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Evaluation of desktop interface displays for 360-degree video

by

Wutthigrai Boonsuk

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Human Computer Interaction

Program of Study Committee:

Stephen B. Gilbert, Co-major Professor

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Iowa State University

Ames, Iowa

2011

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ABSTRACT

A 360-degree video becomes necessary in applications ranging from surveillance to virtual reality. This thesis focuses on developing an interface for a system such as mobile surveillance that integrates 360-degree video feeds for remote navigation and observation in unfamiliar environments. An experiment evaluated the effectiveness of three 360-degree view user interfaces to identify the necessary display characteristics that allow observers to correctly interpret 360-degree video images displayed on a desktop screen. Video feeds were simulated, using a game engine. Interfaces were compared, based on spatial cognition and participants' performance in finding target objects. Results suggest that 1) correct perception of direction within a 360-degree display is not correlated with a correct understanding of spatial relationships within the observed environment, 2) visual boundaries in the interface may increase spatial understanding, and 3) increased video gaming experience may be correlated with better spatial understanding of an environment observed in 360-degrees. This research will assist designers of 360-degree video systems to design optimal user interface for navigation and observation of remote environments.

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CHAPTER 1. INTRODUCTION

A 360-degree video can be generated by combining multiple video feeds from cameras that are circulated to cover 360 degrees on the same horizontal line. This type of view is typically called panoramic view. Large panoramic views up to 360 degrees are commonly used for photographic and artistic purposes. In the human computer interaction field, the 360-degree video is employed for creating an immersive virtual environment in computer simulation, such as pilot cockpit, driving simulator, ship control room, and air traffic control room. Figure 1.1 illustrates a 360-degree video projected on the windows of a cockpit simulator to create an immersive environment.

Figure 1.1. Immersive cockpit simulator

Since a 360-degree video is capable to provide rich information over a typical view size (front view), it could be useful for applications that require observations and/or navigations in wide surrounding areas. For example, teleoperation, such as mobile

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surveillance, remote tour, and search and rescue, could gain benefits in using the 360-degree video for observation purposes. Although projecting a 360-degree video on a large screen may result in better accuracy, when perceiving position and direction of the objects in the scene, multiple operators are required to fully observe the complete 360 degrees. Instead of using a large display, this thesis focuses on horizontally compressing the display view to fit the desktop screen, which allows a single observer for the observation process.

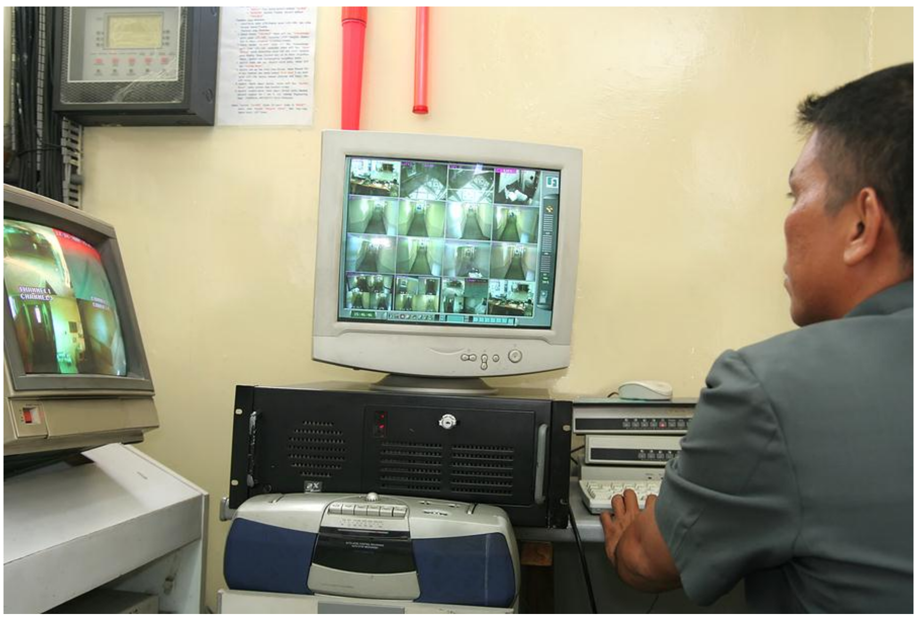

Figure 1.2. Traditional remote surveillance system

A typical monitoring system, such as video surveillance, includes multiple video feeds from either stationary or mobile cameras in extensive areas. A traditional interface for remote camera systems involves observing multiple video feeds over large matrix display arrangements with or without active remote control of the cameras for panning and zooming to observe occluded regions (Figure 1.2). This configuration is usually sluggish and challenging to establish relationships between the video feeds. An interface that provides observers with a complete view at a single glance with minimal perceived distortions of

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information could be an improvement. In contrast to a traditional monitoring system, this thesis focuses on a mobile surveillance system in which cameras are attached to dynamic objects, such as persons, vehicles, or aircrafts to provide remote 360-degree video feeds. These video feeds are usually monitored in real-time and require significant vigilance to examine their contents. To provide accurate and thorough observations, effectiveness of the design of the view interface is crucial.

The interface for displaying the 360-degree video for a single observer requires compressing the display horizontally, which will result in a horizontal distortion of the view. This distortion can disrupt observer's ability to accurately perceive spatial relationships between multiple objects in the camera's view. Human spatial orientation largely relies on the egocentric directions and distances to known landmarks (Foo et al., 2005; Waller et al., 2000). Misperception of these egocentric directions could result in significant errors when determining one's position within a remembered space. Egocentric directions of objects in the display will not necessarily correspond to the egocentric directions of the objects relative to the camera. In light of the potential disruption of normal spatial cognitive processes, the interface should augment the view to leverage our natural sense of presence and spatial awareness.

When the field of view (FOV) becomes larger, humans tend to pay attention on the center view and likely ignore information on peripheral views. However, the main reason for using a 360-degree view is to perceive information from both center and peripheral views. Thus, the interface should help maintain the spatial attention of what occurs in the peripheral views.

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The ultimate goal of this study is to identify the necessary display characteristics that allow observers to correctly interpret 360-degree video images displayed on a desktop screen. This thesis addresses the following research questions:

1) Do different design interfaces affect user's ability to correctly perceive direction in the 360-degree view?
2) Do different design interfaces affect user's understanding of spatial relationships within the observed environment?
3) How do user's ability to perceive the direction relate to user's understanding of spatial relationships?
4) How do different design interfaces affect perceiving information from center and peripheral views of the 360-degree view?

This thesis uses experimental design to examine these questions with various designs of 360-degree view interfaces. This method measures user's performance of given tasks in an observed environment. The results are compared across design interfaces to reveal the best design configuration suitable for mobile surveillance system.

Chapter 2 reviews the literature on several challenges of a 360-degree video, such as video acquisition, video display, and view perception and spatial ability. Chapter 3 presents hypotheses and experimental design for evaluating various designs of 360-degree view interfaces. Chapter 4 describes the system developed for experimental design, including hardware, software, and interface's components. Chapter 5 presents results and analysis of the experiment. Chapter 6 discusses results, conclusions, and future work.

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CHAPTER 2. LITERATURE REVIEW

A 360-degree video is used in several applications, ranging from surveillance, video conferencing, to virtual reality. Surveillance systems typically involve one or more operators that monitor multiple video cameras feeds in extensive remote areas. The 360-degree view becomes useful to this system in order to reduce the number of cameras and blind spots. Surveillance systems can be divided into two broad categories—stationary system and mobile system. Stationary systems involve observing video feeds from a fixed location; whereas, a mobile system allows cameras attached to dynamic objects, such as persons, robots, vehicles, or aircrafts to provide remote video feeds.

This thesis focuses on the mobile system that requires real-time video feeds for navigation and observation in remote environments. There is a difference between the system proposed in this thesis, which utilized a 360-degree video, and the system that involves a rotation within 360-degree image view, such as *Photosynth* (2011) and *Google Street View* (2011). Photosynth and Google Street View use still images to create 360-degree views and allow users to view partial 360-degree views on the screen, while the 360-degree video system utilizes real-time video feeds and displays full 360-degree views on the screen. The 360-degree video system faces challenges in various areas, including video acquisition, video display, and view perception and spatial ability.

2.1 Video Acquisition

The simplest method to produce a 360-degree video can be achieved by combining video feeds from multiple cameras with limited fields of view (FOV) to obtain a wider FOV.

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However, producing a continuous 360-degree view using this method remains a challenge. Several studies have attempted to address this challenge by proposing techniques to combine and register video feeds, including Image Blending (Burt & Adelson, 1983), Piecewise Image Stitching (Foote et al., 2000; Sun et al., 2001), 2D Projective Transformation (Shum & Szeliski, 1997; Szeliski, 1994). Image Blending uses weight average for blending image edges without degrading image details at the border. Park & Myungseok (2009) used this technique to combine video feeds from multiple network cameras for developing a panoramic surveillance system. Piecewise Image Stitching computes the correct lens distortion and mapped multiple images onto a single image plane. This technique combines video images from multiple adjacent cameras for a teleconference system called *FlyCam* (Foote et al., 2000). Projective Transformation uses the development of a video-based system called *immersive cockpit* (Tang et al., 2005). This system combines the video streams of four cameras to generate the 360-degree video.

Other methods to obtain a 360-degree video have used special cameras, such as a camera with fish-eye lens (Xiong et al., 1997), omni-directional camera (Liu, 2008), and a camera with a conic mirror (Baldwin et al., 1999). These cameras produce very high distorted video images. Furthermore, to use these video feeds, image processing algorithms are required to transform input video images into a rectangular view (panoramic view). For example, Ikeda et al. (2003) presented a method to generate panoramic movies from a multiple omni-directional camera called *Ladybug*, developed by Point Grey Research, Inc.

This thesis simulates video feeds in virtual environments and utilizes multiple virtual cameras to produce a 360-degree view. The technique to combine video feeds from multiple cameras is similar to the Piecewise Image Stitching technique. However, since the FOV of

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virtual camera is easily adjustable, combining multiple cameras with small FOV (25-30 degrees) can produce a pleasant 360-degree view without the need for complex image registration. These registration techniques for video feeds will eventually help apply the proposed system to use the video feeds from a real world environment, an extension beyond the scope of this current study.

2.2 Video Displays

After acquiring 360-degree video feeds, the next challenge is to effectively display them to the users. Several types of displays have been developed for displaying 360-degree video feeds. For example, Hirose et al. (1999) presented an immersive projection display, *Cabin*, which has five stereo screens (front, left, right, ceiling, and floor) to display live video. Tang et al. (2005) also proposed the *immersive cockpit* that utilizes a 360-degree video stream to recreate the remote environment on a hemispherical display. Schmidt et al. (2006) presented a remote air-traffic control room called *Remote Tower Operation*. Panoramic video feeds are used to replace the view out of window of the control room. Although the displays in these examples allow users' immersions in the environment, they are not suitable for mobile surveillance systems because multiple users are required to observe the entire 360-degree view.

To compress a 360-degree view into a small display that fits one person's view, a specially-designed interface is needed to view manipulation and arrangement. Several studies presented user interfaces that integrated 360-degree video feeds for a small display. For instance, Kadous et al. (2006) developed a robot system for urban search and rescue, and presented an interface that resembles the head-up display in typical computer games. While

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the main view (front) is displayed in full screen, smaller additional views (left, right, and rear) are arranged around the border of the main view and can be hidden. Another example by Meguro et al. (2005) presented a mobile surveillance system by attaching the omni-directional camera to an autonomous vehicle. Their interface displayed panoramic views from the camera, which were split into two views, each with a 180-degree FOV. Greenhill and Venkatesh (2006) also presented a mobile surveillance system that uses multiple cameras mounted on metro buses. A panoramic view from the cameras was generated for observation. These examples illustrate user's interfaces that might be suitable for a mobile surveillance system; however, existing literature tends to lack the evaluation of their proposed interface, which is critically needed to determine usefulness of the interface. To this researcher's knowledge, effective user interface for a 360-degree view in mobile surveillance system has not been thoroughly investigated.

This thesis evaluated three different user interfaces that utilize a 360-degree view for mobile surveillance system. The interface designs are based on previous implementations from the literature. The first interface, 90-degree x 4, is similar to the interface employed in Kadous's (2006) system. However, all four camera views (front, left, right, rear) are presented at the same size. The second interface, 180-degree x 2, is comparable to Meguro's (2005) mobile system interface, which consists of two views with 180-degree FOV. The last interface, 360-degree x 1, is derived from a typical panorama view interface that has only one single view with a 360-degree FOV.

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2.3 View Perception and Spatial Ability

Another challenge of using a 360-degree view is to correctly identify the spatial relationships between multiple objects within a view. Since displaying a 360-degree view to the user requires compressing the display horizontally, this compression creates horizontal distortion that can disrupt the user's ability to accurately perceive spatial relationships between multiple objects in the 360-degree view. Thus, the effectiveness of an interface could be evaluated by users' abilities to perceive and understand the relationships between objects within the environments. This ability relates to spatial orientation and spatial working memory. Spatial orientation is the knowledge of position and orientation in the environment, and largely relies on the egocentric directions and distances to known landmarks (Foo et al., 2005; Waller et al., 2000); whereas, spatial working memory is the ability to acquire new knowledge with the aspects retrieved from previous knowledge (Logie, 2003). Spatial working memory is required to transform the screen coordinates into body coordinates. This thesis used experiment to evaluate these two spatial abilities when a user performs given tasks using 360-degree view interfaces. Specifically, this thesis uses *pointing task* to determine if the user can understand the direction of objects on a 360-degree view relative to the direction of objects in an observed environment. Further details of the pointing task are described in Chapter 3.

