1.

Since the differences between group means of group pairs (0) base and other methods were significant, the results showed that the position and viewpoint adjustments improved the number of completions significantly. This is consistent with our previous results.

The results showed that the position and viewpoint adjustments including the two-handed control, that is, (4) two:pos+view and (5) one+two:pos+view were the best of
Fig. 8  Average No. of completions with standard deviation bars.

Table 2  Summary of differences between methods.

| Method     | Size M | Size S |
|------------|--------|--------|
| Base       | ***    | ***    |
| One:pos    | ***    | ***    |
| Two:pos    | ***    | ***    |
| Two:pos+view| **     | **     |
| One+two:pos+view | *  | *     |

***: <0.01, **: < 0.05, *: < 0.1

Fig. 9  Average ratings of subjective preference of combinations of methods with standard deviation bars (1 = lowest preference, 5 = highest preference).

6.2 Preference

The subjective ratings with standard deviation bars are shown in Fig. 9. The methods that used adjustments for precise positioning were rated higher than the (0) base method.

The (4) two:pos+view method was found to be the best, and the (5) one+two:pos+view method was regarded as second best. These results are consistent with the above-mentioned experimental performance evaluation.

Friedman rank sum test was applied to analyze the ratings of the methods. It showed that there were significant differences among the ratings of the methods: $\chi^2(5) = 119.443, p < 0.00001$. Except group pair (2) one:pos+view and (3) two:pos, the differences of the medians in all group pairs were significant (group pair (4) two:pos+view and (5) one+two:pos+view, $p < 0.1$ and other groups pairs, $p < 0.01$) based on Wilcoxon signed-rank test for paired comparisons.

Figure 10 shows the average ratings of the subjective preference of adjustment and control methods with standard deviation bars (1 = lowest preference, 5 = highest preference).

7. Discussion and Future Work

For Size S, the methods with viewpoint adjustment were better than those without that adjustment in terms of the number of completions although the differences between...
them were not significant for one-handed methods. This is supported by the preference results and the results of the previous work [12]. This suggests that viewpoint adjustment is useful for small targets.

Among methods with both position and viewpoint adjustments, methods including two-handed control were better than methods with only one-handed control (p < 0.1) in terms of performance. The preference results also support this (cf. (2) and (4) in Fig. 9). In the previous work, the differences in performance between (2) and (4) were significant (p < 0.05) for both sizes, and the preference results were similar to those of this work. These results suggest that it is better to have an option including the proposed two-handed control and both of position and viewpoint adjustments.

The option of using both one-handed and two-handed control methods improved the subject’s freedom of choice but did not necessarily improve the usability. The use of both control methods did not significantly improve the performance for small targets, and the use of both of them was not preferred to the use of only the two-handed control. When both control methods were simultaneously used, unintended adjustments were observed in some cases. For example, a subject tried to control the adjustments by using both hands. He brought both his hands close together and then adjusted positioning but wanted to turn off the viewpoint adjustment to confirm the overall situation and then bring his hands apart. However, the viewpoint adjustment was not turned off because the moving speeds of both hands were slow and the adjustment was still activated by the one-handed control. In this case, he spent some time trying to understand the situation and had to move his hands faster. This is an example of the negative effect of the use of both control methods. Further study is needed to decrease the negative effect of the use of both methods.

In this work, 38 subjects participated in the experiment, which is more subjects than participated in the previous work [12]. Both works showed the same tendency that (4) two:pos+view was better than (2) one:pos+view and (3) two:pos for both sizes. In other words, both works had consistent results. However, in performance analysis, fewer group pairs had statistically significant differences in this work than in the previous work. This work had a subject whose total number of completions in all trials is very low or 1, whereas the average total number of completions over all subjects was 29.6. In the previous work, the minimum and the average total number of completions in all trials were 5 and 33.3, respectively. The results of this work suggest that fixed parameters of adjustment and control methods are not suitable for some people. For a person who cannot stably control his/her hands in mid-air, the relative position scale factor \( F_p \) and the viewpoint scale factor \( F_v \) should be small to reduce the movement of the virtual hand and enlarge the scene. An automatic mechanism for parameter tuning needs to be investigated.

As explained in the introduction, camera-based motion capture systems have been popular and widely used. In environments that use a camera-based motion capture system, tactile feedback is not necessarily important for manipulation methods of virtual objects because the user does not want to hold any device with his/her hands and does not wear special gloves. The proposed methods can be applied to many such environments.

Desktop motion capture systems for hands and fingers, such as the Leap Motion controller and Intel RealSense 3D camera, are available in the consumer market. The proposed methods can also be utilized in such desktops although this work targeted a large immersive space. Therefore, we have a plan to design improved methods based on the proposed methods for desktops.

