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Z-Clutching: Interaction Technique for Navigating 3D Virtual Environment Using a Generic Haptic Device

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Abstract

Navigating a large 3D virtual environment using a generic haptic device can be challenging since the haptic device is usually bounded by its own physical workspace. On the other hand, mouse interaction easily handles the situation with a clutching mechanism—simply lifting the mouse and repositioning its location in the physical space. Since the haptic device is used for both input and output at the same time, in many cases, its freedom needs to be limited in order to accommodate such a situation. In this paper, we propose a new mechanism called Z-Clutching for 3D navigation of a virtual environment by using only the haptic device without any interruption or sacrifice in the given degrees of freedom of the device's handle. We define the clutching state which is set by pulling the haptic handle back into space. It acts similarly to lifting the mouse off the desk. In this way, the user naturally feels the haptic feedback based on the depth (z-direction), while manipulating the haptic device and moving the view as desired. We conducted a user study to evaluate the proposed interaction technique, and the results are promising in terms of the usefulness of the proposed mechanism.

Category: Human computing

Keywords: Haptic interaction; 3D navigation; Virtual reality

I. INTRODUCTION AND RELATED WORKS

One of the interesting aspects of the haptic device is that it can serve as both an input and an output device. For implementing a haptics-enabled 3D graphics application, we need to consider the method used to navigate in the virtual environment using the haptic device's handle, unless there is another special interaction method provided. If we simply assign the device handle's coordinate to the position of the virtual cursor (position control), we ultimately face a physical limit of the device's workspace. While a scaling factor can be applied to expand the virtual workspace [1], this involves a trade-off between large scale and fine control.

The commonly used simple solution to this limitation is to introduce a clutching state using one of the buttons on the device or any key on the keyboard. This "button clutching" has been a comparison target in other research works [2, 3] and was shown to be ineffective. As it requires either an extra key assignment or an extra button on the device, it can be inadequate when the application's task requires frequent manipulation of a nearby key or button. Another simple approach is the use of a rate control to determine the velocity of the cursor's movement based on the device handle's displacement from the center, instead of directly controlling the position. This approach is commonly used with a joystick [4], as well as a generic haptic device [5]. While this ensures seamless

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control of the virtual cursor, this velocity-based control is not usually considered convenient and is prone to higher error rate than position-based control schemes [4].

Various attempts have been made to overcome the abovementioned limitation. Some of the hardware-based approaches include placing the haptic device on a mobile base which allows an additional degree of freedom [6, 7]. While this type of approach can increase the width of the usable workspace of the haptic device without jeopardizing the fine controllability, it requires a wide physical area which can be limiting. In Workspace Drift Control by Conti and Khatib [8], the virtual workspace of the device cursor is slowly adjusted to the user's manipulation. In the Dual Shell method by Isshiki et al. [3], the clutching state is turned off when the handle reaches the boundary (outer shell) of the device's workspace, and then turned on again once the handle returns to the inner shell area. Both techniques adopt automatic adjustments to some degree according to the manipulating context.

The Bubble technique proposed by Dominjon et al. [2, 9] is a hybrid technique that controls the position inside a certain radius around the center, and controls the rate outside of the radius. While the hybrid position-rate control might not be a new concept, the Bubble technique equipped with visual and elastic force feedback at the bubble’s boundary has been recognized as an effective interactive means of using the haptic device. As a subsequent development of the initial point-based Bubble technique, Pavlik and Vance [10] extended their discussion to a coupled-object case. Casiez et al. [11] discussed an issue of discontinuities at the boundary between the position and rate controlled area, when presenting their RubberEdge device.