In addition to the ability to perceive relationships between objects within the environment, the ability to retain and recall an object's location is also important in surveillance task. In this thesis, a memory task called the *map task* is used to evaluate this ability between the proposed interfaces. This map task is inspired by the memory tasks used in Alfano's and Hagen's studies (Alfano & Michel, 1990; Hagen et al., 1978). Their

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experiments were conducted in real world environments, where participants were asked to remember the positions of multiple objects in the environment and report their positions on a top-down 2D map. In this thesis, users must translate object's locations observed in the 360-degree view to a top-down map view. Details of the map task are described in Chapter 3.

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CHAPTER 3. METHODS

This chapter describes the experimental design for investigating the effectiveness of various designs of 360-degree view interfaces, including independent variables (interfaces, targets, and tasks), participants, data, as well as the experiment's procedure. In the next chapter, the system for the experiment, including hardware and software setup will be presented.

3.1 Overview

To understand how a 360-degree view can influence people's perceptions and performances, we conducted an experiment to investigate the effectiveness of various designs of 360-degree view interfaces on spatial tasks, including exploring, searching, and identifying locations and directions of particular objects (targets). In this experimental study, an active navigation was used instead of a passive observation, since the active navigation emphasizes more peripheral perception in a large field of view (FOV) (Richman & Dyre, 1999). Each interface design contains different layout configurations of a 360-degree view that might impact performance and navigating ability in a given environment. Since the 360-degree view in each interface is horizontally compressed to fit to a view for a single user, this distortion could potentially disrupt the user's ability to perceive objects in the environment. Naively, one might expect the design interface that combines views, which have the FOV equal or less than human eyes' FOV, to be better than the interface that has one large 360-degree panoramic view (Figure 3.1).

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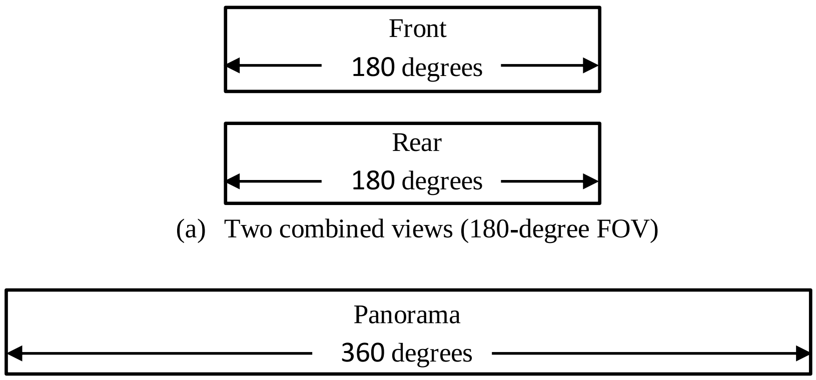

(a) Two combined views (180-degree FOV)

(b) Panoramic views (360-degree FOV)

Figure 3.1. Various design interfaces a of 360-degree

The experiment addresses the following questions:

- *Are there performance differences between the interface designs on a given task?*
- *Can the performance of one task influence the performance on the subsequent tasks?*
- *Do different design interfaces influence user's spatial orientation and spatial working memory to correctly perceive direction in the 360-degree view?*
- *Do different design interfaces influence user's spatial memory to recall target locations?*
- *Is there a relationship between user's ability to perceive the direction and user's understanding of spatial relationships between multiple objects within an environment?*
- *How do different design interfaces affect perceiving information from center and peripheral views of the 360-degree view?*

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3.2 Experimental Design

A 3-D virtual environment was set up to investigate the effectiveness of different designs of 360-degree view interfaces. Although the ultimate purpose of this study was to develop a system interface to use with real world applications, there might be differences in human perceptions and landmark usage between the real and virtual environments. The advantage of creating a simulation in a virtual environment enables the researcher to obtain full control of the environment that participants will experience. It allows for better consistency when repeating the same setting with different participants. Moreover, because participants are immersed in similar control environments, the virtual environment enables us to compare the differences, based on the interface designs.

A within subject study was used in the experiment with order counterbalanced. Each participant utilized three different interface designs to navigate and perform spatial tasks. The goal of this study was to determine how performance on the tasks changes as participants use different interface designs. This experiment had a combination of 3 independent variables:

- Interfaces
    - Four views with FOV of 90 degrees (90-degree x 4).
    - Two views with FOV of 180 degrees (180-degree x 2).
    - One view with FOV of 360 degrees (360-degree x 1).
- Targets (three different target layouts)

3.3 Interfaces

Three different 360-degree interface designs were chosen, based on an informal pilot study with a small number of participants (n = 4) as well as the previous implementation

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from the literature. The views in each interface were simulated by combining views from multiple virtual cameras. These combined views were employed instead of one large FOV camera to reduce distortion or fish-eye effect. Chapter 4 presents more details on how the views in each interface were generated. The size of objects in the views was maintained across all three interfaces. Since the interface was displayed on a 22-inch monitor with the participant sitting approximately one foot away, this yielded a visual angle on the eye of ~30-40 degrees horizontally and ~10 degrees vertically.

The first interface, 90-degree x 4, is a combination of four views: front, left, right, and rear. This interface is similar to the interface employed in Kadous's study for a robot system for urban search and rescue (Kadous et al., 2006). As illustrated in Figure 3.2, each view has a 90-degree FOV and is placed 10 pixels apart from the other. The rear view is placed underneath the front, left, and right view. This first interface is designed, based on the common size of FOV for a video game with additional views to cover 360 degrees.

Figure 3.2. 90-degree x 4, with left, front, right, and rear

The second interface, 180-degree x 2, comprises two views with a 180-degree FOV (Figure 3.3). This interface resembles the interface that Meguro presented for his mobile surveillance system, using the omni-directional camera attached to an autonomous vehicle

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(Meguro et al., 2005). It was also designed to replicate the view based on the natural horizontal FOV of human eyes.

Figure 3.3. 180-degree x 2, with front and rear

The last interface, 360-degree x 1, is a single 360-degree panoramic view as illustrated in Figure 3.4. The design is inspired by typical panorama view interface. It is believed this interface may reduce visuospatial working memory load since the views are grouped into a single element.

Figure 3.4. 360-degree x 1, panorama

3.4 Targets

Each participant was provided all three interfaces in counterbalanced order and instructed to navigate and find targets in the virtual environment. A three-dimensional model of red wooden barrels was used as targets in this experiment. When a target was selected, its color changed to green (Figure 3.5). Although color of the barrel did not test on a participant who has colorblindness, we are confident the participants could distinguish these barrels. In

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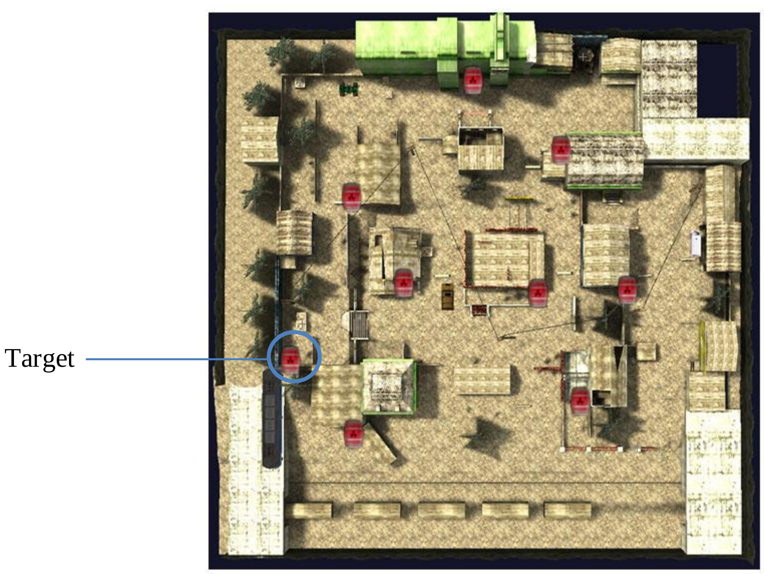
this experiment, a total of 10 targets were placed along the virtual environment for participants to locate.

Figure 3.5. Target color changed to green when it was selected

Layout A

Layout B



Layout C

Figure 3.6. Target layouts A, B, and C

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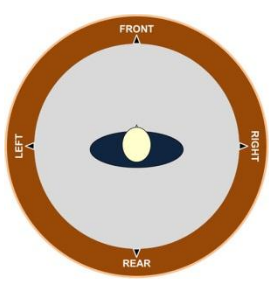
As illustrated in the top-down map of the virtual environment in Figure 3.6, three different target layouts were developed to reduce the effect of the learning curve on target locations. It was expected the target locations in each layout are well distributed, so that difficulty with one specific target layout will not occur. Target layouts and interfaces were randomly matched so that each participant experienced all three target layouts, but may or may not get the same interface-layout pairing as other participants.

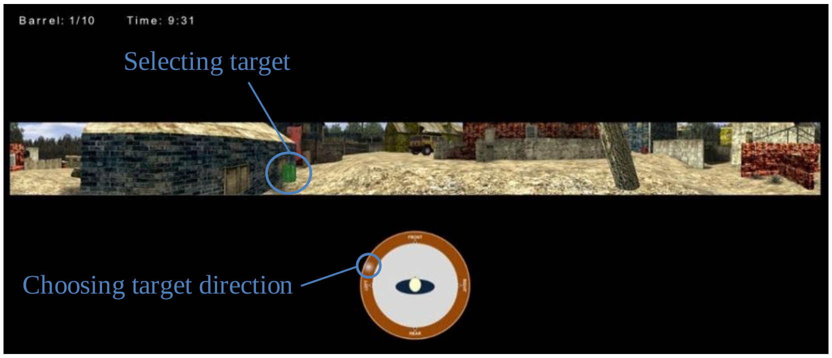
3.5 Tasks

The general tasks for each participant are to navigate, using all three interfaces, and find targets in the virtual environment. There are two main tasks participants are required to perform—pointing task and map task. Since human spatial orientation relies on the egocentric directions and distances to known landmarks (Foo et al., 2005; Waller et al., 2000), the idea for these two tasks is to determine if the participant can utilize the interface to accurately determine both direction and position of objects in space. The results of these tasks are later used to evaluate the effectiveness of each interface. The pointing task is performed during the navigation in a virtual environment, while the map task is performed after completing each interface session.

3.5.1 Pointing task



(a) Compass rose



(b) 360-degree x 1 interface with compass rose

Figure 3.7. Compass rose for pointing task

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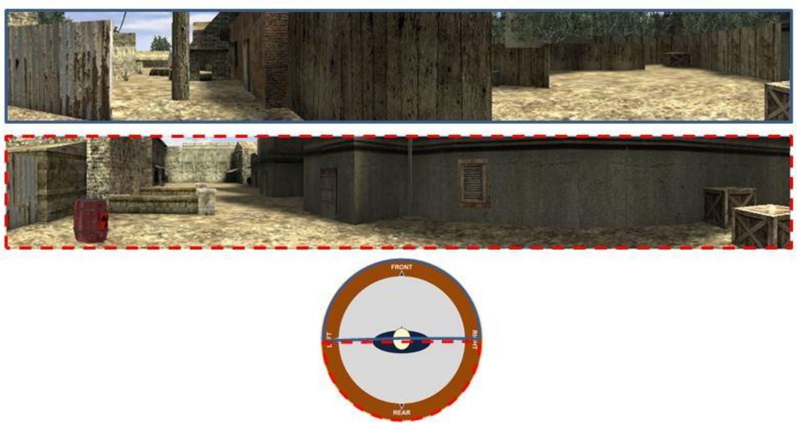
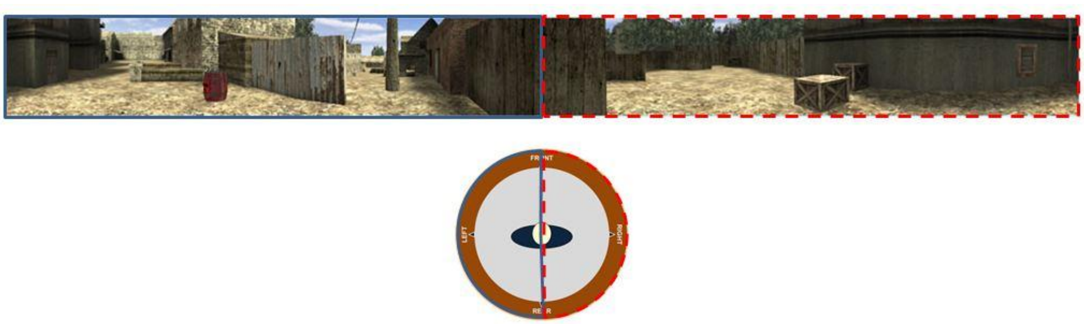
For this task, participants must show if they can understand the direction of targets within each interface virtual environment using the compass rose (Figure 3.7a). Specifically, spatial orientation and spatial working memory are required to complete this task.

