Spatial reference frame based user interface design in the virtual reality game design

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***Abstract*—Virtual reality (VR) creates a virtual environment for learning and education as its strong sense of presence and real-time interactivity. Much research focus on the issues of VR hardware and platform, however, little research involve the design of user interface in VR systems. Different from other interface, a VR interface is designed as a floating menu that virtually presented in the front of users. This paper aims to investigate the influence of user experience from the various spatial reference frames and how three spatial reference frames based user interface and the sense of presence impact user performance in the virtual environment. We developed a VR game for fire safety training and evaluated three types of VR user interface commonly used in VR systems. Sixty participants were involved in this evaluation based on the task completion times, completion rates and error rates. Our results show that the spatial reference frames can be critical important to the user experience when users interact with the game in the virtual environment. We found that the user interface of different spatial reference frames also has significant difference in the sense of presence and user performance of virtual environment.**

Keywords: User interface; VR; Virtual environment; Presence; spatial reference frame

I. INTRODUCTION

In the learning and education, virtual reality has been used to create the experience of immersion, interactivity and imagination [1]. Although VR systems have been developed for various purposes, designing user interface for a VR system still encounters many challengers, which includes the lack of hardware pointing tool and unestablished interactive modes [2]. It is partly because the limitation of VR hardware and design fails to meet human cognitive ability. User interface design is an important part of VR system, but the guidelines of user interface design relies on the traditional two-dimensional user interface paradigm on video game, which is difficult to meet the good uses' experience in three-dimensional immersive virtual environment [3].

The challenge is how users can easily find the information in a large free space [4]. Currently, the floating menus are used in the most of VR user interface design, which has no a physical screen similarly to that used in two-dimensional user interface device. The floating menus in virtual environment have a number of issues, including interface manipulation and unsatisfied user experience. For example, it is difficult for users to touch the floating menu with their fingers, which is different from the physical screen menu. When users encounter difficulty to manipulate the interface, they struggle to sort the problems that cause low sense of presence. In this paper, we aim to explore how user interface design influences the immersion and user performance in the virtual environments. Spatial reference frames are main design factors, which have important influence on the user experience in virtual environment. It lacks the sufficient experiment to prove how influence on the sense of presence and user satisfaction in virtual space [5].

II. THE SPATIAL REFERENCE FRAMES

There are three types of the space reference frames in 3D virtual environment, which are Head Reference Frame (HRF), Body Reference Frame (BRF) and Virtual World Reference Frame (VWRF), which are used in the design of user interface. The selection of reference frames may have different influence on the sense of presence and user performance of virtual environment. Some research demonstrates that menus displacement has impacted to users in virtual environment. For example, placing a menu above a user's head may cause the tiredness and using different reference frames affecting the user's performance with elements, such as buttons and slider bars on the menus [15]. Other research suggests that the displacement of a menu can also affect user's perception of distance when manipulating an element by hand, thus affecting accurate positioning [16]. It suggests that virtual environment emphasized spatial activities are more likely to depend on choosing reference frame, which directly leads to enhance performance.

Obviously, virtual reality has an advantage in the development of educational programs that focus on spatial activities, such as exploring the world, learning geography, and various safety training. The teaching tasks rely on the spatiality and immersion in virtual reality, such as learning the knowledge of galaxies or exploring spatial structure of a building from a virtual space. Therefore, we developed a VR game based on fire safety training to investigate the impact of interface design with three types of spatial reference frames. Sixty students were recruited to evaluate immersion and performance in the user interface based on HRF, TRF and VWRF as a set of variables. We collected the data of task completion times, completion rates and error rates [6]. We also collected the data from users' subjective experience via Semi-

DOI reference number: 10.18293/DMSVIVA20-020

structured interview and Presence questionnaire (PQ) to investigate participant's sense of presence.

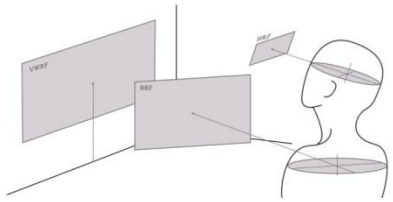

Figure 1. Three types of spatial reference frames, which are commonly used in virtual environment.

III. VR User Interface and Presence

User interface (UI) allows users to interact with a virtual environment [7], such as exploring the environment, switching scenes, adjusting proportions, settings and other tasks. A good user interface provides users instant information, and adapts quickly to the virtual environments and completes the tasks accurately; while a bad user interface can largely reduce the user's experience even cause them to give up. In the early research, Laurel and Mountford [8] highlight the UI design principles including user-oriented, consistent, immediate feedback and others. In the 1990s, research demonstrates that a virtual menu is an effective tool to interact with a virtual environment. To evaluate the menu presentation, Kim et al. [9] compared three positions, which include static with the scene, static with the user view and static with a scene object. However, Kim's study failed to find out the impact of the menu on user' performance. Dachselt and Hübner [10] examined taxonomy of interfaces of controlled menus, in which most of the interfaces were considered as the "simple menu". However, the choice of the division criteria has limited to a particular requirement, which may not require in a given approach [11].

