Double Hand-gesture Interaction for Walk-through in VR Environment

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Abstract—In this paper, we present a double hand-gesture interaction (DHGI) method for walk-through in VR environment with an Oculus Rift headset and Leap Motion function. The user can control the avatar (first-person view) to move (walk/run) forward or backward by turning the user's left palm upward or downward, and by turning the avatar to the left or right with the right thumb pointing toward either direction. Compared with the results of the joystick input device and portal method using Oculus Rift Touches, the objective and subjective findings of this study indicate that DHGI is intuitive, easy to learn, easy to use, and causes low fatigue. Moreover, the user feedback shows that DHGI significantly improves immersion and reduces the sense of motion sickness in VR.

Keywords—Virtual Reality; Double Hand-gesture Interaction (DHGI); Walk-through; Leap Motion

I. INTRODUCTION

Navigation or traveling (walk-through) is one of the basic and essential 3D interaction tasks in a VR environment [1, 2]. However, head-mounted displays (HMD) pose a challenge if their input options are limited [3].

Devices, such as joysticks and head orientation tracking using Gyro in VR headsets, is a common technique for walk-through in the VR environment. These devices are convenient and familiar, easy to use, and effective for users focusing on control movement in VR. However, joysticks often control the view to move suddenly and irregularly, thereby causing motion sickness [4, 5] as a result of a sensory mismatch[6] between visual and vestibular stimuli [7, 8].

Portal method is another common technique to mitigate the motion sickness by supplying several portal targets that enable users to jump suddenly from one location to another. However, these techniques are not natural enough to improve the immersive experiment in the VR system because of the discrete motion that adversely affects the user's experiment and may increase disorientation [2, 9].

Walking-in-place (WIP) [10]technique enables the user to walk in a place to control the avatar movement and rotation using physical body gesture recognition devices such as Microsoft Kinect [11, 12]. This technique strengthens the match between proprioceptive information from human body movements and sensory feedback from computer-generated displays, which is more intuitive and can reduce the user's dizziness. However, this technique requires the user to stand in a fixed area and the user's whole body must be active. However, a good travel interface should produce low fatigue for walk-through solution [13].

To provide a low-fatigue walk-through operation that allows users to sit in a certain place in the VR environment, researchers have proposed various techniques such as finger walking[13, 14] and touch-based travel using smartphones [15] or gamepads[13]. However, these methods may also cause motion sickness when joysticks are used.

The VR environment is similar to riding a car, where passengers are more likely to experience motion sickness than drivers because drivers can anticipate[16] and have more motion cues and intuitive metaphors such as the hands controlling the steering wheel where the car will be turning. By using this method, we can add some intuitive metaphors that are easy to use and can decrease the motion sickness when users are traveling in the VR environment.

In this paper, we present a simple double hand-gesture interaction (DHGI) method to support user's walk-through activities within VR environments that allow users to feel comfortable while sitting in a place as if they are in the real world.

We research, implement, and evaluate this interaction with Oculus Rift (HMD device) and Leap Motion (hand gesture tracing in-air controller). Compared with the joystick and portal methods, we design and conduct a user study focus on a 3D VR scene that simulates a maze to test the DHGI's user-centered approach examination quality factors (speed, accuracy, spatial awareness, ease of learning, ease of use and presence) introduced by Bowman [2].

Results show that the DHGI method can provide obvious operational metaphors that are easy to remember and operate. At the same time, it gives users a better sense of immersion than the portal method. Finally, compared to the joystick method, the DHGI method spent slightly more time to complete the task, but it can reduce the motion sickness significantly. The results suggest that DHGI is more suitable for the applications that do not need high response speed,

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such as exploring and decryption games or VR training courses.

The contributions of this paper include the following: (1) a simple double hand-gesture interaction (DHGI) method for walk-through task in VR environments, and (2) a user-centered examination of the three types of interaction (DHGI, joystick input device, and portal method using Oculus Rift Touches) for traveling in VR environments.

II. RELATED WORKS

Hand-based interaction to control direction of motion and walk-through in the VR environment is suggested by Mine [17]. A high-accuracy hand-gesture tracing device, such as Leap Motion, is a novel technology that provides input via hand gesture tracing, thereby enabling bare hand interaction [18] in a 3D environment. For example, Ni et al.[19] explores menu selection using freehand gestures, and Kulshreshth et al. [20] presents the results of the first comprehensive study on finger-count menus to investigate its usefulness as a viable option for 3D menu selection tasks. Beattie et al.[21] presents a CAD Interaction Laboratory to dissect a mechanic model to manipulate and inspect individual components in VR. Lee et al. [22] proposes a hand-based interaction technique called TranSection for playing a puzzle game in VR. Salomoni et al.[23] presents a study where entertainment virtual environment interfaces are rethought in the light of the emergence of HMD devices. However, these designs are not yet involved in how to control walk-through action in the VR environment.