(a) 90-degree x 4 interface



(b) 180-degree x 2 interface



(c) 360-degree x 1 interface

Figure 3.8. Relationships between views and compass rose

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Since the view of an interface is compressed to fit the visual angle of participants, direction in the virtual environment is different than the real world environment or typical game environment (first-person shooter style). Participants were instructed and provided training beforehand about the FOV of the view interface. The relationships between the views in each interface and the direction on the compass rose are illustrated in Figure 3.8.

During navigation when participants select a target, they need to identify the relative direction of the target to their heading direction. Participants input their approximated direction on a compass rose as shown in Figure 3.7b. This task was repeated every time the target was selected until all targets were found or the session time expired.

3.5.2 Map task

The purpose of the map task is to determine if individuals can use spatial working memory to recognize and locate objects in the remembered space, as well as to utilize known landmarks based on different interface views. This task is similar to the memory tasks used by Hagen and Alfano in real world experiments (Alfano and Michel, 1990; Hagen et al., 1978). At the end of a given interface session, after locating all 10 targets or the session time expired, participants were asked to locate the found targets on the top-down map as shown in Figure 3.9. Participants were asked to move the target (red barrel) to the recalled location. After saving the target's location, the barrel's color turned grey indicating that no further editing was allowed to that location. This process was repeated until all targets previously found were located.

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Figure 3.9. The top-down map for map task

3.6 Participants

A total of 20 college students and faculty from a variety of majors (4 females and 16 males) were recruited to participate in this study. Participants ranged in age from 18 to 35 years. To gauge their ability to understand a video-game-like virtual environment and navigate using the control keyboard, participants were asked to indicate their number of hours of video game playing per week. The median number of hours spent for video game playing each week for all participants was 1. Most participants did not routinely spend time playing video games. Figure 3.10 illustrates the distribution of participants, based on the number of hours of video game playing per week. Chapter 5 will examine whether the number of hours of video game playing per week influences the participants' performance using view interfaces.

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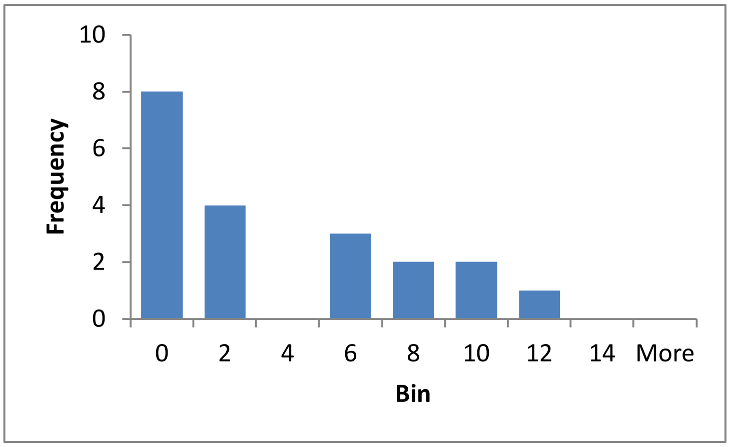

Figure 3.10. Histogram of number of hours of video game playing per week

3.7 Data

To measure the effectiveness of each interface, the following information was recorded from each participant:

- Number of selected targets.
- Target direction is the angle between two vectors that start from the camera position with direction toward the heading direction and the target ranging from 0 to +/-180 (Figure 3.11).

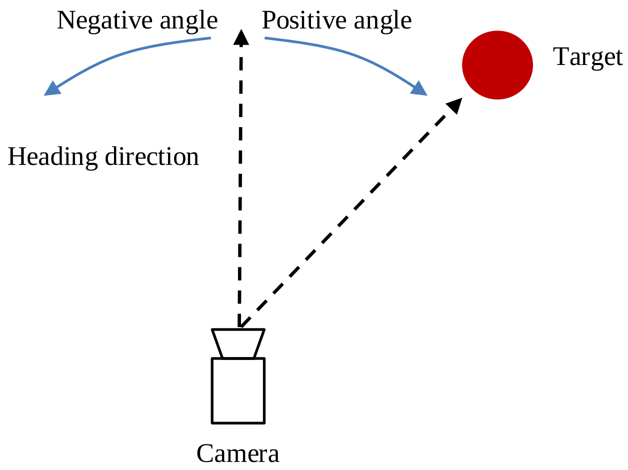

Figure 3.11. Target direction

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- Time spent navigating each interface and the compass rose (between selecting target and selecting direction on the compass rose).
- Distance between camera and the target when the target was selected.
- Target location on the overhead map selected by the participant.

Table 3.1. Questionnaire

1. Which interface for 360-degree viewing did you prefer? a. 90-degree x 4 b. 180-degree x 2 c. 360-degree x 1
2. Which interface for 360-degree viewing allowed you to place the barrels on the top-down map most accurately? a. 90-degree x 4 b. 180-degree x 2 c. 360-degree x 1
3. Which interface for 360-degree viewing allowed you to determine the direction of objects in the scene accurately? a. 90-degree x 4 b. 180-degree x 2 c. 360-degree x 1
4. Which interface for 360-degree viewing provided the most natural feel for navigating through the environment? a. 90-degree x 4 b. 180-degree x 2 c. 360-degree x 1
5. How seriously did you perform the tasks? a. Not at all b. Very little c. Somewhat d. Serious e. Very serious
6. To what extent did you pay attention to the parts of the scene outside the center view? a. Not at all b. Very little c. Sometimes d. Often e. All the time
7. Do you think your performance improved over time (after practicing some with the 360-degree view)? a. Not at all b. Very Little c. Somewhat d. Much better
8. Can you think of some other way that you would like to see the 360-degree view? If yes, please describe or refer to website/game.

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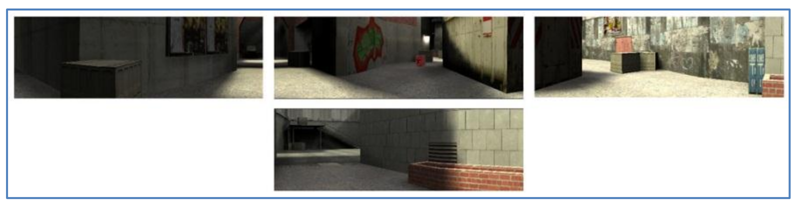
At the end of the three interface sessions, a questionnaire was provided to collect participants' feedback on the interfaces. This questionnaire consists of eight questions (Table 3.1). Questions 1 through 7 are a multiple-choice type of question, and question 8 is an open-ended question. Answers for questions 1 through 4 are expected to correspond to the previous (automated) records during the experiment. The purpose of question 8 is to receive feedback from participants about improvements that can be made on the design of the view interface, as well as initiating ideas for a different interface design that can be considered in a future study.

3.8 Procedure



(a) Training environment

(b) Experimental environment

Figure 3.12. The top-down view of two environments

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The view interfaces and target layouts were chosen in counterbalanced order for the participants. When participants arrived, they signed an informed consent form (5 minutes). Before performing any tasks, at the beginning of an interface session, participants were trained to use the view interface for finding five targets within 5 minutes using a tutorial environment as illustrated in Figure 3.12a. Participants were also trained to perform the pointing task for each interface session, but they were trained to perform the map task only for the first interface session. After the trainings, participants were provided 10 minutes to locate 10 targets in the experimental environment (Figure 3.12b) using the view interface as previously trained. Participants performed the pointing task during the navigation. After 10 targets were found or the 10-minute time expired, participants were asked to locate the target locations on the top-down map. At the end of the experiment (after all interface sessions were completed), participants were asked to complete the questionnaire. The entire experiment for each participant took less than an hour.

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CHAPTER 4. THE SYSTEM

This chapter describes a system developed for the 360-degree view experiment. This includes the hardware setup, software development, procedures used to create the interface components, such as virtual environment, 360-degree views, targets, compass rose, and top-down map, as well as the data collection process.

4.1. Hardware Setup

The system was set up on a personal computer with a Radeon ATI 5750 graphic card. The interface was displayed on a 22-inch monitor with the participant sitting approximately 12 inches from the screen. This yielded a visual angle on the eye of ~30-40 degrees horizontally and ~10 degrees vertically as shown in Figure 4.1.

4.1.1. Touch system

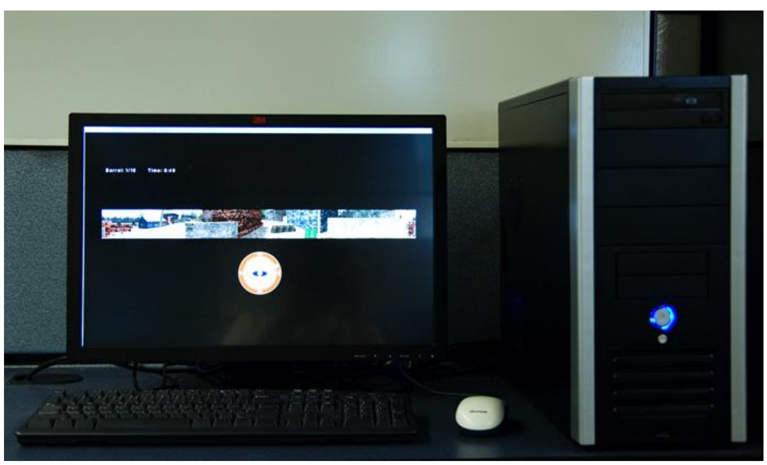

Figure 4.1. The 360-degree view system

The 360-degree view system utilized a 3M multi-touch display (Figure 4.1) to present views from multiple virtual cameras and to receive participants' responses for the tasks. The

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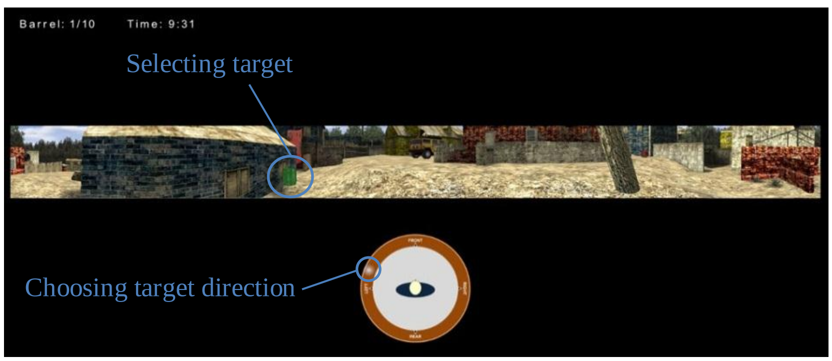
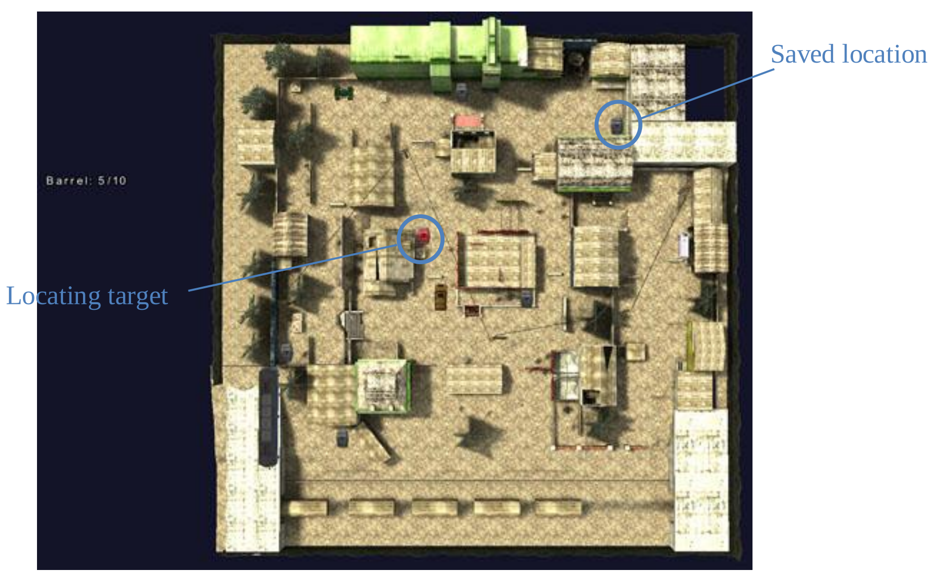
resolution was set at 1680 x 1050. A touch system was used to provide a quick and intuitive interaction with 3D targets in the scene. For the pointing task, the touch system allowed participants to tap on the targets with their finger to select them. The target's color changed to green when it was selected. Immediately after selecting the target, a compass rose appeared underneath the scene views for participants, prompting them to select the relative direction of the target. When participants tapped on the compass rose, a small blue dot appeared on the compass rose to indicate the direction selected (Figure 4.2a).



(a) Pointing task



(b) Map task

Figure 4.2. Touch system for pointing task and map task

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For the map task, the touch system allowed participants to tap on the top-down map to identify the location of a target. A red barrel image appeared at the tapping point. Participants could drag the red barrel image to any location on the top-down map and save the location by pressing the space bar on the keyboard. Once a location was saved, the barrel changed into a grey color and the location of the image could no longer be modified (Figure 4.2b).

