World and Object Designs for Virtual Environments

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Abstract

Three dimensional displays such 3D television, Oculus Rift, and Sony Project Morpheus, provide a virtual reality gaming capabilities in the home. However, broad interface guidelines for developing applications for these systems are limited. In particular, object size and three dimensional world structures in virtual reality are in earlier stages of interface design. Serious games will be unable to leverage the immersive qualities of these systems if interfaces are confusing and lead to disorientation or cybersickness. We reviewed two dimensional guidelines, past applications using virtual reality systems, and observation in our own virtual reality system to offer guidance on what performs well in these systems. We offer suggestions as to minimum object size and world design that consider the limitations of accurate navigation in immersive virtual reality.

Keywords: Virtual Reality, Interface Design, Guidelines

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The introduction of stereoscopic three dimensional displays to the general public has offered new opportunities in entertainment, training, and education. They provide a more immersive experience and have the potential for much greater application impact: an important factor in serious games usage of this technology. Virtual environments can display information 360° around a user, but many modes of navigation have been copied directly from their two-dimensional counterparts. We consider past virtual reality applications and feedback given by participants in studies we have conducted and present an overview of navigation and object designs that perform well in these systems.

Virtual environments have the ability to provide experiences that would be too costly or too impractical to provide in real life. They have been implemented for geography education (Virvou & Katsionis, 2008), stroke rehabilitation (Burke, et al., 2010), and phobia treatments (Walshe, Lewis, Kim, O'Sullivan, & Wiederhold, 2003). They permit better location identification which can decreases the errors due to previous mistakes (Tang, Owen, Biocca, & Mou, 2003). In entertainment settings, it is "presence," or the feeling of being "there" that is of importance. In this aspect, virtual environments and stereoscopic displays perform better than most two dimensional displays (Avery, Piekarski, Warren, & Thomas, 2006) (Avery, Piekarski, Warren, & Thomas, 2006).

One of the greatest advantages of stereoscopic displays and virtual reality is that they can display information that is closer to the real world. However, achieving successful immersive environments has many nuances. Studies have demonstrated that participants misjudge distances in these systems, and the interfaces need to adjust accordingly (Jaekl, Jenkin, & Harris, 2005). This study did not include the ability to physically step towards a virtual object permitted in

many virtual environments, and therefore decreases the applicability to general systems. However, we observed in our immersive virtual reality system that permitted restricted walking that participants still underestimated the distances dramatically in both HMD and one-wall CAVE settings. One stated they felt as if they needed to stand on top of an item to pick it up, although the minimum distance was 1.5 meters. Therefore, we will assume the results still apply to mostly environments composed mostly of virtual objects. There is also the familiarity of traditional computer applications that impedes stereoscopic input. In our experiments, participants that frequently played console games attempted to apply the same interaction methods, but reported difficulty with some navigation and identification tasks.

At present, use of these systems is sporadic and generally has very specific goals. However, many past virtual environments have immersive worlds with floors, horizons, and objects with which to interact. By considering these past applications and feedback from study participants, we offer underlying virtual world design suggestions that provide better navigation and object identification.

Motivation

Ideally, an interface should allow a participant to accomplish a given task as quickly and intuitively as possible. Achieving this is not straightforward, as users have varying levels of familiarity and past experience. Users are more familiar with the common WIMP (windows, icons, menus, pointer) format of most computer applications and operating systems. When shifting to virtual environments, another dimension is gained which disrupts use and layout of these familiar interfaces. The closest approximation of WIMP in a three dimensional setting could be approximated as volumes, icons, menus, and selection.

By switching to three dimensional spaces, the concrete borders of the screen are lost, which changes selection and navigation requirements. There are many varieties of interaction in three dimensional environments including gestural, pinch gloves, walking, joystick, two/three dimensional mice, and virtual clip boards. However, participants misjudge the distances in virtual reality and think objects are closer than they truly are. Jaekl, Jenkin, and Harris (2005) stated the distance actually traveled is 1.4-1.5 times the participant's assumed distance. Virtual environments need to consider this issue. Also, usability heuristics have been vague as to the minimum volume required to readily select objects and easily travel within a virtual environment.