To fill this research gap, several works have investigated how to perform an intuitive and comfortable interaction technique in VR using Leap Motion. For example, Codd-Downey et al. [24] introduces a travel technique using finger tracker, which adopts a 2DOF steering metaphor used in traditional mouse and keyboard navigation in 3D computer games. Khundam [25] introduces a new interactive single hand-gesture system with palm normal for control steering. The results shows that using hand gestures to control walk-through action is more intuitive than the joystick method. However, single hand gestures do not provide a way for a user to turn while walking.

III. DOUBLE HAND GESTURE INTERACTION(DHGI) FOR MOVEMENT CONTROL IN VR

The main objective of this study is to design a simple, comfortable, and low-fatigue double hand gesture to control an avatar (first-person view) movement that allows the user to become fully immersed in the VR environment. The left hand is used for moving and the right hand for turning.

We divides the walk-through task into four actions:

A. Forward/backward movement

If the users intend to move the avatar forward, they have to raise and open their left hand, and then keep the palm normal pointing downward. On the contrary, users flip the palm normal upward to move the avatar backward (not turning back by changing the walk straight direction).

Generally, FPS games, etc., supports two movement speeds: walking (1 m/s) and running (3 m/s). When using this method, users only raise five fingers to indicate the walking speed. Otherwise, users raise four fingers except the thumb to indicate running speed (see Fig. 1). Both movements are controlled by implementing a "slow-in, slow-out" (SISO) technique[26] in which the user begins slowly, accelerates to a maximum speed, and then decelerates as the destination is reached [2].

Fig. 1. Hand gesture for walking/running straight action. ((a) gesture for walking forward, (b) gesture for running forward, (c) gesture for walkingbackward, (d) gesture for running backward, and (e) gesture for stopping.)

B. Turning the avatar's body spatial orientation according to the yaw direction

Our method involves detecting the right thumb direction to turn the avatar's body spatial orientation (to improve the robustness, other fingers on the right hand should be closed). When the thumb points to the left, the avatar's body rotates to the left gradually. On the other hand, pointing the thumb to the right enables controlling the avatar's body to turn right (see Fig.2). All the turning speeds are constant with reference to the real world (15 degrees per second), enabling the user to feel more comfortable and the movement to become seamless. Simultaneously, the orientation is superimposed with the user's head yaw rotation.

Fig. 2. Hand gesture for turning action.((a) gesture for turning left, (b) gesture for turning right, (c) gesture for stop turning, and (d) gestures combined for turning left when walk forward.)

C. Looking upward and downward in pitch direction

In this action, users look upward or downward according to the facing direction that is tracked by the HMD's head orientation tracker.

D. Stopping movement and rotation

To stop moving, users only grasp the left hand or leave it out of Leap Motion's tracking range. At the same time, the user stops the rotation action by collapsing the right thumb or taking it out of the tracking range. We also used the SISO technique to slow down the action to prevent the user from feeling a sudden stop.

IV. EXPERIMENT EVALUATION

We compare two different methods to evaluate the overall performance of our movement control by using the DHGI method. The methods used is Xbox joystick (called joystick method), and Oculus Touch controller for portal method (called portal method).

We apply the quality factors introduced by Bowman[2] to evaluate our results. The factors include speed (appropriate velocity or the total time spent to complete the task), accuracy (proximity to the desired target), spatial awareness (the user's implicit knowledge of his position and orientation within the environment during and after travel), ease of learning (the ability of a novice user to use the technique), ease of use (the complexity or cognitive load of the technique from the user's point of view), and presence (the user's sense of immersion or "being within" the environment).

We perform travel time to represent the speed factor, offset time for accuracy, and stop time for awareness. The three attributes are measured in seconds. Other factors such as ease of learning, ease of use, and presence are obtained from the user questionnaires.

A. Apparatus

The Xbox joystick has two analog sticks for two-dimensional input, one for each thumb. We use the left stick to control the avatar's movement and the right stick to control the avatar's body rotation and to look upward and downward. Meanwhile, body turning can be controlled by rotating the user's head.