4.1.2 Controller

In addition to the touch system, a keyboard was also used to provide additional control. Participants used the arrow keys (up, down, left, and right) on the keyboard to control the direction of the virtual camera (forward, backward, left, and right) to navigate in the virtual environment. For the map task, participants used the space bar key to save the location of a target on the top-down map.

4.2. Software Development

4.2.1. Virtual environment

The virtual environment was created using Open Source graphics game engine called Irrlicht (2011) with C++ and OpenGL. Two environments were developed in this study—tutorial environment and experimental environment. The tutorial environment was used for the training session to allow participants practice with the view interface and the control system. The tutorial environment was created using a 3D model of a small city block (Urban Zone (1), 2011) with a dimension of 225 (width) x 275 (length) square feet (Figure 4.3). The city block consisted of grey painted brick walls, shipping containers, and small green ponds. Five targets (red wood barrels) were placed inside this city block for training purposes.

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Figure 4.3. Tutorial environment

Figure 4.4. Experimental environment

The experimental environment was created using a larger 3D model of a hilly village (Urban Zone (2), 2011) with a dimension of 360 (width) x 360 (length) square feet (Figure 4.4). This environment was used to observe and collect data for the study. The experimental environment consisted of uneven terrains, several rectangular buildings, a large green cement

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building, wood fences, and wooden boxes. Ten red barrels are located throughout this environment as the targets.

4.2.2. Landmarks

Landmarks are essential for spatial orientation and navigation in a virtual environment. From the pilot study, it was determined the original experimental environment was too difficult to navigate and identify the location of targets on the map task. Additional landmarks added to the experimental environment included color on the building walls and several 3D models of vehicles, such as a green dune buggy, yellow SUV, and ambulance.

4.2.3. The 360-degree view

The 360-degree view can be created by combining multiple views of virtual cameras circularly arranged on the same horizontal level in the 3D virtual environment. To display these views with the cameras, one could use a multiple viewport rendering technique to supply the view from the virtual camera to display on the screen. However, not all game engines support this rendering technique. Render-to-texture is another technique in which the camera view is furnished as a texture on a specific surface. This technique is typically used to create a video texture in a 3D virtual environment. This video texture can display a view from the camera positioned anywhere in the space. Multiple viewport rendering and render-to-texture techniques can be implemented with the Irrlicht game engine. However, in a pre-development of the 360-degree view system, it was determined the render-to-texture technique allowed participants to easily manipulate the shape of the view that might be useful for redesigning a 360-degree view interface in a future study. For example, the render-to-texture technique can map the camera view on any irregular shapes, such as curve, circle, trapezoid, etc., while the multiple viewport technique is restricted to only rectangular shapes.

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Moreover, the render-to-texture technique also allows for easier rear-view mirror effect creation by flipping the normal direction of the surface. The rear view mirror effect was applied to 90-degree x 4 and 180-degree x 2 interfaces in the study.

In the 360-degree view interface, a group of moving cameras and one fixed camera were used. Views from multiple moving cameras were rendered as textures and subsequently mapped onto rectangular surfaces arranged and positioned outside a 3D scene. The fixed camera displayed these texture views on the monitor screen. Figure 4.5 illustrates how the group of moving cameras and the fixed camera are set up.

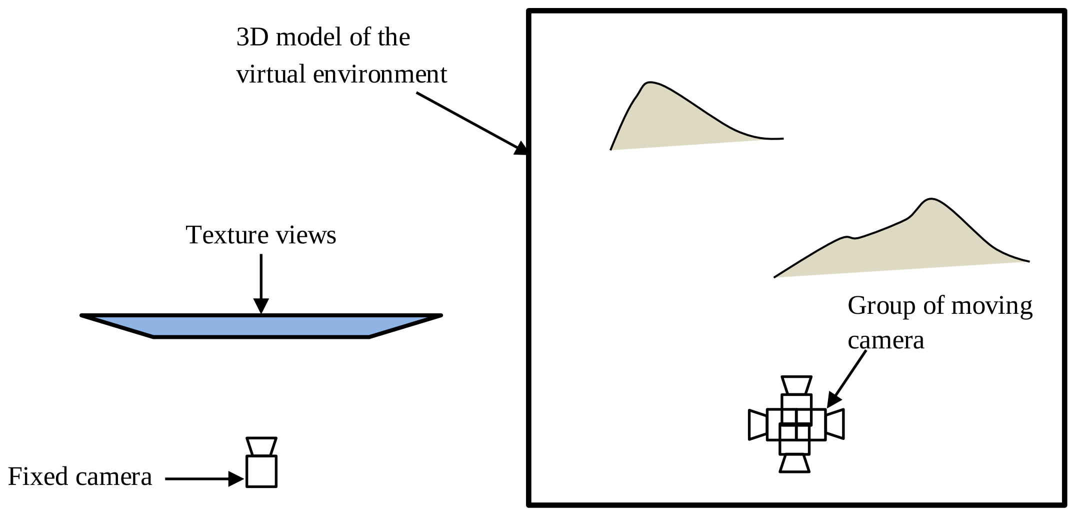

Figure 4.5. Fixed camera and moving camera in the 360-degree view interface

Since there is a limitation of game engines to create a camera with FOV larger than 180 degrees, at least two cameras are needed to display 360-degree views. Moreover, as illustrated in Figure 4.6, distortion of the image increases tremendously when FOV of the camera is set from 90 to near 180 degrees. Thus, this thesis combined multiple views of cameras with small FOV (~25 to 35 degrees) for creating view of each 360-degree view interface. For each interface, a different number of (moving) cameras, that could be arranged

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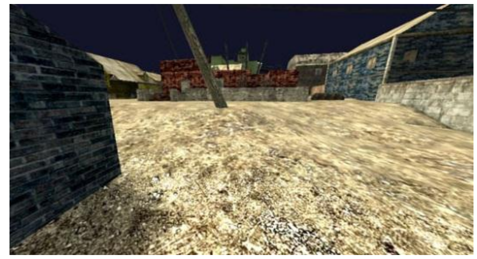
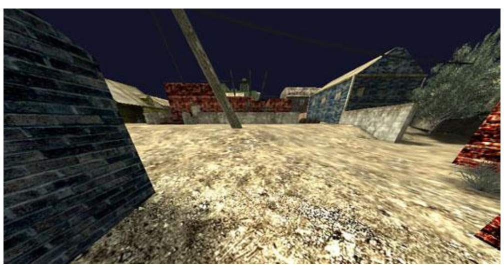
and fitted within the interface design, was utilized. The 90-degree x 4, 180-degree x 2, and 360-degree x 1 interfaces employed 12, 14, and 11 moving cameras, respectively.

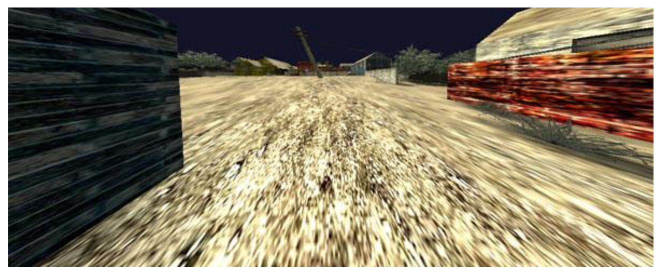
(a) FOV = 30 degrees



(b) FOV = 90 degrees



(c) FOV = 135 degrees



(d) FOV ≈ 180 degrees

Figure 4.6. Views from virtual cameras with different FOV

Each moving camera was circularly rotated with equal angle space from each other. To move the cameras simultaneously in 3D space, one camera was assigned as a front camera that can move as the user manipulates it. The remaining cameras (in the group) followed the same transformation as this camera. For each interface, texture views of the moving cameras were arranged as shown in Figure 4.7. The front camera was set as camera #1 and the camera numbers were incremented in counter clockwise order. The cameras with * were rendered on surfaces, where their normal directions were reversed to create a rear view mirror effect.

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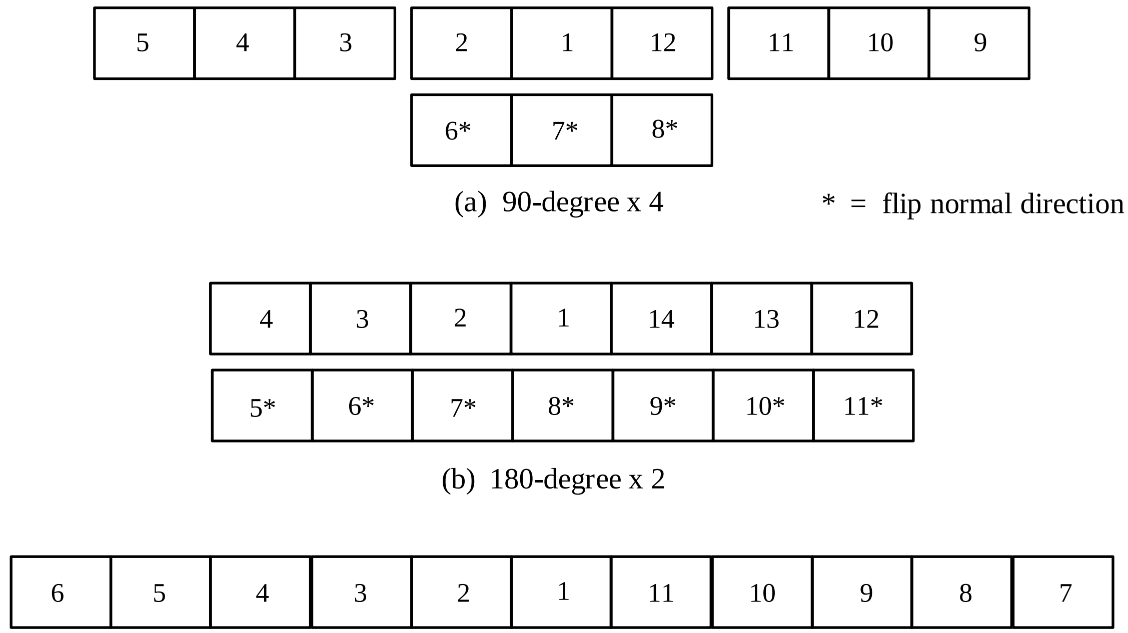

(a) 90-degree x 4

(b) 180-degree x 2

(c) 360-degree x 1

Figure 4.7. Texture views arrangements

To maintain the same size of objects in the 3D scene across all three interfaces, the scene aspect ratio (width x height) was set to 4:3. However, because the number of moving cameras in each interface was different, texture views for each interface had different dimensions, when they were displayed on the monitor screen. Therefore, the distance between the fixed camera and the texture view had to be adjusted so the size of texture views on the monitor was equivalent for all interfaces. Figure 4.8 illustrates an example of how the distance between fixed cameras and the interfaces should be adjusted. Numbers in the following example are used for demonstration purposes only and are not the actual numbers used to develop the 360-degree view interfaces.

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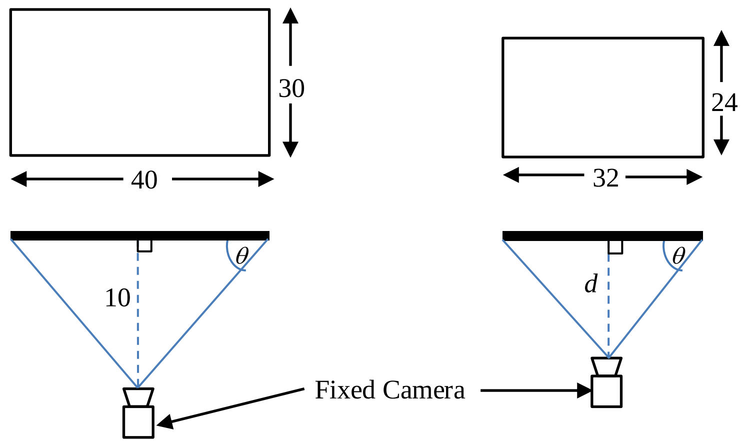

Figure 4.8. Distance adjustment from the fixed camera

In this example, there are two texture views with dimensions of 40 x 30 units and 32 x 24 units (width x height), respectively. The fixed camera in the first setting has a distance of 10 units from the texture view. In the second setting, distance (*d*) from the fixed camera to the texture view needs adjusted so the texture views for both settings appear the same size on the monitor screen. The equation below shows *d* is computed by using $\tan\theta$ for the first setting. The results show the fixed camera of the second setting needs to be closer to the texture view.

$$\tan\theta = \frac{10}{20} = \frac{d}{16}$$

$$d = 8 .$$

4.2.4. Target selection

Similar to typical game engines, Irrlicht uses ray intersection to pick objects in the 3D scene. A ray is first generated from the screen coordinate of a picking point. Then, the

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collision (intersection) between this ray and the object in the view is identified. However, this method only works when camera views are directly rendered on the monitor screen (i.e., multiple viewport rendering technique). For the 360-degree view system, images from the moving cameras are rendered on the textures and displayed by a fixed camera to the monitor screen. If the ray intersection method was used, choosing a picking point on the screen would result on only selecting the texture views. To solve this problem, a new ray must be generated, based on the view coordinate of moving cameras. This view coordinate is equivalent to the screen coordinate view of a single camera. Figure 4.9 illustrates the process of ray intersection for the 360-degree view system.