Even with the existing techniques that can be effectively adopted in a wide variety of haptics applications, much improvement is needed in the development of an application environment that is not originally designed and implemented for haptic interaction. This type of scenario can arise when implementing a haptic device supporting patch for a 3D interactive graphics application, or applying haptic interaction to existing plug-in type applications [12]. Good examples can be found from the games supporting the Novint Falcon haptic device (http://www.novint.com/index.php/novintfalcon). When existing techniques such as the Bubble technique are used in this type of scenario, only the x- and y-coordinate axes of the haptic device are utilized to generate an input signal, and the usable workspace range is reduced further in some interaction techniques. If the application provides a depth-based haptic rendering effect such as in [12], device manipulation using the existing techniques does not naturally connect to the touching of the rendered scene. In addition, when an application's interface is originally intended to be used by the mouse and the user is accustomed to this, the user might feel uncomfortable with haptic interaction techniques of partly adopting rate control or techniques not totally under the user's control. The clutching action introduced to remove such problems is not necessarily harmful [13].

In this regard, we present a new interaction technique of maximizing the utilization of all 3 basic axes and all possible workspace ranges for the handle of generic haptic devices. The proposed interaction technique, named “Z-Clutching”, is based on position control and a clutching mechanism using the z-coordinate axis. Our intended aim in terms of the user experience is to provide a more immersive experience than the existing interactive graphics applications through haptic interaction.

II. Z-CLUTCHING INTERACTION TECHNIQUE

In the Z-Clutching (ZC) interaction technique, the clutching action is controlled by the z-coordinate of the device handle (Fig. 1). As mentioned in the previous section, this type of clutching control is possible under the assumption that the actual input signal is generated only by the x- and y-coordinates, similar to the mouse input signal. While a graphics application with a full 3D haptics functionality cannot be the target, a haptics add-on for existing interactive games or a haptic rendering system based on the depth map [12] can adopt our technique.

Basically, the clutching state is turned on when the z-coordinate of the device handle goes beyond a certain depth value. We assume a plane placed on this depth value of the z-coordinate axis (lies in x- and y-coordinate space), and call the plane the “virtual clutching plane” (a vertical bar placed near the middle of the frustum in Fig. 2). If the target application does not provide haptic rendering from the scene's geometry, an elastic force feedback can be added to the virtual clutching plane similar to that of the Bubble technique. If the application provides depth-based haptic rendering, which is our basic

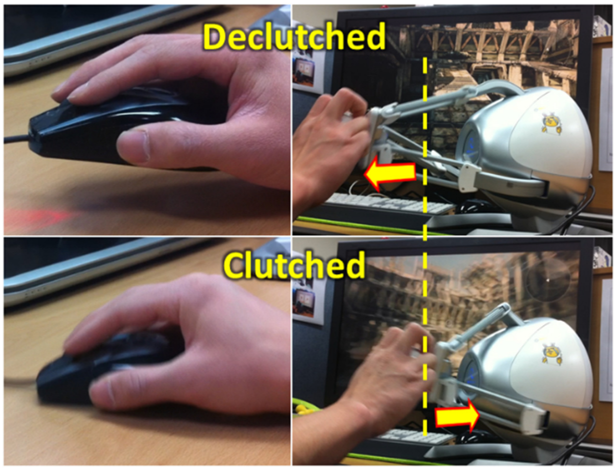

Fig. 1. Basic concept of Z-Clutching interaction.

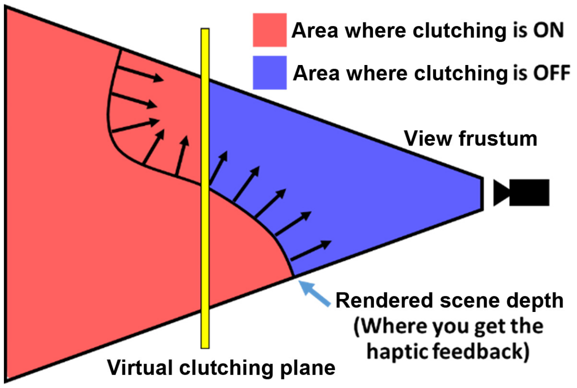

Fig. 2. Diagram of clutching state criteria in depth-based haptic rendering environment.

Fig. 3. Experimental setup.