Related Work

Despite a long and illustrious experimental history, virtual environments are relatively new to the public so usage paradigms are often unknown to participants. These paradigms should permit common application tasks such as movement, selection, open file, close file, start, stop, and save within the program. These commands imply basics needs. Text must be readable and responses must be a reliable. Since the appearance is often similar to three dimensional console game worlds, users may assume similar selection and navigational paradigms. Therefore, when determining the underlying requirements of virtual world's design and navigation, we draw from usability heuristics of these traditional computer applications and three dimensional console games.

Nielsen (1994) posed a large list of questions to ask when checking for usability of a program. He categorizes these questions into 10 majors groups: 1) v*isibility of system* (proper feedback), 2) *match between system and the real world,* 3) *user control and freedom*, 4) c*onsistency and standards*, 5) e*rror prevention,* 6) *recognition rather than recall* (ability to

request information when needed), and 7) *flexibility and efficiency of use*. The last three categories have a minor effect on overall design: 8) *aesthetic and minimalist design;* 9) *help users recognize, diagnose, and recover from errors;* and 10) *help and documentation.* Of these categories, virtual environments lend themselves to the *match between system and the real world* category, but have difficulty with *flexibility and efficiency of use* as users rarely have direct access to the program and depend on the operator to change the settings.

Perhaps ironically, the *visibility of system* from Neilson can be poor in virtual environments. Due to the change in mode of navigation, the distance estimation issue, and lack of familiarity, placement of the icons and objects is uncertain. Desurvire, Caplan, and Toth (2004) offer more specifics for games and playability by adding the ability to easily turn the game on and off. They also include navigation in an abstract sense, stating players should be able to remember their route, so that they can backtrack if desired. Bowman, Kruijff, LaViola, and Poupyrev (2001) add that while three dimensional spaces create more possible modes of input to users, many tasks, such as menu interaction, are naturally two dimensional. Sutcliffe and Kaur (2000) further emphasize the additional requirements of games by arguing the Neilson does not include the issues of location, manipulation, and three dimensional navigation. Among the questions they pose, the following are significant issues in virtual environments:

- Can the objects necessary for task action be located?
- Can the users approach and orient themselves to the object so the necessary action can be carried out?
- Can the user carry out the manipulation or action easily?
- Can the user recognize the search target?

A few of these issues are due to the viewpoint being dynamic. In two dimensional applications, the necessary object can be readily forced into view. In three dimensional worlds, it is simple to remove desired objects from view by becoming too close to the object or turning the wrong direction. This means the relative size and location of the objects are important, and we examine possible minimal sizes to meet these requirements.

The inclusion of navigation issues in virtual environment usability heuristics is particularly relevant. Navigation and the user interfaces components in virtual environments are more correlated in virtual reality than in most 3D games. For examples, if a 3D menu is placed near a person using a controller navigated virtual environment, the controller's buttons permit easy interaction with the menu. If the navigation changes to gestural, this menu would become unusable without alterations. Pointing and other gestures would need to be mapped to controller button presses. Similarly, if a gestural navigation system using a 3D menu in space to which a participant points, is changed to a heads-up-display or 2D band (as in tradition desktop applications), the menu becomes unusable without alterations. There would need to be a method to switch between menu and navigation modes. Also, due to the smaller viewing area, object placement may need to be revised. Removal of a constant 3D object may also remove a practical directional marker.

The interaction between navigation and user interfaces in virtual environments can be disorientating to participant and oculus rift has suggested best practices for their HMD (Oculus Rift, 2014). Many of the topics include gain, viewpoint manipulation, and application design to avoid cybersickness and have varying degrees of support from the literature. How many of the suggestions apply to screen or CAVE systems is uncertain. We focus on the underlying

restrictions of object identification and the ability to move smoothly through an environment despite the navigation paradigm.

Example of Virtual Interfaces

We collected informal feedback from our virtual reality experiments and reviewed previous virtual and augmented reality applications. We restricted our selection of prior systems to applications that required near continual interaction and head tracking. In our own experiments, we observed navigational and interaction behaviors of our participants and reviewed their feedback on the system. We collected five virtual environment examples, all of which employed a head mounted display (HMD).