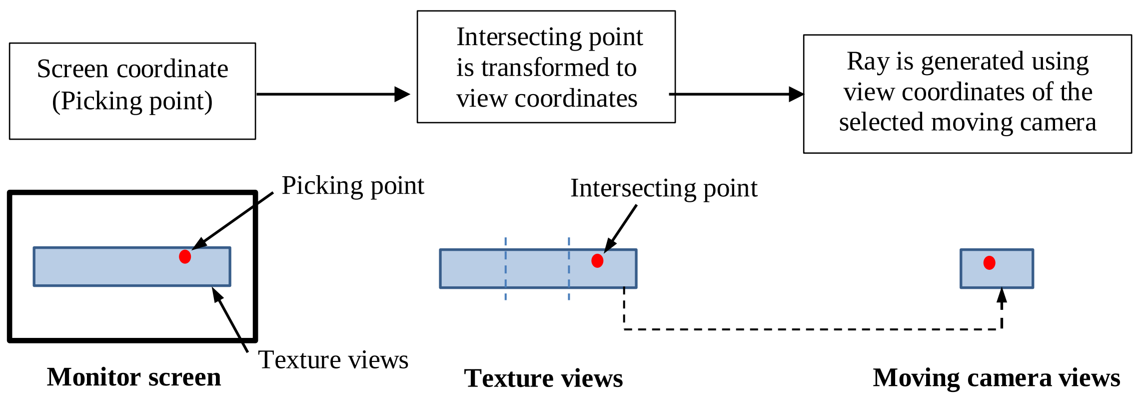

Figure 4.9. Process of ray intersection for the 360-degree view

In the experiment, when a user taps on the monitor screen, a ray is generated from this picking point, based on the screen coordinate. If the ray intersected with one of the texture views, it meant the view of that moving camera was selected. This intersecting point was transformed to the view coordinate of the selected moving camera. A new ray was computed using this view coordinate and intersection with objects in the scene was identified.

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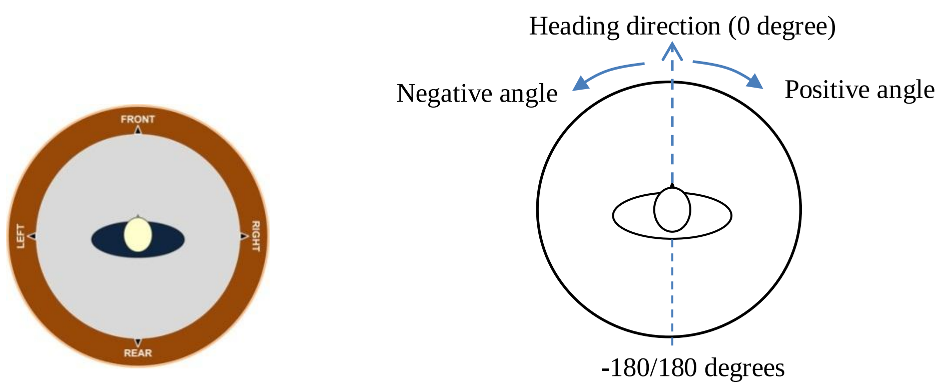
4.2.5. Compass rose

The compass rose was created by rendering a 2D image (Figure 4.10a) on the 2D plane of the monitor screen. The ray intersection method was used to detect a position where participants picked on the compass rose. Then, the angle between the heading direction (front label) and the picking point was computed. If the picking point was located to the left of the heading direction, a negative angle (0 to -180 degrees) was returned. On the other hand, a positive angle (0 to 180 degrees) would indicate the picking point was located to the right of the heading direction. The angle was automatically recorded and later used as one of the criteria for evaluating effectiveness of the interfaces.



(a) Compass rose image (b) Angle computed

Figure 4.10. Compass rose

4.2.6. Top-down map selection

The top-down map was created by positioning the camera above a 3D model of the virtual environment. The ray intersection method was used to identify the location of a target the user provides. The 2D target image was drawn using screen coordinates, which allowed the user to manipulate its location above the top-down map. Once the user saved the target location, a ray was automatically generated from the screen coordinate and an intersection

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(3D position) on the map was determined. Although the 3D position was recorded, because users only perceived the location of target in two dimensions on the top-down map, only the 2D coordinate (XZ) was used for analyzing the map task in Chapter 5.

4.3. Data Collection

Three log files were used to record the dependent measure during the experiment. Two log files, navigating path and pointing task results, were generated when the user navigates the scene in the virtual environment. The purpose of logging the navigating path was to track the location and heading direction of participants on the screen. A pointing task log was used to measure participants' performance with the pointing task. During the map task, a log of map tasks was generated to record the location of the targets that users selected on the top-down map. Details of the data obtained in each log file are listed below.

Navigating path (recorded every 1 second until the interface session ended).

- Time in virtual environment (seconds).
- Participant's position (moving camera position) – X, Y, Z coordinates.
- Participant's heading direction – X, Y, Z direction.

Pointing task

- Target name.
- Time when the target is selected (seconds).
- Time when the compass is selected (seconds).
- Relative angle selected by user on the compass rose (described in Section 4.3.5).

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- Relative angle of the real target (computed angle between the heading direction and the selected target).
- Participant's position (moving camera position) – X, Y, Z coordinates.
- Ray intersection position on the target – X, Y, Z coordinates.

Map task

- Target ID number.
- Target position where participants locate on the top-down map (described in Section 4.3.6).

Data in these log files are used for the data analysis in Chapter 5 to evaluate the effectiveness of each interface.

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CHAPTER 5. DATA ANALYSIS

This chapter presents the results of participants' performances, based on the two given tasks— pointing task and map task—used as indicators of effectiveness of the 360-degree view interfaces. This chapter also discusses: (1) how previous gaming experiences may influence the participant's performance for these two tasks, (2) how participant's questionnaire responses could be compared with the results from experimental data, and (3) how peripheral views could be utilized to navigate, using the different interfaces. Figure 5.1 illustrates the list of variables in the study. This chapter will analyze dependent variables and a moderating variable.

Independent variables

Interfaces

- 90-degree x 4
- 180-degree x 2
- 360-degree x 1

Target layouts (3 layouts)

Dependent variables

Performance

- Pointing errors
- Map errors

Other

- Distance to targets
- Compass times
- Travel distances

Moderating variable

- Prior video game experience

Figure 5.1. List of independent variables, dependent variables, and moderating variable

5.1 Performance Measured Variables

Participants' performances were measured by computing the difference between the values estimated by participants during the experiment and the actual values computed by the system. The results were compared across all design interfaces.

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5.1.1 Pointing errors

For each of the 360-degree view interfaces, participants were asked to perform the pointing task to identify the direction of the target relative to their heading direction. Pointing errors measured the accuracy of a participant's response for each target direction as compared to the actual target direction. Based on a participant's heading direction, the relative angle selected by participants on the compass rose and the relative angle of the real target were recorded as described in Section 4.4 of Chapter 4. Pointing errors are computed by finding the absolute differences between these two angles. Figure 5.2 illustrates an example for computing a pointing error.

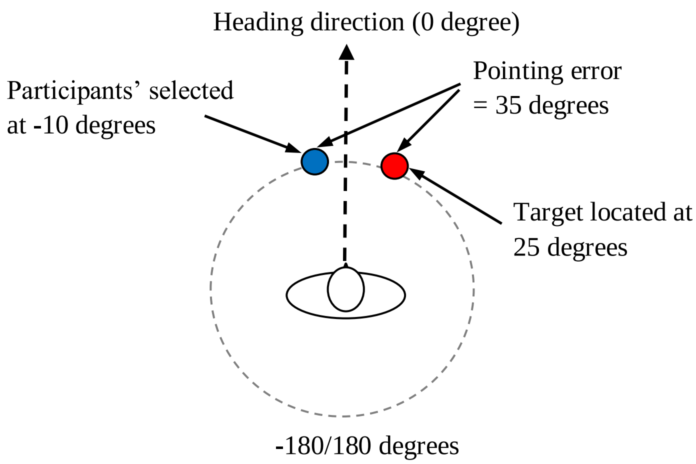

Figure 5.2. Example of a computing pointing error

In this example, the participant estimated the relative angle of the target from the heading direction as -10 degrees. However, the relative angle of the target's actual location from the participant's heading direction was 25 degrees. There are two possible results from the calculation—35 and 325 degrees. While 35 degrees is from the absolute value of the difference between 25 and -10, 325 degrees is computed from the difference between the 35

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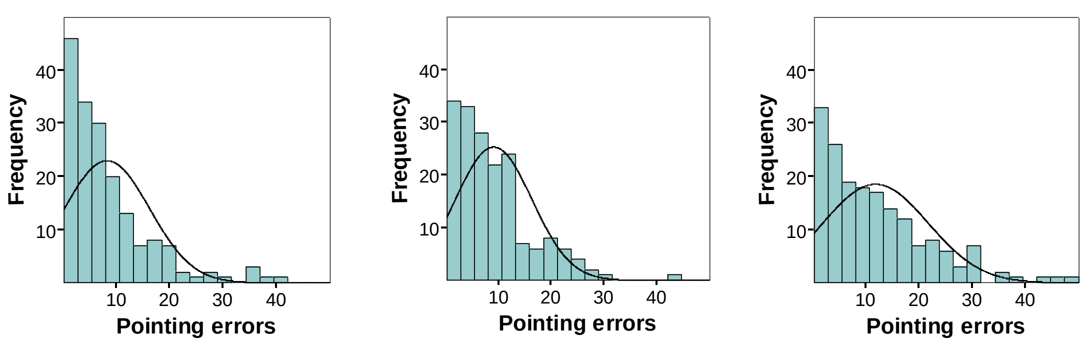
and 360 degrees. However, it is assumed the participants made minimal mistakes to determine the relative angle; thus, in this case, the pointing error is 35 degrees.

The pointing error is computed for all selected targets for each interface. In this study, experimental data were collected from a total of 20 participants. However, data from two participants are excluded from further analysis because their pointing errors were extremely high (more than six standard deviations) and inconsistent, compared to the data from the other participants. Table 5.1 illustrates the descriptive statistics of pointing errors for all three interfaces from the 18 participants.

Table 5.1. Descriptive statistics of pointing errors

	N	Minimum	Maximum	Mean	Std.	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
90-degree x 4	176	.110	40.339	8.183	8.012	1.771	.183
180-degree x 2	176	.106	43.493	8.982	7.281	1.387	.183
360-degree x 1	176	.178	49.591	11.717	9.912	1.213	.183
Valid N (listwise)	172						



(a) 90-degree x 4 (b) 180-degree x 2 (c) 360-degree x 4

Figure 5.3. Histograms of pointing errors

As presented in Table 5.1, the skewness of the pointing errors for the three interfaces is greater than 1. This is also supported by the highly skewed right distributions of the data from all interfaces illustrated in Figure 5.3. Pointing errors across the three interfaces tend to

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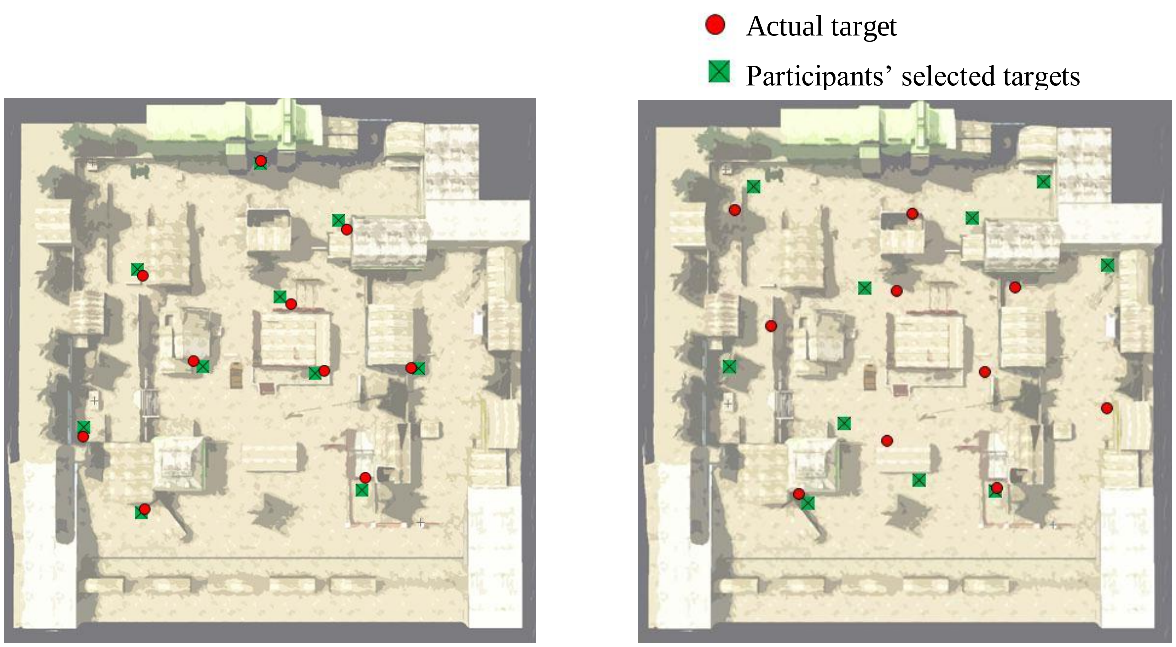
concentrate on the lower values (right-skewed). Thus, the present study uses the median to represent the center of the pointing errors distribution for each participant.