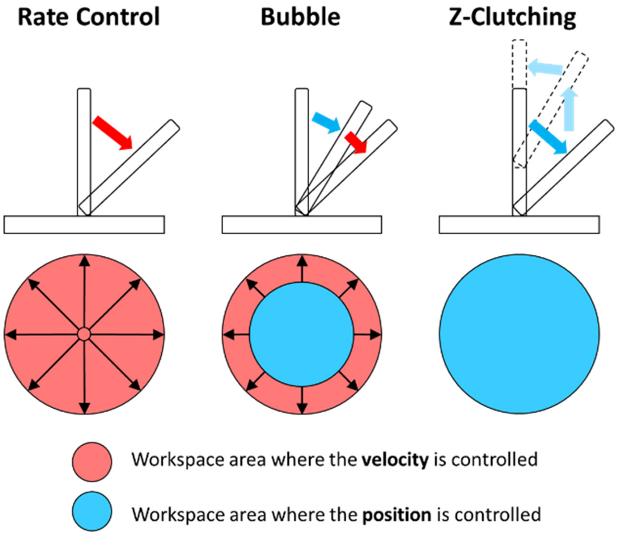

Fig. 4. Three interaction techniques compared for evaluation.

target environment, the clutching state is also turned on when the z-coordinate of the device handle reaches beyond the depth of the scene. Therefore, when the depth of the scene is shallower (closer to the virtual camera) than the depth of the virtual clutching plane, the controlling action by the haptic device will be accompanied by a sense of touching the scene's geometry. On the contrary, the controlling action is not necessarily accompanied by a touching sense when the depth of the scene is deeper than the depth of the virtual clutching plane. The user can still feel the haptic feedback by pushing the haptic handle deeper into the scene's geometry. This scheme can lend a sense of “touching and sliding” to the user manipulating the 3D application. Fig. 2 illustrates the described clutching state criteria.

III. EVALUATION

An experiment involving 14 participants (10 males and 4 females, aged 18–33 years) was conducted to verify the usefulness of our interaction technique. Three interaction techniques—rate control (RC), Bubble, and ZC—were compared using the Novint Falcon haptic device as shown in Fig. 3. These interaction techniques were implemented in the AnyHaptics [12] framework to be tested with arbitrary OpenGL-based graphics applications. The AnyHaptics framework also provided depth map-based haptic rendering from the applications used in the experiment. Fig. 4 shows a conceptual diagram of the compared techniques. None of the techniques requires any extra mechanical features such as a button, other than the device handle, and do not require any automatic intervention.

To measure the basic usability, both a quantitative test and a qualitative questionnaire were designed. This is because we predicted that the ZC will show a result competitive enough to be compared to existing techniques, without overwhelming them. In addition, two of the questionnaire items were designed to evaluate the contribution in terms of the immersive virtual reality experience.

A. Experiment Design

The entire experiment consists of two phases. First, the subject played a sample first-person shooting game of UDK (Unreal Development Kit by Epic Games, https://www.unrealengine.com/products/udk/) (shown on the top in Fig. 5). No special instructions were given to the subject regarding the game play, other than the explanations on the interaction techniques. The subject was asked to play the game 4 times using different interaction techniques—mouse, RC, Bubble, and ZC—to become familiar with each technique. The single play time duration was 3–5 minutes. In this phase, no quantitative data was recorded, but we asked subjects to respond to a questionnaire about their experience.

In the second phase, the subject played a ball-click game (shown on the bottom in Fig. 5) which involves controlling the virtual camera to place the viewpoint cen-

Fig. 5. (Top) Snapshot of UDK used for the first experimental phase. (Bottom) Ball-click game used for the second experimental phase. Only one ball is visible at a time during the actual experiment.

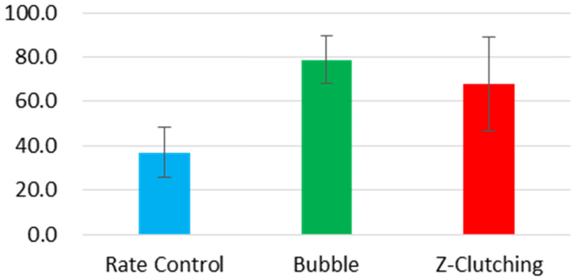

Fig. 6. Average ball click count with the standard deviation range for all subjects.