Nilsen, Linton, and Looser (2004) created an augmented reality "Worms" game. Participants moved around the table looking through a HMD that overlaid the game map onto a table as seen in Figure 1. Selection was accomplished by looking directly at an object and game play was accomplished through a controller or PDA. They reported a high level of enjoyment and movement around the table, although less actual game play. However, due to the size of the objects, selection was difficult for some participants. They also reported reading difficulty due to the resolution of the displays.

Virvou and Katsionis (2008) created a virtual reality game alternative to a traditional teaching application for geography. As seen in Figure 2 (a), the virtual reality game viewed through a HMD had an environment similar to computer games like *DOOM*. Hints and tutorials could be found by the players, which helped them pass through doors guarded by dragons that quizzed them. In contrast, the traditional application in Figure 2 (b) asked questions and gave tutorials in linear order. Most students preferred virtual reality over the traditional interface, even though they found it more complex to use. The game world had wide corridors and simple

rooms, but non-gamer players were far more likely to become stuck between objects or be unable to steer in the correct direction. Virvou and Katsionis suggested better use of maps to counter this.

Cheok et al. (2004) created the *Human Pac-Man* game. Participants wore an HMD display, pressure sensors, GPS, and a computer with blue tooth capabilities. The Pac-Men and ghost players traversed a wide area covering a portion of their campus. Ghosts could "eat" Pac-Men by touching their pressure sensor. Pac-Men collected virtual cookies by walking over that location as seen in Figure 3. Most users reported enjoying the game and reported that the system was intuitive and fast to learn. Although the cookies in Figure 3 seem large, and appear to be approximately 50cm from the image, some users felt the positioning was off and had difficulty collecting them.

Thomas et al. (2000) created the *AR Quake* game. They also had their participants wear a HMD and a computer with GPS capabilities, but included visual location markers for the system as well so that the game could continue indoors. The game had the goal of defeating virtual monsters as seen in Figure 4. The participants aimed with crosshairs centered in their field of view. Participants found the system easy to use, although a few found that they attempted to point their controller at the monsters rather than with their head. Similar to *Human Pac-Man,* drift proved problematic in some instances. Monsters could "pop" out of walls if the registration was incorrect, but the authors reported that if the wall was far away that this issue was not particularly noticeable.

Avery, Piekarski, Warren, and Thomas (2006) built a three dimensional version of *Space Invaders* called *Sky Invaders 3D*. The game begins by choosing the location of a turret, bunker, and the direction the UFOs will arrive. The player then uses the crosshairs centered in their

HMD as seen in Figure 5 to shoot large UFOs. The player may physically move between the bunker and turret at any time, but the display is snapped to those locations preventing strafing. Players reported *Sky Invaders 3D* was easy to learn and that it was preferable over the desktop version. They reported players had some issue with switching between the turret and bunker due to the GPS accuracy.

From the above studies, there were several repeated comments. Participants generally preferred immersive systems over the desktop alternative. They also find them fairly intuitive despite minor issues in interaction. Large objects such as the UFO and monsters are readily identified, but small objects had selection and location issues.

Our System

We created a virtual reality treasure hunt. Participants were given a virtual world consisting of several connected rooms and a menu of objects to collect. We have had 42 participants with 7 females and 35 males most participating multiple times. There were a total of 120 sessions. Most participants were under the age of 25. Examples of the rooms are shown in Figure 6. In addition to items on the menu, participants could collect keys to unlock specific doors and stars that removed 30 seconds from their total time. Participants had to be within 1.5 meters of an object to collect it with a button press.

Participants were given either a Sony Glastron HMD or active shutter glasses with a rear projection screen. The physical and rendering field of view was 30° on the diagonal for most experiments. Both the HMD and projection screens were head tracked with six degrees of freedom and rendered in stereo for the large majority of experiments. Participants were permitted to take a one step in each direction and an Xbox controller was used to travel larger distances. The Xbox movement was independent of the head tracking, and the head tracked position and

orientation were added onto the Xbox's position and orientation. To partially offset the advantage of prior experience, a tutorial was given before a participant's first world to learn the controls and practice moving around the environment. Most participants learned the controls quickly, despite having six active buttons and the joystick.

Informal Feedback and Observation

After completing a session, participants were asked if there was anything they liked or disliked about the program. In general, participants enjoyed the system and some gave suggestions for improvement. Several wanted to continue beyond the time limit if they could not locate all the items. When asked where they would like to use virtual environments, use in games was a near universal response.