The Oculus Touch controller consists of two handles, one for each hand. Each handle has an Axis2D thumb stick at the top panel. We implement a portal method that allows the avatar to only stand at a location. If users want to translate the avatar to another position, they have to press and hold the left handle's stick button and select a destination. Users release the pressed stick button after selecting a target. The avatar moves to the target immediately.

The DHGI method is implemented by Leap Motion that is mounted in front of the Oculus Rift headset. The control action is switched on to work when users raise their hand into the Leap Motion's tracking viewport and pause when the user's hand leaves the tracking range.

B. Experiment Tasks

The main task of this experiment is to simulate a 3D maze that is built in Unity3D game engine. We require participants to walk from the entrance to the target exit.
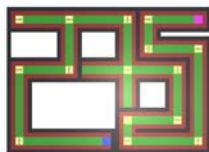

Fig. 3. In the maze scene for the experiment.(the blue tile represents the start position and the purple tile represented end position. Green tiles represent the walkable path. Red tiles indicate the offset area. Dark yellow tiles with arrow indicate prompt directions that represent turning corners. Black tiles represent the maze wall.)

This experiment includes two 3D maze scenes. One (training scene) is used to familiarize the participants with each interactive method. The other is the formal experiment scene as shown in Fig.3. The walkable path contains 16 straight aisles, 14 turning corners (7 for turning left and 7 for

turning right), and 1 obstacle wall that the participants cannot walk through unless they perform a backward walking action. The maze of the road is 4 m in width with 2 m in the center, which represent the walkable area that participants can walk through, and 1 m for each side that is called offset area, which the avatar collides with when it deviates from the walkable area (offset event as shown in Fig.4).
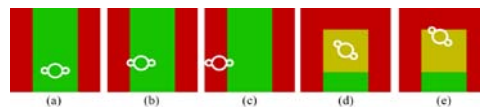

Fig. 4. Avatar walking states.((a) Avatar walks in the walkable area. (b), (c) Offset event occurs when walking. (d) Avatar turning in a corner. (e) Offset event occurs when turning.)

To prevent participants from getting lost, the route is fixed and we placed an obvious directional sign and audio hint at each fork. Participants only need to follow the prompt direction and do not need to find a path by themselves.

C. Participants and Procedurec

A total of 16 volunteer participants (8 males and 8 females, aged 19–22) are recruited from Zhejiang University of Media and Communications. All of them have experienced using a joystick, but none has previously used the Oculus Touch and Leap Motion. Fig.5 illustrates the experiment environment and setting. The environment is quiet and had no other interference.

Fig. 5. Experiment environment

Before the experiment, we introduce the objective to each participant. We require the participants to control the avatar movement from the start point (blue tile) to the end target (purple tile) with each device. After the participants have adapted to each device, they are asked to complete the experiment using one device at the time. We start to record the travel time when the avatar left the start point and stopped when it reach the exit target. Meanwhile, we collect the offset time when the offset event occurred. Finally, participants are asked to complete a short questionnaire to collect subjective feedback on the devices. In this experiment, Latin Square design is employed for counterbalancing purposes.

V. RESULT

The main dependent measures are travel time (speed) and offset time (accuracy). The travel time (time to complete each trial) is separated into walking-straight total time, turning total time, and stopping total time. The offset time (time accumulated when the avatar collided with or entered the offset area) is divided into walking-straight-offset total time and turning-offset total time.

Furthermore, the walking-straight total time consists of forward-walking time (time for walking forward action) and backward-walking time (time for walking backward action).

Turning total time is included with turning right time (time spent on turning the body to the right) and turning left time (time spent on turning the body to the left). The stop time is for the avatar stopping at one place, without movement and body rotation, which is generally meant to identify the orientation when the avatar reached a turning corner.

Meanwhile, we separate walking-straight offset total time into forward-offset time (time accumulated during which the avatar walk out to the offset zone when walking forward) and backward-offset time (time accumulated during which the avatar walk out to the offset zone when walking backward). Turning-offset total time is divided into turning-right offset time (time during which the avatar collided with the offset zone when turning right) and turning-left offset time (time during which the avatar collided with the offset zone when turning left).