5.1.2 Map errors

At the end of a given interface session, participants were asked to locate targets found during the pointing task on the top-down map. Map errors are the Euclidean distance between participants' selected locations and the actual targets' locations, measured in feet.



(a) (b)

Figure 5.4. Example results of map task with the actual target locations

Finding the appropriate pairs between participants' selected locations and the actual targets' locations can be difficult because there is no relationship between these locations when participants perform the map task. Figure 5.4 illustrates two examples of the map tasks' results. While it might be easy to identify the pairs between participants' selected locations and the actual target locations in Figure 5.4a, participants' selected locations can be scattered across the map away from actual targets' locations, as illustrated in Figure 5.4b. Thus, this

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study considers minimizing the sum of squared differences (*SSD*) between the participants' selected locations and the actual target locations.

Several steps will be used to determine the minimum *SSD*. First, all possible matches between participants' selected locations and the actual targets' locations must be considered. The permutation method identifies the possible arrangement of participants' target locations that will be paired with the actual target locations. For example, if 10 chosen locations must be matched with 10 actual target locations, the total sets of the matches will be $P(10, 10)$ = 10 factorial solutions (3,628,800). Although this number of calculations is high, it can be performed in less than two minutes. Then, the *SSD* is computed for each match and the lowest summation of *SSD* for the possible matches is selected as an optimal solution. This method is straightforward, if the number of found targets is equal to the number of total targets. However, if participants could not find all targets, the number of solutions will be the possible arrangement of the found targets $\{P(n, n)\}$ multiplied by the possible arrangement of the real target $\{P(n, m)\}$, where n = number of the found targets and m = total number of the real targets. For example, if eight targets were found from the total of 10 targets, the possible sets of the matches will be $P(8, 8) \times P(8, 10) = 40{,}320 \times 1{,}814{,}400 =$ 73,156,608,000.

When the optimal solution (lowest SSD) is found, the distance error (map error) is computed for each pair of participants' selected locations and the actual target location. Figure 5.5 shows two examples of matching, using the *SSD* method to determine the optimal solution.

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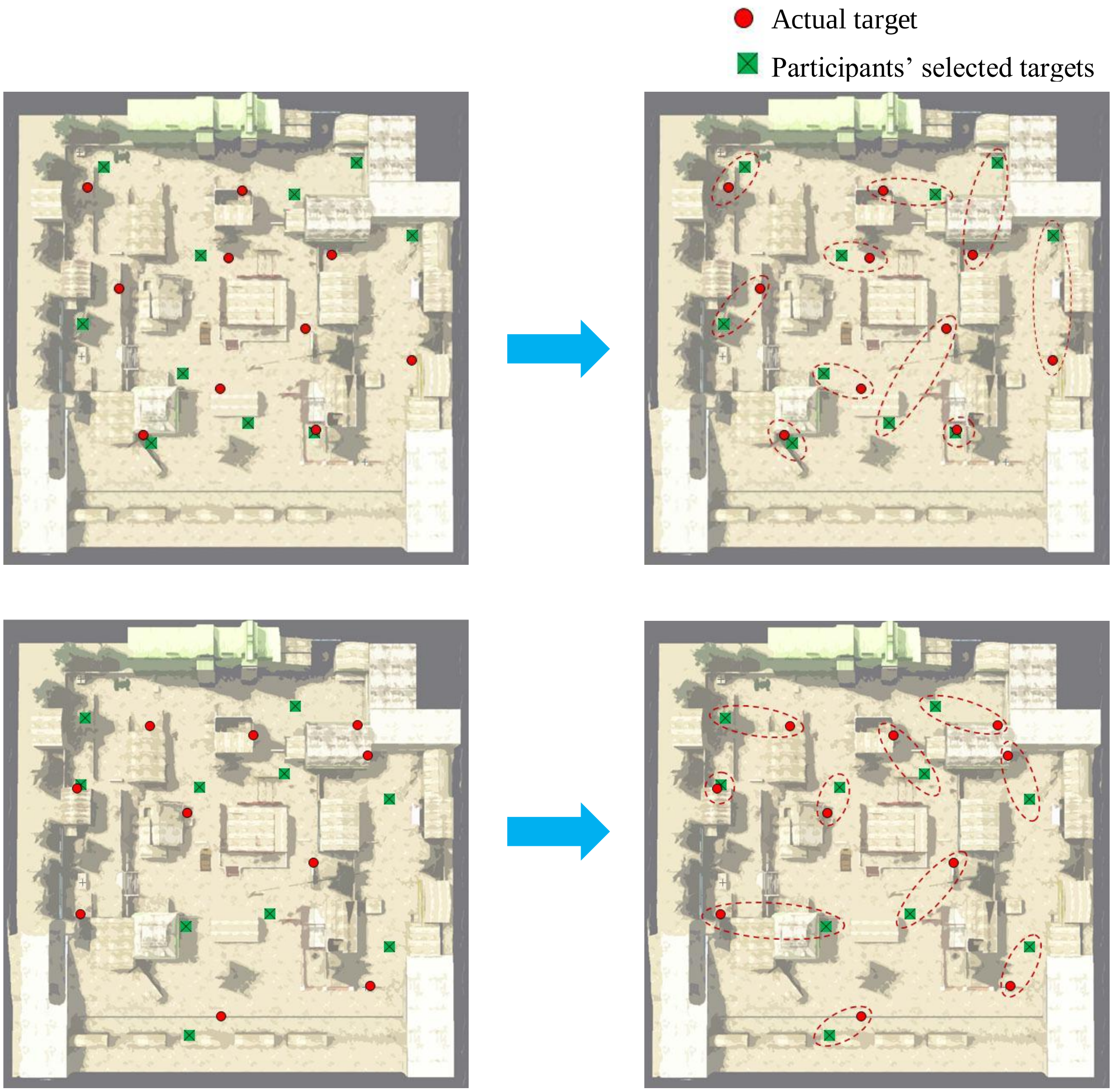

Figure 5.5. Examples of matching using *SSD*

In this study, map error data have a similar characteristic to the pointing error data described in Section 5.1.1. As reported in Table 5.2, the skewness of data for the three interfaces is higher than 1. The distributions of data for the three interfaces are also right-skewed (Figure 5.6). Thus, the median is used instead of the mean to represent the center of the data distribution for each participant.

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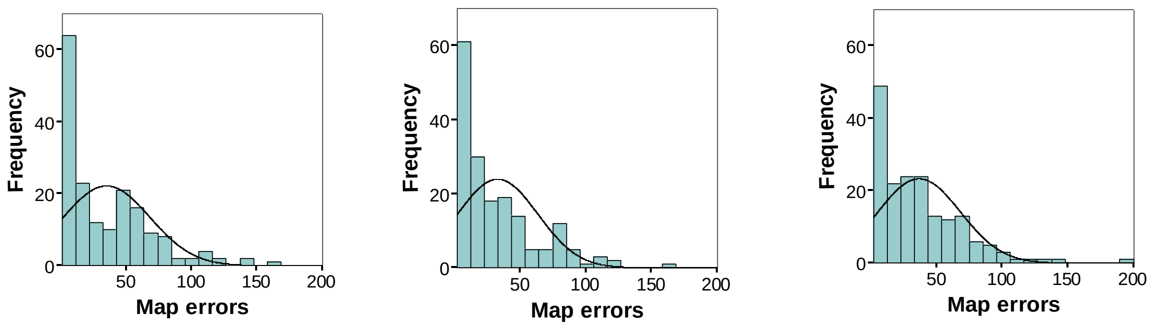
Table 5.2. Descriptive statistics of map errors

	N	Minimum	Maximum	Mean	Std.	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
90-degree x 4	176	.643	159.238	34.617	33.229	1.251	.183
180-degree x 2	176	1.055	168.148	32.104	30.719	1.420	.183
360-degree x 1	176	1.774	192.160	36.464	31.436	1.476	.183
Valid N (listwise)	172						



(a) 90-degree x 4 (b) 180-degree x 2 (c) 360-degree x 4

Figure 5.6. Histograms of map errors

5.2 Other Measured Variables

Other measured variables that might influence participants' performances include the distance to targets, compass time, and travel distance. Distance to target is the distance measured from the participant's position to a target, when participant selects the target in the pointing task. The compass time is the time the participant spends between selecting the target and identifying the target direction on the compass rose. This compass time may be an indicator of the difficulty to identify the target direction using the 360-degree view. Finally, travel distance is the total distance that participants used during navigation in the virtual environment using each interface. Figure 5.7 illustrates two examples of participants' paths used to compute the total travel distances.

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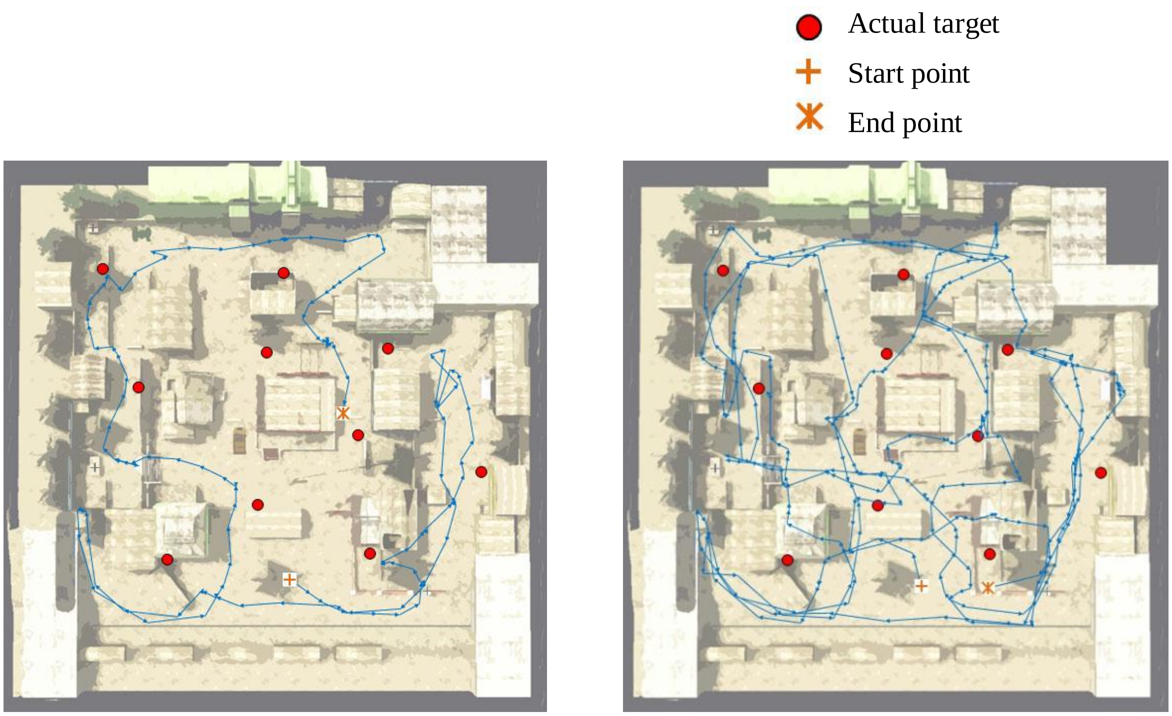

Figure 5.7. Examples of travel paths

5.3 Results

This section uses data from 18 participants, who utilized all three interfaces, 90-degree x 4, 180-degree x 2, and 360 x 1, in counterbalanced order.

5.3.1 Performance

5.3.1.1 Pointing performance

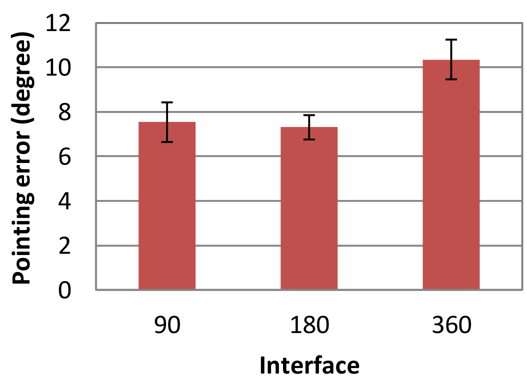

Figure 5.8. Pointing errors of interfaces

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Pointing errors are used as one of the indicators of effectiveness of the interface. The purpose of using a pointing error is to evaluate which interface yields the best performance to determine the direction of objects in the space. Figure 5.8 shows the average of pointing errors for the three interfaces computed from the median of pointing errors for each participant. The average pointing error for 180-degree x 2 interface is the lowest among the three interfaces. The average pointing errors for 90-degree x 4 interface is slightly higher than the 180-degree interface. The average pointing errors for 360-degree x 1 interface is the highest.