However, we noticed several navigational difficulties. Participants often became lost and forgot where they had been. They had difficulty near corners and ran into walls. The first environment created had a room with hallways 2.3m wide. We had designed the system to scale when possible, but due to the distance underestimation as mentioned by Jaekl, Jenkin, & Harris (2005), this proved to be far too small. We steadily increased the minimum hall size until participants could walk smoothly through. This minimum hall size we found to be effective was 3m. Experiments with far larger fields of view greatly helped at preventing users from with becoming lost, but aided only slightly with preventing them from running into walls. Unfortunately, increasing the field of view also increased feelings of dizziness and illness which agrees with research by (Dizio & Lackner, 1997) that states that field of view has a strong effect on illness from these systems.

Comments regarding the textures of the environment varied. Some participants were quite pleased, but some reported specific textures that made it difficult to navigate. These

textures were low orientation, generic textures (see the hedge in Figure 6 *e* and Figure 6 *f*). If a participant stated a sudden increase in feeling dizzy or ill, it was in these rooms. Conversely, very open rooms such as *b* and *d* from Figure 6 were well liked and a few participants stated a feeling of relief when reaching these room.

While most three dimensional items were readily recognized, there were also several items that were regularly misidentified. These items fell into three groups: too small, too flat, and too low. Our objects ranged in size from pencils to 2m pikes. The only objects that our participants misidentified were smaller than our 16cm by 9cm by 9cm boxes and 10cm high, 3cm radius cans. Granted, good color variation was important for identification at these sizes. Smaller objects, such as pens or pencils, would present difficulties even with good color variation. In addition to items that were too small, objects that were too flat also proved problematic. These objects, such as a plate, could meld into the pedestal on which they sat. Simply rotating the object to stand on end removed this issue. Lastly, we had a few objects not located on a 1m pedestal. We had low shelves, low barriers, and benches in a few rooms. The most noticeable were the benches in the starting room. Originally, the benches were only 40 cm high. Participants would regularly step onto the benches, and then wonder how they had jumped because they had not seen the bench. Similarly, we had a room with shelves at 45 cm where participant regularly missed objects on these shelves. We slowly started to increase the height of the benches and shelves. Only at 65 cm did participants start to notice the bench on a regular basis, and low barriers at 80 cm were rarely missed.

Discussion

Reviewing past virtual environments and feedback from our participants revealed that participants generally like virtual environments and the options that they bring. For these

environments to be easily used there are several design and navigations issues that must be considered. Using prior reports of ease of use and observation, we offer the following design recommendations:

1) Hallways and paths should be a minimum of 3m for small fields of view, 2.75 for large fields of view, or 1.5 times the real world size according to Jaekl, Jenkin, & Harri (2005).
2) Objects should be no smaller than 8cm in any dimension, and objects near this size should exhibit good color variation.
3) Avoid flat objects that are flush with another surface.
4) Items and barriers should have a minimum height of 80cm.
5) Have many open areas and allow view of the horizon if possible.
6) Avoid generic textures, particularly if the object covers the majority of a participant's vision.
7) Larger FOVs are better for navigation, but also increase feelings of dizziness and illness.

These design and navigation recommendations should be used in conjunctions of application level usability and device specific heuristics. Initially, the minimum hallway size posed by suggestion 1 seems quite large. A 2.75 m hallway adjusted by Jaekl, Jenkin, & Harris's (2005) gain would result in a real world size of 1.80m. However, the UN *Accessibility for the Disabled Design Manual* suggests a hallway width be 60in or 1.52m for wheelchair accessibility, which in similar to what we observed (SOLIDERE & ESCWA, 2004). Suggestion 3 is derived by taking the average size of the smallest object readily identified by our participants.

Suggestions 5-7 consider navigation and potential dizziness and are derived from comments from our participants and observation of their navigation.