A. Travel Time Analysis

TABLE I. MEAN OF TRAVEL TIME AND OFFSET TIME IN SECONDS USING JOYSTICK, PORTAL, AND DHGI METHODS

Travel time/Offset time	Joystick		Portal		DHGI	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Travel time (speed)						
forward-walking-time	51.96	5.7	0	0	49.68	3.53
backward-walking-time	3.24	0.62	8.57	1.71	5.67	1.35
walk-straight-total-time	55.2	5.67	8.57	1.71	55.35	3.88
turning-right-time	11.57	1.2	14.28	3.37	14.49	2.95
turning-left-time	11.48	2.42	16.85	2.18	14.02	3.37
turning-total-time	23.05	2.6	31.13	5.69	28.51	4.58
stop-total-time	2.4	1.48	4.67	0.95	4	1.17
travel-time	80.65	5.93	44.37	6.08	87.86	3.83
Offset time (accuracy)						
forward-offset-time	30.29	6	0	0	14.69	3.24
backward-offset-time	4.21	1.22	0	0	2.2	1.14
walk-straight-offset-total-time	34.5	5.84	0	0	16.89	3.48
turning-right-offset-time	3.14	0.85	0	0	2.06	0.81
turning-left-offset-time	3.04	0.57	0	0	1.57	1.19
turning-offset-total-time	6.18	0.95	0	0	3.63	1.39
offset-time	75.18	5.62	0	0	37.41	4.28

Table I illustrates the travel time and offset time using the joystick, portal, and DHGI methods. The total time of the portal method only consists of turning action that have no forward-walking action and stopping action. Therefore, the value of the forward-walking time, stopping time, and offset time is zero.

TABLE II. TRAVEL TIME ANOVA ANALYSIS

Travel time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	9.931	<0.05
DHGI	Portal	344.952	<0.0001
Joystick	Portal	281.267	<0.0001

Table II reveals that the difference in the value of travel time in each method is statistically significant. According to Table I, the travel time that participants spend to complete the task shows that the portal method is the fastest (44.37 s, SD = 6.08), follows by the joystick method (80.65 s, SD = 5.93), and the DHGI method is the slowest (87.86, SD = 3.83).

TABLE III. WALKING STRAIGHT TOTAL TIME ANOVA ANALYSIS

Walking straight total time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	0.0065	0.936
DHGI	Portal	3047.116	<0.0001
Joystick	Portal	1419.456	<0.0001

Table III shows that the portal method have large statistical significance with DHGI ($F_{(1,30)}$ = 3047.116, p < 0.0001) and joystick ($F_{(1,30)}$ = 1419.456, p < 0.0001). The reason is that the portal method uses jumping action to move from one position to another; thus, the walking-straight speed can be considered infinite. However, no significant effect is observed between DHGI and joystick ($F_{(1,30)}$ = 0.0065, p = 0.936) because they are at the same walking speed (1 m/s) and running speed (3 m/s).

B. Turning Total Time Analysis

TABLE IV. TURNING TOTAL TIME ANOVA ANALYSIS

Turning total time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	16.132	<0.001
DHGI	Portal	1.922	0.1758
Joystick	Portal	24.962	<0.0001

The results in Table IV shows that the turning action had no main significant effect on DHGI and portal ($F_{(1,30)}$ = 1.922, p = 0.1758). The mean of the turning time in seconds is 28.51 s (SD = 4.58) for the DHGI method and 31.13 s (SD = 5.69) for the portal method. Both are different from that of the joystick method (M = 23.05 s, SD = 2.6).

TABLE V. STOPPING TIME ANOVA ANALYSIS.

Stopping time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	10.852	<0.05
DHGI	Portal	1.674	0.206
Joystick	Portal	58.911	<0.0001

We find that the stopping time that the participants took in the DHGI and portal methods are not statistically significant (see Table V). The portal method spends 4.67 s (SD = 0.95), the DHGI method take 4 s (SD = 1.17), and the joystick spends 2.4 s (SD = 1.48 s).

According to the preceding analysis, the difference between the DHGI and joystick methods is mainly due to the turning and stopping actions. When the participants reach a turning corner, they have to identify the orientation and perform a right thumb direction to achieve rotation, which make the stop time slightly longer in the DHGI method. However, the participants only operate the right stick and spend minimal time using the joystick. For the portal method, the participants have to spend more time to relocate because of their disorientation when they turn a corner.

C. Offset Time (Accuracy) Analysis

TABLE VI. WALKING STRAIGHT OFFSET TOTAL TIME ANOVA ANALYSIS

Walking straight offset total time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	100.844	<0.0001
DHGI	Portal	353.093	<0.0001
Joystick	Portal	523.426	<0.0001

Table VI reveals that each method have a large difference in accuracy compared with the others. The offset time presents in Table I shows that the offset time of the portal method is zero. As the portal method uses jumping action from one fixed location to the next fixed target, it can avoid collision with the offset bounce.