Table 5.3. Pairwise comparison of pointing errors

Measure: MEASURE_1

(I) Interface	(J) Interface	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
90	180	.235	.956	.809	-1.781	2.251
	360	-2.802*	1.196	.032	-5.324	-.279
180	90	-.235	.956	.809	-2.251	1.781
	360	-3.037*	.861	.003	-4.853	-1.220
360	90	2.802*	1.196	.032	.279	5.324
	180	3.037*	.861	.003	1.220	4.853

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

One-Way Repeated-Measures ANOVA is used to analyze the median result for pointing errors. The analyzed results indicated a significant effect of different interfaces on pointing errors, F (2, 34) = 5.54, p < .01. In Table 5.3, the post hoc analysis shows the pointing errors between 90-degree x 4 interface and 180-degree x 2 interface are not significantly different (p = .809), while the pointing errors for 360-degree x 1 interface is

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significantly different from both the 90-degree x 4 interface (p = .032) and the 180-degree x 2 interface (p = .003).

5.3.1.2 Map performance

For the map task, map errors are used to evaluate the effectiveness of each interface to aid recall of the targets' locations. To investigate whether participants' estimates of the target location are more accurate than randomly generated results, a total of 10 targets were randomly placed inside feasible regions of the map (Figure 5.9).

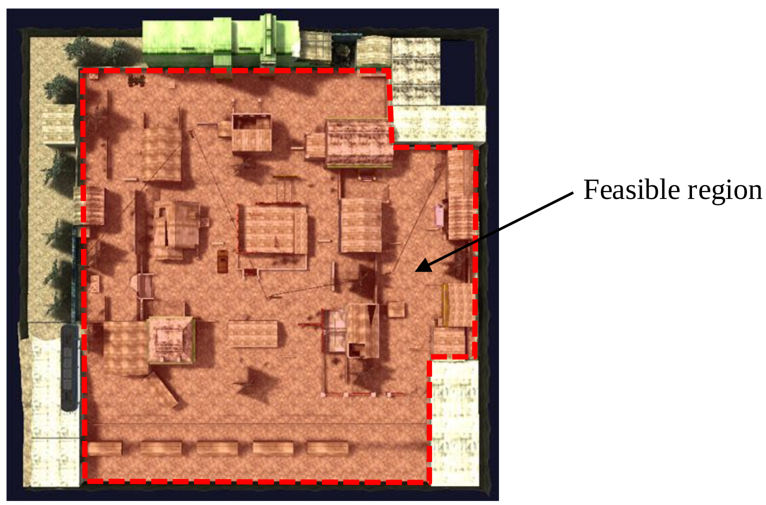

Figure 5.9. Feasible region for placing targets

Map errors were then calculated for each target as described in Section 5.1.2. This simulation is repeated 50 times for each of the 3 interfaces. The results of map errors using this random method are shown in Table 5.4.

Table 5.4. Result of map errors from random

Layout	Average mapping errors (feet)
A	60.67
B	60.94
C	63.80
Average	61.80

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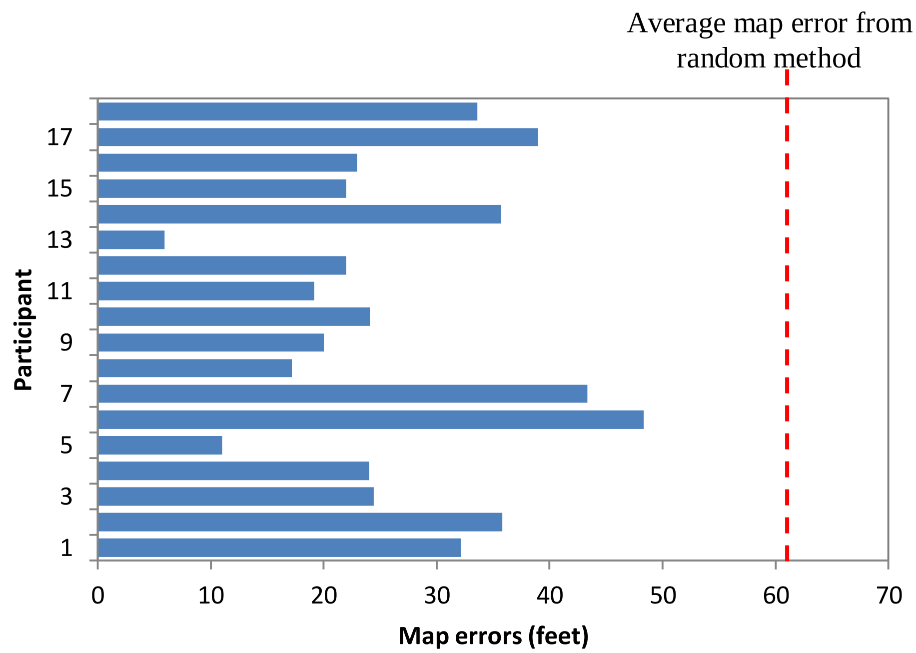

Figure 5.10. Participants' map errors vs. random map error

Figure 5.10 compares the average of participants' map errors across the three interfaces with the random results. Across all three interfaces, participants' map errors were lower than the random results (i.e., their performance is better than random or guessing). To determine the most effective interface, the average map errors for all three interfaces are compared. Figure 5.11 shows the map errors for the 90-degree x 4 interface and the 180-degree x 2 interface are nearly equivalent and both are noticeably lower than the 360-degree x 1 interface.

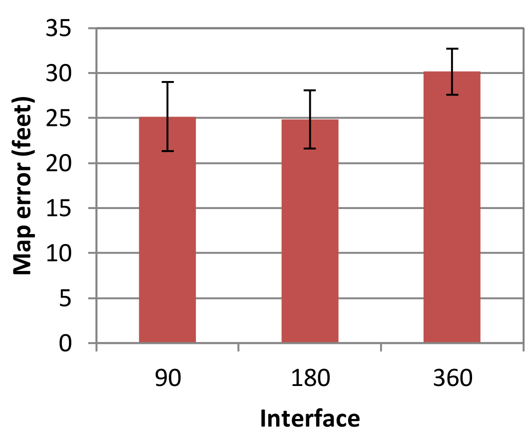

Figure 5.11. Map errors of interfaces

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However, the One-Way Repeated-Measures ANOVA test shows no significant differences between interfaces on the map errors (F (2, 34) = 1.589, p > .05). This indicates the performance on the map task tends to be the similar across the three interfaces.

5.3.2 Correlations between pointing errors and map errors with other variables

Spearman's rho correlation coefficient for pointing errors, map errors, hours of video game playing per week, compass time, target's distance, and travel distance are shown in Table 5.5. Pointing error does not correlate to other variables. Map errors are negatively correlated with hours of video game play per week at the 0.01 level. Map errors tend to decrease as the number of hours of video game playing per week increases, suggesting that compared to participants who played video game less often, those who routinely played video games weekly were able to recall the location of targets in the map task better. The compass time is also positively correlated with the distance of the target in view (Section 5.2) at the 0.01 level, indicating participants needed more time to determine the relative direction of the target when the target is far from them. There is no relationship between travel distance and any the other variables.

Table 5.5. Correlation table for pointing errors, map errors, and other variables (N = 18)

	Pointing errors	Map errors	Video game hours	Compass time	Target distance	Travel distance
Pointing errors	-	.164	.026	-.295	.135	-.022
Map errors	-	-	*-.609***	.052	.249	-.172
Video game hours	-	-	-	-.014	-.094	.118
Compass time	-	-	-	-	*.570**	.042
Target distance	-	-	-	-	-	-.364
Travel distance	-	-	-	-	-	-

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

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5.3.3 Group comparisons

As suggested in the previous section (5.3.3), participants' video game experiences may influence their performance on the map task. Thus, to investigate this relationship further, the 18 participants are divided into two groups based on the number of hours of video game play per week: (1) equal or more than 3 hours (N = 8, *Mean* = 7.75 hrs, SD = 2.71) and (2) less than 3 hours (N = 10, *Mean* = 0.3 hrs, SD = 0.48). This threshold of 3 hours was determined by examining the point with a significant gap in the distribution of hours of video game play per week. Results of the map errors between these two groups are shown in Figure 5.12. Across all three interfaces, participants who spent 3 hours or more video game playing per week tend to perform the map task better than those who spent less than 3 hours per week.

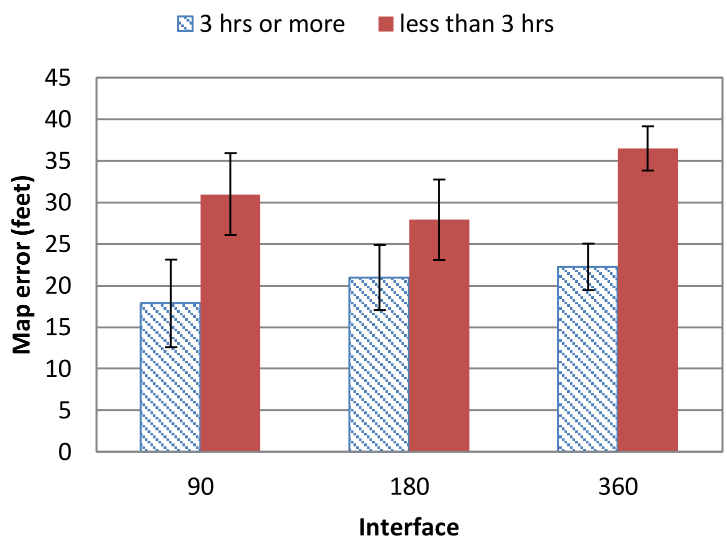

Figure 5.12. Group comparison for map errors by hours of video game play

The One-Way Repeated-measures ANOVA test also shows significant differences between the two groups, F (1, 16) = 6.174, $p < .05$. However, there is no significant effect of different interface within the group, F (2, 32) = 1.4, $p > .05$.

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In addition, the 18 participants are also divided into two groups, based on high and low map errors, since this might show a difference of an using interface within each group. A threshold of 25 feet was determined by examining the point with a significant gap in the distribution of map errors. Figure 5.13 shows two group of participants; (1) high map errors (N = 7, *Mean* = 38.28 feet, SD = 5.76), and (2) low map errors (N = 11, *Mean* = 19.36 feet, SD = 5.94). The One-Way Repeated-measures ANOVA test shows significant differences between these two groups, F (1, 10) = 5.409, p < .05. However, the effect of different interfaces within the group is not significant, F (2, 20) = 2.143, p > .05.

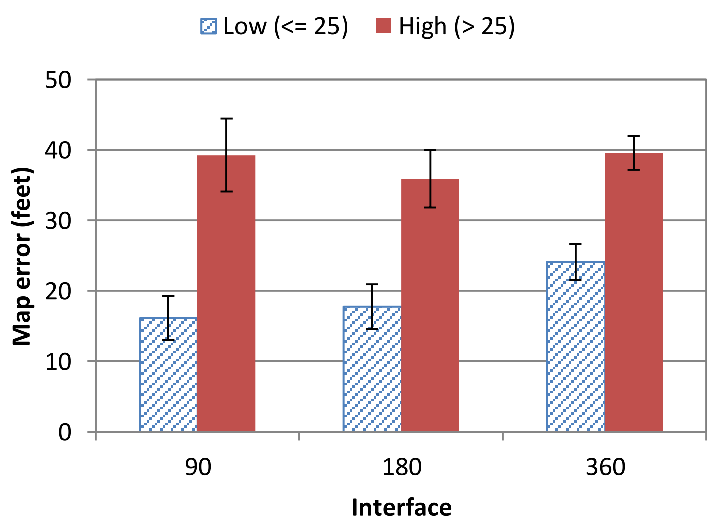

Figure 5.13. Group comparison for map errors by high-low map errors

5.3.4 Questionnaire results

Participants' feedback was collected after experiments with all interfaces were completed. The questionnaire results from the 18 participants are shown in Figure 5.14. The original survey questions are in Table 3.1.