Although not directly related in object identification and navigation, there were a few common behaviors we noticed in our participants. The HDM we utilized permitted participants to see under the display, and they regularly used this. Participants would look under the display to confirm a button press, when taking a step, and speaking to the virtual environment operator. Also, while the display did not hinder their movement, several participants stated they disliked the weight on their nose from the display. Current HMDs sometimes cover the nose to block out the outside world. This is a safety and practicality concern of HMDs. Being able to see under a display can help to prevent tripping and improve comfort of the display. Several participants also noted that the decrease in brightness with the active shutter display made some objects more difficult to discern. This is easily remedied by either increasing the brightness of the object or increasing the ambient lighting.

Use of prior two dimensional and three dimensional system guidelines and heuristics will help in the creation of virtual environments. Participants tend to use these systems as though the applications were their console game counterparts. There was very little movement. During the tutorial we coached participants that their head will turn faster than the joystick, physically strafing was permitted, and that it would be easier to examine a room with their head than with the joystick. Despite reminders, many failed to use these navigational options. Since virtual environments are still relatively new, we have the option to thoroughly test these systems and develop navigation and design guidelines prior to their widespread use.

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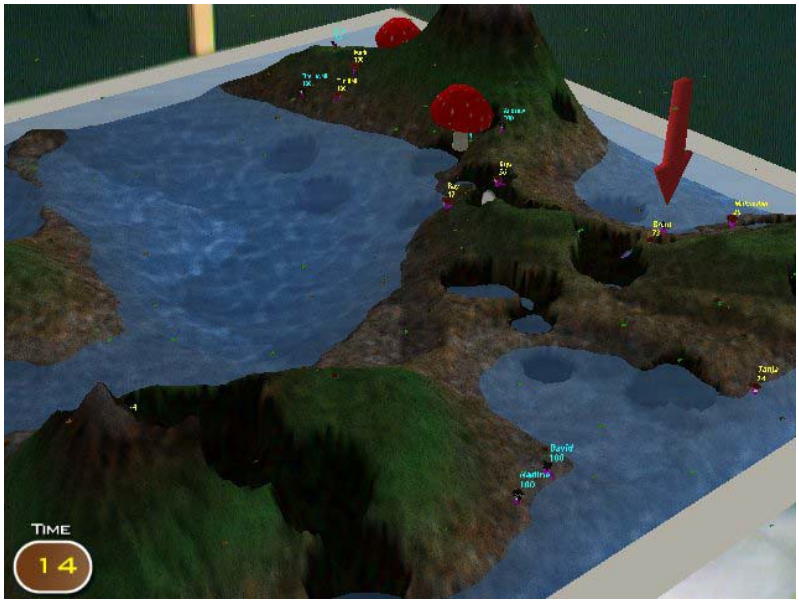
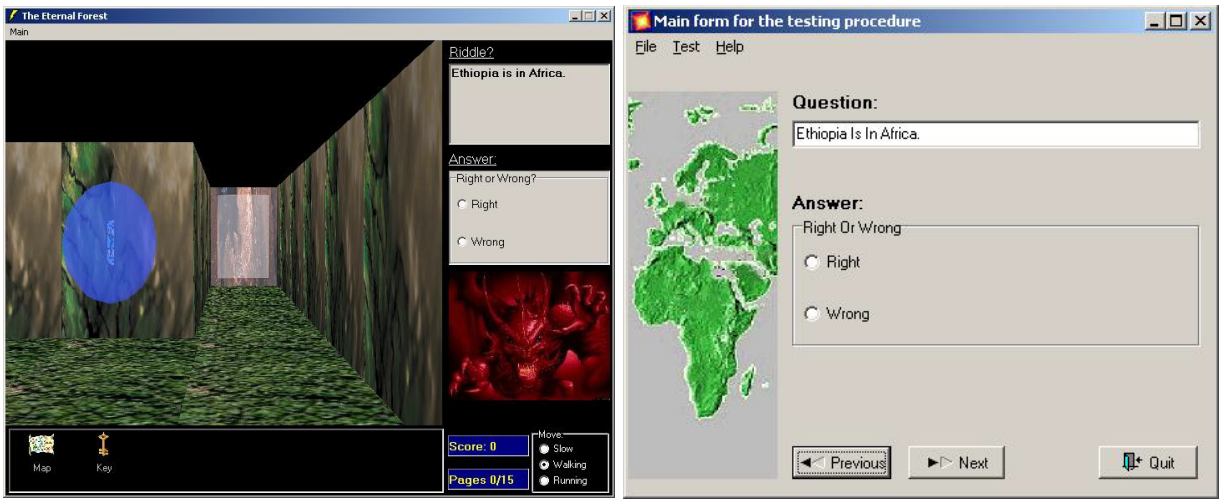