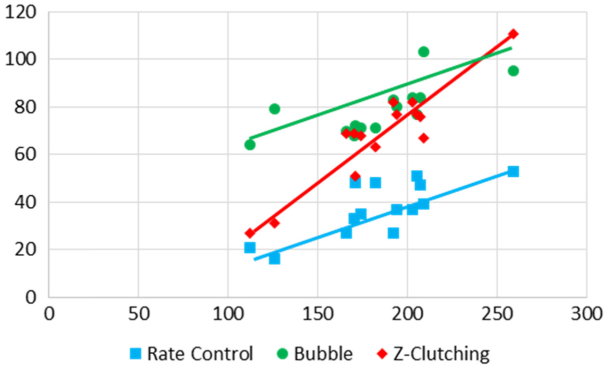

Fig. 7. Distributed plot of 'total click count' vs. 'click count from each interaction technique'.

ter within the range of the current target ball's radius and click the button. Once the ball is clicked at a point within its radius, the next ball appears at another location. The new ball's location can be outside of the current field of view, so a simple moving animation heading towards the new location was displayed for a short time. The subject was told to click as many balls as possible in 2 minutes. The 2-minute session was repeated twice for all 3 haptic interaction modes, and the order of interaction modes was randomly set at the starting point of the game. The clicked count was recorded for analysis, and the displacement of the exact hit point from the ball's center was recorded, although the participants were not asked to click the ball precisely.

In the ball-click game, we considered the sensitivity of the control to be the important parameter as it directly affects the frequency of the clutching and the possible precision of the rate control. Therefore, we allowed the subjects to control the sensitivity at any time during the experiment using the minus/equals key on the keyboard.

For the Bubble technique, the elastic feedback force at the boundary of the bubble was implemented, but the bubble was not visually presented. In our experiment, the virtual camera was coupled to the haptic handle and the cursor was always at the center, so a simple visual presentation of the bubble was not feasible. This could be seen as a disadvantage of the Bubble technique, but the ZC could provide some benefit by visually presenting the clutching depth in various ways; we therefore do not believe this is a critical factor.

B. Quantitative Analysis of the Result

The average value of clicked counts was 37.07 (SD 11.49) for RC, 78.64 (SD 10.76) for Bubble, and 67.86 (SD 21.18) for ZC (Fig. 6). Although the Bubble technique scored the highest average, the result of the ANOVA test showed that there is no significant difference between the Bubble and the ZC with p=0.160. From the results shown in Fig. 6, we can say that the Bubble and the ZC both overwhelm the RC, while they (Bubble and ZC) are in close competition.

An interesting aspect of the ZC is revealed upon closer examination. Overall, the result of the ZC shows relatively high variance. During the experiment, we noticed that a subject with better overall proficiency at 3D interaction also tends to show better results in the ZC. To visually represent this observation, we plot the correlation between 'total click count from all 3 interaction techniques' and 'click count from each interaction technique' (Fig. 7). The graph in Fig. 7 illustrates that the ZC shows a much steeper increase rate along the total click count than the other two interaction techniques. Furthermore, to quantify this observation, we analyzed the correlation between 'total click count from all 3 interaction techniques' and 'click count ratio from ZC to Bubble'. The correlation coefficient was 0.752 with the p=0.002 in the correlation analysis, which means that a subject showed relatively good skill at the ZC when he/she had a higher total click count, in a highly significant correlation.

Thus far, results showing the speed at which the user could manipulate the virtual cursor were presented. While we only asked the subjects to click the target as many times as possible and did not ask them to consider the precision of the hit, there was an obvious tendency for the subject to consider their precision in clicking the target. From the result of the hit point displacement from the center of the ball, the RC showed the worst result of 0.635 (SD 0.0335). The Bubble and the ZC showed close results with 0.580 (SD 0.0343) and 0.570 (SD 0.0286), respectively. This time, the ZC showed a slightly better result than the Bubble, but analysis showed that it was not significant.