Much research emphasize the relationship between virtual reality interface design and user experience [2] and how the UI design improve user experience and performance in virtual environment. Some studies argue that users' experience and performance are affected by the level of presence in the virtual environment. A higher level of presence will result in higher user experience and performance [12]. When a spatial task is completed through a monitor in the traditional computer, the information is a flat image in human brain [13] and users cannot perceive the depth. The notion of spatial depth is realized by binocular vision to detect the distance and stereoscopic object of three-dimensional space [14]. Therefore, the influencing factors of UI design in virtual environment not only include design factors, such as color and observation in two-dimensional environment, but also involve a three-dimensional space of x, y and z axis, which makes VR interface design more challenging.

The sense of presence is considered as an important factor to create good user experience in virtual environment. Without an interactive environment conformed to the real human life, it is unlikely to have experience of presence. Therefore, the level of presence is also considered as important criteria to evaluate the user experience in the virtual environment.

IV. Research Methods

A. Participants

Sixty students were recruited for this study. They were thirty females and thirty males aged between 20 and 25 and the average age are 23. All participants have some knowledge of fire safety. None of the participants had any experience in VR fire safety training. All participants were randomly divided into three groups (A, B and C) with the same number of participants. The UI design in each group is based on the spatial reference frame factors and all other design is the same (Table 1). During the process in the virtual environment, all the participants' performances were recorded.

TABLE I. Design of experiment groups.

Group	NUMBER OF PEOPLE	SPATIAL REFERENCE SYSTEM TYPE
A	20	HRF
B	20	BRF
B	20	VWRF

B. Experimental design

HTC Vive device was used as the platform for the development of fire safety VR game. We tested three VR user interfaces under three different spatial reference frames, which were HRF interface layout, BRF interface layout and VWRF interface layout. For accuracy, other factors, such as color, font, layout of interface, icon were keep as the same. We explored the different level of presence and user performance with three different interfaces at three different spatial reference frames to each user. User performance includes task completion times, completion rates, and error rates. The task completion times (item/min) was defined as the task completion phase divided by the total manipulating time (in minutes). The completion rates was defined as the number of quests completed divided by the number of all quests in the game. Error rates were the number of mission errors recorded during the game. The level of presence was assessed by semi-structured interviews and PQ. After the semi-structured interview, we asked participants to complete a PQ questionnaire to assess the level of presence in the virtual environment.

C. Procedures

The experimental process is as follows: basic information was collected from the participants, including age, gaming experience, fire safety knowledge and experience (including field exercises and fire-related science videos). All participants were informed the VR game tasks, and received an adaptation period of half an hour to reduce the additional psychological load. We assigned sixty participants with three tasks of user interfaces: HRF-UI, BRF-UI and VWRF-UI.

Before the game began, participants need to familiarize themselves with the game environment. They were required to practice all game with HTC Vive device. Throughout the tests, the system automatically recorded each action and evaluated the user performance of the training, including the

speed of manipulation, percentage of completion, and error rates. After completing the tasks, all participants were required to complete the semi-structured interview and a PQ questionnaire.

V. DISCUSSION

We analyzed the data collected from each participant. The results indicate that user interfaces based on different spatial reference influence the presence and user performance in the virtual environment. Group A that has 20 participants reported 35% prefer the HRF-UI manipulation. The distribution of group B reflected 40% likes and 60% dislikes. The distribution of group C was 55% liked and 45% dislikes. It is clearly that VWRF-UI is much more popular user interface than others. In addition, there is a significant correlation between the three groups' interface design patterns presence and user performance (Table 2). VWRF-UI is positively correlated with expressive presentation, which may be the fact that the user interface based on VWRF enables participants to accurately identify directions in the virtual space. However, when choosing HRF-UI to interact with virtual environment, the influence on user performance is not significant.

TABLE II. THE CORRELATION BETWEEN 3 TYPES OF UI AND USER PERFORMANCE.

spatial reference frame	**Indicators**	**Task completion times**	**Completion rates**	**Error rates**
HRF	Pearson correlation Sig.	0.341 0.197	-0.534* 0.033	-0.827* * 0.000
BRF	Pearson correlation Sig.	0.037 0.021	0.006 0.001	0.154 0.013
VWRF	Pearson correlation Sig.	-0.053 0.819	0.301 0.185	0.533* 0.013

* At the 0.05 level (1-tailed), the correlation is significant.
** At the 0.01 level (2-tailed), the correlation is significant.

VI. CONCLUSIONS

In this study, spatial reference frame, a major factor of interface design in VR games, is analyzed on the basis of experiments by the level of users' sense of presence and user performance. It explores how interface design in different spatial reference frames affect users' presence and user performance. The results show that participants could quickly interact with the virtual environment using HRF-UI, but the level of presence is relatively poor and the score of user performance is low. Using the BRF-UI, participants reported that the interface delayed as the body moved, but no delay in performing the manipulating task, while the level of presence and user performance were moderate. When using the VWRF-UI, most participants reported a high level of presence, and being able to accurately identify directions, complete individual game tasks, but the speed of the manipulation of interface was slow. Therefore, the design of user interface should help people to locate the spatial position and identify the spatial direction. Although the influence of spatial reference frame is important, other factors including the user's cognition, gender difference, and the level of fire safety knowledge will also affect the presence and user performance of users in the virtual environment. Therefore, other factors should also be considered in the design of virtual reality game.

ACKNOWLEDGMENT

The author wish to recognize the support of Shanghai Pujiang Program (18PJ068).

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