Figure 1. AR Worms (Nilsen, Linton, & Looser, 2004)



(a) (b)

Figure 2. VR engage (Virvou & Katsionis, 2008)

Figure 3. Human Pac-Man (Cheok, et al., 2004)

Figure 4. AR Quake (Thomas, et al., 2000)

Figure 5. Sky Invader (Avery, Piekarski, Warren, & Thomas)

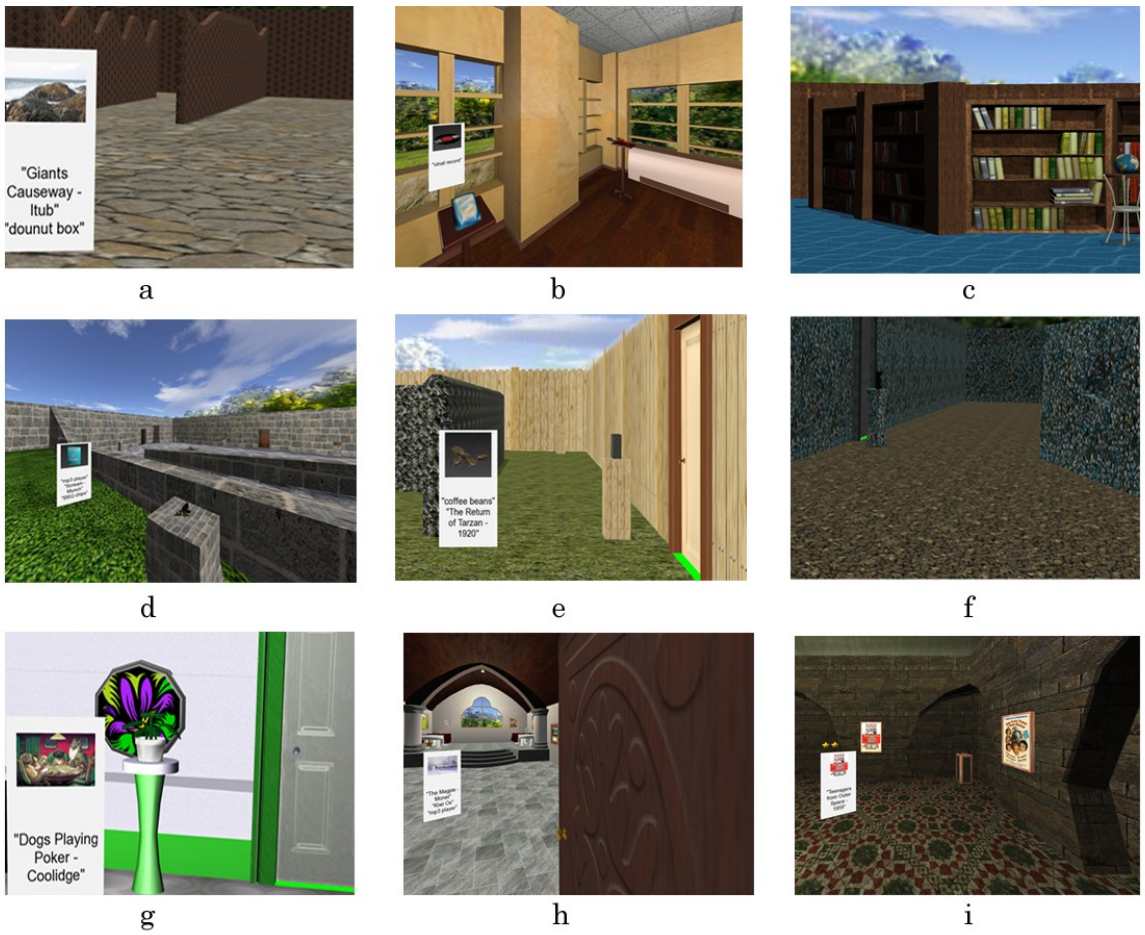


Figure 6. Screenshots of the Virtual World