The two-handed control method can be extended to precisely adjust the rotation of a virtual object. It is possible to control the orientation of virtual objects with the relative positions of both hands. The relative direction can be more easily controlled than controlling the orientation by one hand. As the distance between both hands becomes larger, it is easier to adjust the relative direction. Moreover, it is possible to introduce a rotation scale factor to enable precise rotation in this method. We will investigate rotation methods for desktops in the future.

8. Conclusion

The proposed methods for automatic adjustments were experimentally evaluated. The results showed that, in terms of the number of completions and the subjective evaluation, methods including two-handed control with position and viewpoint adjustments were better than the other methods that were tested. In other words, the proposed two-handed distance control method is more effective than the one-handed speed control method to position a virtual object precisely and efficiently. This work presents a new option to design an interface using hand movement. Since simultaneous use of both one-handed and two-handed controls did not necessarily improve usability, further studies on usability improvements are needed. The two-handed method can be enhanced for rotational manipulation, that is, future research on enhanced methods will make it possible to achieve more flexible and precise manipulation.

References

[1] D.A. Bowman and L.F. Hodges, “An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments,” Proc. of Symposium on Interactive 3D Graphics, ACM, pp.35–38, 1997.

[2] S. Frees and G.D. Kessler, “Precise and Rapid Interaction through Scaled Manipulation in Immersive Virtual Environments,” Proc. of IEEE Virtual Reality 2005, pp.99–106, 2005.

[3] B. Fröhlich and J. Plate, “The cubic mouse: a new device for three-dimensional input,” Proc. of the CHI 2000 Conference on Human Factors in Computing Systems, pp.526–531, 2000.

[4] Y. Guiard, “Asymmetric Division of Labor in Human Skilled Bi-manual Action: The Kinematic Chain as a Model,” Journal of Motor Behavior, vol.19, no.4, pp.486–517, 1987.

[5] Microsoft Research, NUI: Natural User Interface. Retrieved from
http://research.microsoft.com/en-us/collaboration/focus/nui/

[6] M.R. Mine, F.P. Brooks, and C.H. Sequin, “Moving objects in space: exploiting proprioception in virtual-environment interaction,” Proc. of SIGGRAPH'97, ACM, pp.19–26, 1997.

[7] K. Nickel and R. Stiefelhagen, “Pointing Gesture Recognition based on 3D-Tracking of Face, Hands and Head Orientation,” Proc. of the 5th international conference on Multimodal interfaces (ICMI’03), pp.140–146, 2003.

[8] D.A. Norman, “Natural user interfaces are not natural,” Interactions, vol.17, no.3, pp.6–10, 2010.

[9] N. Osawa, K. Asai, and F. Saito, “An Interactive Toolkit Library for 3D Applications: IT3D,” Proc. of 8th Eurographics Workshop on Virtual Environments, pp.149–157, 2002.

[10] N. Osawa, “Enhanced Hand Manipulation for Efficient and Precise Positioning and Release,” Proc. of 9th Int. Workshop on Immersive Projection Technology, 11th Eurographics Workshop on Virtual Environments, Eurographics, pp.221–222, 2005.

[11] N. Osawa, “Automatic adjustments for efficient and precise positioning and release of virtual objects,” Proc. of ACM SIGGRAPH International Conference on Virtual Reality Continuum and Its Applications (VRCAI 2006), pp.121–128, 2006.

[12] N. Osawa, “Two-handed and one-handed techniques for precise and efficient manipulation in immersive virtual environments,” International Symposium on Visual Computing (ISVC), G. Bebis et al. (Eds.), Advances in Visual Computing, Part I, LNCS 5358, pp.987–997, Springer, 2008.

[13] S. Oviatt and P. Cohen, “Perceptual user interfaces: multimodal interfaces that process what comes naturally,” CACM, vol.43, no.3, pp.45–53, 2000.

[14] J.S. Pierce, A.S. Forsberg, M.J. Conway, S. Hong, R.C. Zeleznik, and M.R. Mine, “Image plane interaction techniques in 3D immersive environments,” Proc. of Symposium on Interactive 3D Graphics, ACM, pp.39–43, 1997.

[15] I. Poupyrev, M. Billinghurst, S. Weghorst, and T. Ichikawa, “The go-go interaction technique: non-linear mapping for direct manipulation in VR,” Proc. of UIST’96, ACM, pp.79–80, 1996.

[16] P. Song, W.B. Goh, W. Hutama, C.-W. Fu, and X. Liu, “A handle bar metaphor for virtual object manipulation with mid-air interaction,” Proc. of SIGCHI Conference on Human Factors in Computing Systems, ACM, pp.1297–1306, 2012.

[17] S. Zhai, W. Buxton, and P. Milgram, “The Partial Occlusion Effect: Utilizing Semi-transparency in 3D Human Computer Interaction,” ACM Transactions on Computer Human Interaction, vol.3, no.3, pp.254–284, 1996.

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