Excluding the portal method, the DHGI method (16.89s, SD = 3.48) is more accurate than the joystick method (34.5s, SD = 5.84). The participants unconsciously use the right stick to adjust the movement direction when operating the walking-straight action using the joystick. Furthermore, they always make an overturn leading to deviation which leads a offset event while turning at a corner.

TABLE VII. TURNING OFFSET TOTAL TIME ANOVA ANALYSIS

Turning offset total time ANOVA analysis			
Method	*~Method*	*F(1,30)*	*P-value*
DHGI	Joystick	34.681	<0.0001
DHGI	Portal	101.808	<0.0001
Joystick	Portal	641.773	<0.0001

The ANOVA analysis shows that the three methods had significant differences. When the participants perform rotation at a location in the portal method, they can only control the rotation without moving. They can avert to be out of bounds; thus, the turning-offset total time is zero. In the DHGI and joystick methods, when the participants are rotating the avatar, they may be confused by the movement action because of inertia that causes them to go out of bounds. However, the deviation in the DHGI method (3.63 s, SD = 1.39) is less than that in the joystick method (6.18 s, SD = 0.95).

D. User Satisfaction

Most of the participants (13 out of 16) express preference for the DHGI method. They argue that they find this method more natural, low fatigue, and easier to learn. However, it is slightly slower than the joystick. They can get more motion cues and feel more at ease with the hand model, which is displayed in the viewport. Interestingly, when they intend to stop motion or turning, they prefer to use the grasp gesture to achieve the stopping action. Instead, if they employ the gesture in which the hand leave the viewport, they feel slightly dizzy because of the SISO method.

Considering the joystick method, the participants claim that "although it is faster, it may be likely to cause motion sickness and be less accurate, and sometimes may confuse us about the direction."

The participants feel that the portal method, which move discretely, affect the sense of immersion and can lead to disorientation as they have to find the correct direction to rotate. Furthermore, in the portal method, the participants declare that they intend to stand up when trying to rotate their body backward in the back-walking action when they sit on the chair.

VI. DISCUSSION

The portal method take the least amount of time as the travel time (speed factor) result of the analysis is performed.

The joystick method follows and the DHGI method spends the longest time. However, the portal method use jumping action to move from one location to the next, in which the moving speed is considered to be infinite. Furthermore, the DHGI and joystick methods in the speed of walking-straight action had no significant differences. The difference between the DHGI and joystick methods is mainly affected by the turning and stopping actions. Meanwhile, the DHGI method is more efficient than the portal method. The participants may be confused when the avatar jumps from one location to the next with regard to the portal method. Therefore, they have to spend more time searching for the correct orientation.

By analyzing the offset time (accuracy factor), the portal method obtains the highest accuracy in the walking-straight and turning actions because of its portal jump mechanism. The DHGI method is more accurate than the joystick method. We realize that in the joystick method, the participants tend to adjust the movement direction automatically when traveling straight and always made an overturn when turning.

In the sense of immersion (presence factor), the DHGI and joystick methods exhibits the best performance. However, the disadvantage of the joystick is that it easily made the participants uncomfortable and dizzy, especially when rotating. The rotating action in the portal method can prevent motion sickness because the rotation is synchronized with the physics rotation in the real world. However, the discrete jump influences and weaken the immersion.

According to the users' questionnaire, most of the participants prefer the DHGI method because of its characteristics such as comfort, intuitiveness, low fatigue, ease of learning, and ease of use. Interestingly, the participants feel at ease if they can see the hand model in the viewport when using the DHGI method.

Subsequently, because the sensitivity of the DHGI method is slightly less than that of the joystick, we suggest that this method is more suitable for applications such as exploration or decryption games (see Fig.6) or training courses that do not require high response speed.

Fig. 6. An exploration and decryption game that we designed using DHGI method.

VII. CONCLUSION

We explore the possibility of walk-through in the VR environment on an emerging form of interaction: walk-through method with Leap Motion that provides high-precision hand-gesture tracing in air. The advantage of using a double-hand method is in combining the movement and turning action together. The basic idea is to apply the left palm normal to map the walking/running straight (forward and backward) action, the right thumb to operate turns, the

left-hand grasp gesture to stop the movement, and the right-hand grasp gesture to stop turning. We analyze the usability issues in designing the DHGI method compares with the joystick and portal methods. In user studies, both objective and subjective results shows that the DHGI method is intuitive, low fatigue, and easy to use.

We focus on the walk-through action in VR in this study. We intend to improve the efficiency of this research by trying to adjust the walk-through analysis and introducing additional features such as jumping, squatting, and interacting with virtual objects.

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