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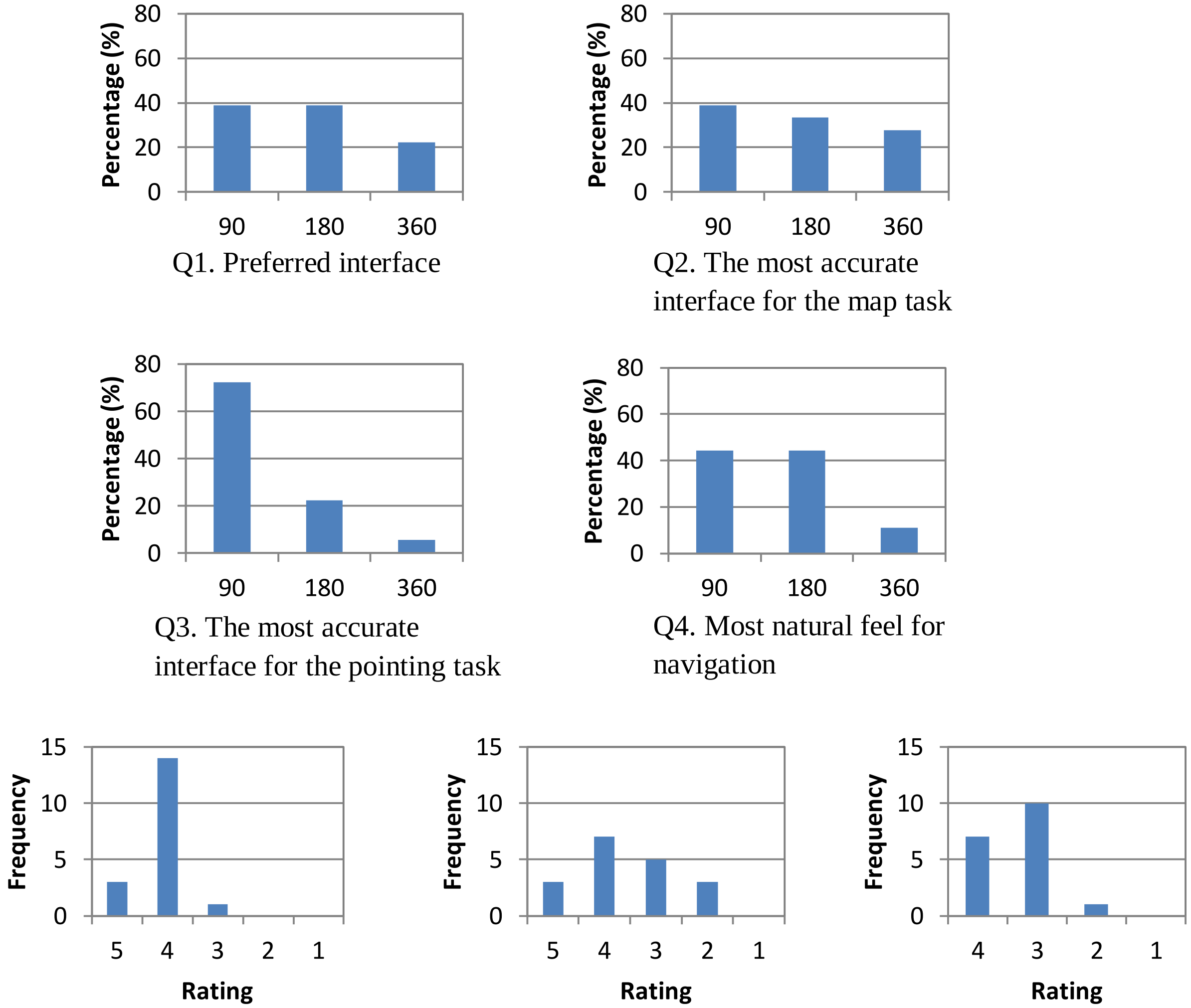

Q1. Preferred interface

Q2. The most accurate interface for the map task

Q3. The most accurate interface for the pointing task

Q4. Most natural feel for navigation

Q5. Seriousness of performing the tasks

Q6. Using peripheral view

Q7. Performance improve over time

Figure 5.14. Questionnaire results

In general, participants tend to choose the 90-degree x 4 and the 180-degree x 2 interfaces over the 360-degree x 1 interface. Participants also ranked the 90-degree x 4 as the most accurate interface for performing the pointing task. However, results from the experiment indicated no differences in performance between the 180-degree x 2 interface and the 90-degree x 4 interface. For the map task, participants picked the 90-degree x 4 and the 180-degree x 2 interfaces over the 360-degree x 1 interface. The 90-degree x 4 and the 180-

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degree x 2 interfaces had higher votes for the preferred design as well as provided the natural feel for navigation. From the results of questions 5-7, participants rated their level of seriousness to take the tasks from medium to high. Their attention on the peripheral view ranged from very little to all the time. The usage of the peripheral view during the navigation will be further discussed in the next section. Finally, most participants believed their performance might improve over time if they continuously use the interfaces.

5.3.5 Peripheral views

In this section, experimental data from the pointing task are analyzed to identify whether or not the participants used the peripheral views (non-center views) during the navigation. Figure 5.15 displays the distribution of the real target angle relative to the participants' heading direction during the pointing task. For the 90-degree x 4 interface, targets were most frequently selected when they appear at the center view. The peripheral views were utilized more to select target when participants used the 180-degree x 2 interface and the 360-degree x 1 interface. Although the 360-degree x 1 interface lacks data near +/-180 degrees, the selected target angles across the view were slightly better distributed than the 180-degree x 2 interface, suggesting the use of peripheral views tends to increase when the field of view (FOV) of the interface becomes larger. However, although the participants may gain more benefit of using peripheral views when the FOV of the interface is larger, it does not mean their performance would be improved. In fact, the results from the pointing task show that participants' performances tend to worsen when they used the 360-degree x 1 interface.

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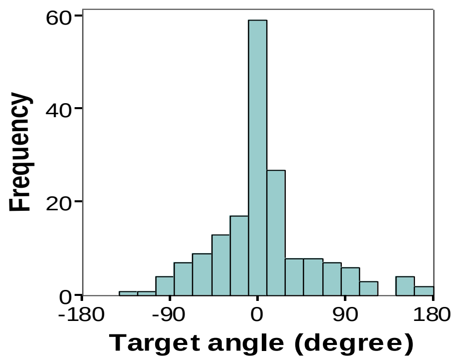
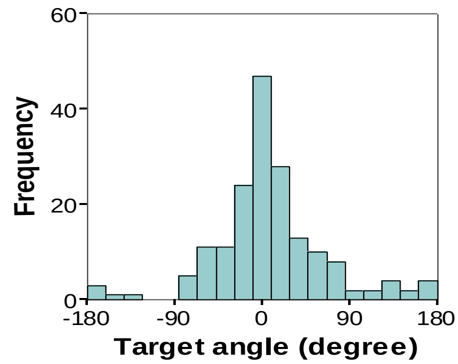
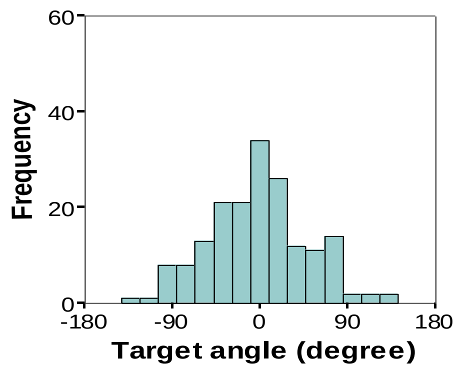


(a) 90-degree x 4



(b) 180-degree x 2



(c) 360-degree x 1

Figure 5.15. Histograms of the real target angle that participants selected

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CHAPTER 6. DISCUSSION AND CONCLUSIONS

This thesis presented a 360-degree view interface for spatial exploration, based on egocentric viewing and navigation. It is an attempt to identify the necessary display characteristics that allow viewers to correctly interpret 360-degree video images displayed on a screen that fits one personal view. The experimental design was set up in a virtual environment to investigate the effectiveness of various interface designs that integrated 360-degree view. Three different 360-degree view interfaces were studied: (1) 90-degree x 4, (2) 180-degree x 2, and (3) 360-degree x 1. Each interface was designed with a different size of field of view (FOV) that dictates the number of views to the interface.

6.1 Pointing Task

In this experiment, spatial orientation and spatial working memory were investigated, using pointing task. Experimental results showed the direction of targets in the views is easier to determine using the 90-degree x 4 and the 180-degree x 2 interfaces rather than using the 360-degree x 1 interface. The views of 90-degree x 4 and 180-degree x 2 interfaces might present less distortion than the 360-degree x 1 interface. However, further analysis showed the performance for the pointing tasks between the 90-degree x 4 interface and the 180-degree x 2 interface were not significantly different, suggesting that since natural FOV of human eyes is expanded to approximately 200 degrees, if the FOV of the views does not exceed the natural FOV, we may still be able to maintain the egocentric direction without difficulty.

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6.2 Map Task

The results of the map task showed potential performance in translating an egocentric view (first-person view) to a top-down map view. However, the difference of the interface design did not influence participants' abilities to recall the locations of targets in the virtual environment. Across all three interfaces, the performance of the pointing task also was not related to the performance of the map task. These results might suggest that remembering the targets' locations in a larger spatial context may not rely on egocentric directions as much as remembering landmarks during navigation in the environment. Moreover, performance on the map task can be influenced by the number of hours of video game playing per week. Participant who had prior video game experiences tended to perform better with this task. However, regardless the video game experience, design of interfaces did not significantly affect the ability to memorize the locations of targets.

6.3 Peripheral Views

Evidence from the pointing task showed the peripheral views (non-center views) of the interface were utilized during navigation. Non-center views in the 360-degree x 1 interface tend to be used more often than the 180-degree x 2 interface, while in the 90-degree x 4 interface participants tend to use the center view the most. This suggests that when the size of the FOV of the front view is larger, participants can perceive more information from the part of the view that was increased. Although it may help improve the ability to detect the targets in the scene, the current study did not discover it affected participants' abilities to correctly identify the direction of the targets. In fact, compared to other interface designs, the performance of the pointing task using a 360-degree x 1 interface was determined the worst.

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6.4 Future Work

Several extensions that may improve the current experimental design to further investigate the effectiveness of the design interfaces include providing equivalent reference angles on the interface and varying training time period. In the pointing task, the 90-degree x 4 interface and the 180-degree x 2 interface may provide additional reference angles that allow for better performance when determining the relative direction of objects (Figure 6.1).

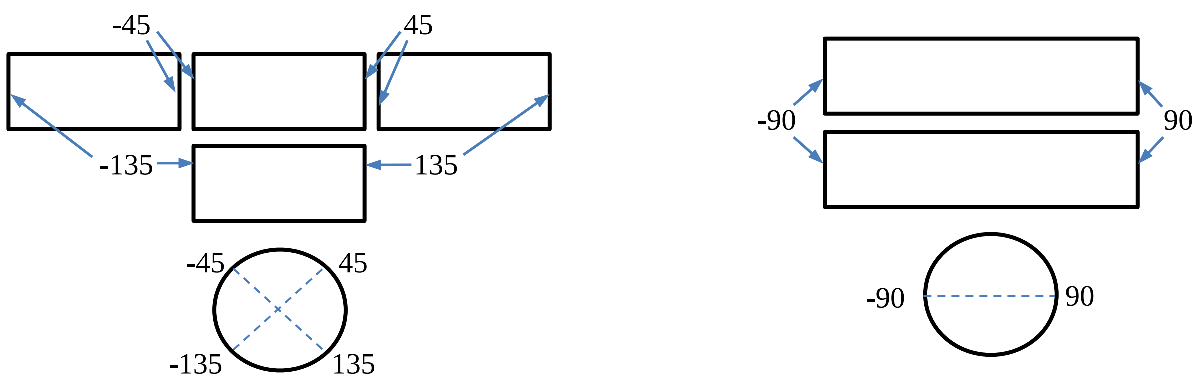

Figure 6.1. Compass rose and additional reference angles (degrees)

Thus, adding equivalent reference angles across all three interfaces may reveal the actual effectiveness of the interface during the pointing task. The results from the current study suggest that training time may influence performance. There was also a study using prism glasses (Stratton, 1896; Welch, 1971) that addressed human's ability to adapt to new stimuli when experiencing it for a period of time. Therefore, future studies can vary the amount of training time to determine the optimal time necessary for participants to acclimate with the interface.

The current study can be extended to investigate how peripheral views of 360-degree views are used in spatial navigation. The current study does not obtain formal data to verify how peripheral views are utilized along with the center view. Employing eye tracking and

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head tracking devices can help provide insight on how participants identify objects in peripheral views. Furthermore, these data might reveal some opportunities to enhance the usage of peripheral views using certain designs of the interface. Alternatively, controlling the position of targets when they appeared in view during navigation may also help to study the usage of peripheral views. Instead of placing fixed targets in the environment, future experiments might control the direction and location of targets that will appear in peripheral views, based on participants' heading direction. For simplicity, this may be flashing 2D images on the screen. The number of targets missed and errors of relative direction on compass rose may count toward the effectiveness of peripheral views on the design interface.

Future work can also explore passive navigation using the same designs of the interfaces. The example of passive navigation is a passenger who is sitting in a car. Even though the passenger is not driving, the passenger still perceives the environment. However, the results would be different as Noe (2004) suggested—perception is strongly influenced by the ability to act on an environment. The current study focuses on active navigation to determine how participants utilize egocentric direction, spatial working memory, and memory in the virtual environment. Rather than generate new navigation data (active navigation), future studies can incorporate available navigation data to create video feeds that will be used for passive navigation. Participants might observe and report the targets and targets' relative directions to heading direction within all three interfaces. They can also perform the map task after each interface session. The same video feed can be repeated with several participants to compare the reliability of the results.

Finally, future studies can integrate computer vision aids, such as image analysis, to identify unusual contents in the scene by exploring whether participants can track augmented

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display indicators in the scene, as well as identify situations where image analysis may not be effective. Computer vision aids can be very helpful when participants need to observe several video feeds, as in typical surveillance tasks. Future studies may combine passive navigation with computer vision aids to allow participants to track multiple video feeds simultaneously.

In summary, this thesis was an attempt to utilize the 360-degree view for navigation and observation. It can be applied to several remote systems, such as mobile surveillance, unmanned aerial vehicle (UAV), and robot navigation. These systems may require control in real-time or observation of live video feeds. Developing effective user interface may provide an improvement for the systems. The results from this study point to potential usage of 360-degree view for navigation and observation. It also reveals the characteristics of 360-degree view interface that will aid spatial orientation and spatial working memory during navigation and observation in the virtual environment.

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