C. Qualitative Evaluation

Table 1 shows the questionnaire items and averaged results from the participants. In general, the Bubble technique got the best appraisal in terms of the usability. Most participants expressed that they felt comfortable once they started using the Bubble technique. Still, a few expressed that the ZC improved once they were accustomed to it. This opinion coincides with the tendency of 'click count from each interaction technique vs. total ball click count' shown in Fig. 7.

The second and third questions were designed to determine whether the ZC fulfils our intended goal of enhancing an immersive virtual reality experience. Accordingly, obvious differences between the Bubble and the ZC could be observed. Although the participants could feel the haptic feedback while manipulating the game with the Bubble interaction, the depth map-based haptic rendering provided during the experiment was more easily experienced with the ZC. The ZC naturally leads the user to feel the haptic feedback from the depth of the rendered scene in a 'touching and sliding' manner as described in Section II, which supports the result score of the second and third questionnaire items in Table 1.

D. Discussion

Overall, the experiment results showed that our proposed ZC was indeed useful in terms of providing a more immersive experience by utilizing all possible 3-DOF workspaces of the haptic device, especially in the z-coordinate axis.

In terms of usability, while the Bubble technique received the best appraisal, the ZC showed competitive results, making it difficult to conclude that the Bubble technique was the most successful. We observed that the ZC technique merely required slightly more time to learn, and that a subject with better 3D interaction skill was inclined to be better at ZC. Although the ZC cannot dominate the Bubble technique or other possible means of haptic interaction in terms of the usability, the ZC can also be useful in some circumstances or for certain users.

Regarding the result of the precise hit, we believe that the usability of the interaction technique can affect the user's precision in hitting the target to some extent because fine control can hardly be expected when the user feels fatigue. For most of the participants, simply clicking the target using the RC appeared to be a difficult task. On the contrary, with the position control provided by the ZC and the Bubble technique, it was not difficult to click the target once the cursor approached close to the target.

IV. CONCLUSION

We presented a new interaction technique for generic haptic devices referred to as Z-Clutching. The ZC requires a certain target environment—replacing the mouse interaction when the haptic interaction is plugged into an existing interactive graphics application—that can be effectively used. Especially, in an immersive virtual environment that provides a depth-based haptic rendering effect, the ZC helps to fully utilize all the device workspaces while providing precise position control of the entire. From the experimental results when comparing the ZC to the existing RC and Bubble interaction techniques, we demonstrated the possibilities of the ZC providing a more immersive virtual reality experience.

As a future enhancement, visualization of the clutching

Table 1. Questionnaire items and the results in 1–5 scale

	Subjective usability			**Was it possible to feel the haptic feedback from rendered scene?**			**Does the haptic feedback help to enhance the reality of the virtual environment?**		
	RC	**Bubble**	**ZC**	**RC**	**Bubble**	**ZC**	**RC**	**Bubble**	**ZC**
Avg.	1.29	3.39	2.36	2.57	3.11	4.04	2.86	3.21	3.71
SD	0.469	0.964	0.842	0.958	0.739	0.843	1.027	0.802	0.914

RC: Rate Control, ZC: Z-Clutching, SD: standard deviation.

depth (e.g., a slight color gradation along the depth) can help the users to become familiar with the ZC. In terms of the interaction itself, a recent work by Nancel et al. [13] showed overlooked possibilities of clutching in human-computer interaction, being not merely the consequence of the physical limitation of the workspace. In this context, our experiment may have some limitations in fully demonstrating the benefits of ZC. We plan to improve the ZC in terms of the classification of subjects and the overall testing procedure, ensuring sufficient learning time, and we believe that even further possibilities in the ZC interaction technique will be revealed.

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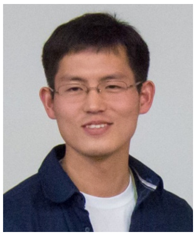

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