Enhancing the Gaming Experience Using 3D Spatial User Interface Technologies

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Three-dimensional (3D) spatial user interface technologies have the potential to make games more immersive and engaging and thus provide a better user experience. Although 3D user interface (3DUI) technologies such as stereoscopic 3D display, head tracking, and gesture-based control are available for games, it is still unclear how their use affects gameplay and if there are any user performance benefits. A systematic study of these technologies in game environments is necessary to understand how they affect gameplay and how we can use them to optimize the gameplay experience.

This article presents some of our explorations in this area. We specifically looked at three user interface technologies: stereoscopic 3D, head tracking, and hand-gestural interfaces. We conducted several experiments to understand their role in gaming environments. Our lessons learned from these experiments can serve as a framework for the future explorations of games that utilize 3DUI technologies.

Stereoscopic 3D
Stereoscopic 3D is not a new technology, but it has not been readily available to consumers until recently. Most recent video games are designed in 3D game engines, so the 3D data is already present in games. A stereoscopic driver (such as Nvidia 3D Vision or Tridef Ignition) uses this 3D data to create stereoscopic images that can be rendered on a stereoscopic display. However, the overall experience is not optimal when the games are not designed with stereoscopic 3D viewing in mind. Therefore, it is important to study how stereoscopic 3D affects the gameplay experience and how to improve gameplay in general.

User Study
A previous study of PC games showed that playing games with 3D stereoscopic display does not provide any significant performance benefits over using a 2D display. However, that study used a traditional game controller (the Xbox 360 controller) as the interaction device, and the games used were not designed with 3D stereoscopic display in mind. Other studies have shown that an increase in body movement imposed, or allowed, by the game controller results in an increase in the player’s engagement level. Based on these studies, we hypothesized that coupling 3D stereoscopic display with 3D spatial interaction using motion controllers in video games could lead to better user performance than with a 2D monoscopic display and a motion controller. Furthermore, to test this hypothesis, we conducted a usability experiment with five 3D games (see Figure 1). We had our study participants play each game in either a 2D or 3D viewing mode using a 3D interaction device.

The experiment required a gaming environment that natively supports stereoscopic 3D and 3D spatial interaction. At the time of our study, the only system that supported both these features was the PlayStation 3, which uses a Move controller as the 3D spatial interaction device. Therefore, we picked five PlayStation 3 games (see Figure 1) with stereoscopic 3D display and Move controller support that could potentially provide performance benefits in a stereoscopic 3D environment. We conducted a between-subjects experiment with
50 participants (38 males and 12 females, ranging in age from 18 to 34). We divided the participants into two groups: one group played on a stereoscopic 3D display and the other played on a 2D monoscopic display. Because the participant’s gaming expertise could be a factor in their gaming experience, we further divided the participants into casual and expert categories. Our user study examined the effect of gameplay expertise (beginner or expert) and the display mode (stereoscopic 3D or monoscopic 2D) on the user performance. (See our earlier work for more details.)

**Lessons Learned**

We learned several lessons from our user study.\(^4\)

We found that when participants interacted with only a single object at a time with a more or less static background environment (such as aiming a cue ball or putting blocks on a table in 3D space) significant performance benefits occurred for the stereoscopic 3D viewing condition over the 2D display. However, no significant user performance benefits were found for tasks where the scene was complex (such as a fight scene when the player moved around) or dynamic (such as many incoming objects in *Pain* or tracking a moving ball in *Virtua Tennis 4*). Furthermore, in some games (*The Fight* and *Virtua Tennis 4*), users need to move around with the 3D glasses, which can cause the 3D glasses to flicker in the event of a loss of synchronization signal between the 3D TV display and the glasses. This flicker can also cause distraction and affect user performance.

Gaming expertise has the potential to nullify the benefits of stereoscopic 3D viewing because expert gamers may have learned to rely on depth cues (such as shadows) other than binocular disparity. We noticed that one of our games (*Tumble*) included object shadows as an additional depth cue. That helped only the expert users however because it is common in their gameplay experience. The beginners indicated that 3D stereo served as a better depth cue than shadows.

Based on our experiment,\(^4\) we devised the following recommendation for game designers:

- Utilize relatively simple scenes or static environments where interaction is focused on isolated tasks to provide user performance benefits with 3D stereo. This approach can help to avoid user distraction.
- Try to emphasize the stereo effect, showing how to use it in gameplay. This is especially important for expert users, who might not take it into account.
provide a way to manage the controller’s sensitivity to enable a more enjoyable user experience.
- Avoid requiring a lot of user motion in front of the display to prevent the loss of synchronization signal with active stereoscopic 3D glasses and to reduce geometric errors when leaving the sweet spot for the 3D effect. Alternatively, provide RF-signal-based sync, which avoids issues with a line-of-sight-based sync signal.

Head Tracking

Head tracking is commonly used in virtual and augmented reality applications, and it has potential to be a useful approach for controlling certain gaming tasks. Recent work in head tracking and video games has shown some potential for this type of gaming interface. In addition, previous studies have shown that users experience a greater sense of presence (the illusion of being in the virtual environment) and satisfaction when head tracking is present. It is important to understand how head tracking affects the gameplay experience and what kind of games make better use of this technology.

We systematically explored head tracking as an interaction technique in games to be able to help game designers better utilize head tracking. We chose NaturalPoint’s TrackIR 5 as our head-tracking device because it is natively supported in many commercially available games (about 130 at the time of our experiment). We chose four games (Arma II, Dirt 2, Microsoft Flight, and Wings of Prey) that we thought could benefit from being played in a head-tracked environment (see Figure 2). All these games support alternate control methods, such as using a joystick or buttons on the Xbox 360 controller, when head tracking is not available.

User Study

We conducted a between-subjects experiment where participants played each game either with or without head tracking using the Xbox 360 controller. We examined both quantitative metrics, based on each game’s goals and tasks, and qualitative metrics, based on whether participants preferred playing the games with head tracking and whether they perceived any benefits. We included 40 participants (36 males and four females, ranging in age from 18 to 30) and divided them into two groups: with or without head tracking. Similar to our stereoscopic 3D experiment, we also subdivided participants into casual and expert gamers. Our user study examined the effect of gameplay expertise (casual or expert) and the head-tracking mode (present or absent) on user performance. (See our earlier work for more details.)

Lessons Learned

Our user study found that head tracking offered significant performance advantages, but only for expert gamers playing Arma II (better survival time) and Wings of Prey (better time and more enemies shot). Both Arma II and Wings of Prey are...
shooting games, and in both games head tracking helps players find enemies around their current position. In *Arma II*, gamers found it useful and natural to rotate their heads to look around and to move closer to the screen to zoom in and use iron sight. In the case of *Dirt 2*, however, the user had to look forward most of the time. In fact, rotating one’s head makes it difficult to focus on the road, especially at fast speeds, so head tracking was not that useful for this game. In the case of *Microsoft Flight*, although the head tracking added depth perception and a sense of realism to the game, the game itself was slow paced and not difficult to play.

Head tracking was an added feature in all the games we tested, so it was up to the user whether to take advantage of it. The expert gamers seemed to make better use of head tracking, whereas the casual gamers appeared to focus more on game basics and did not pay much attention to head tracking. This may explain why casual gamers performed almost equally well in both groups (with or without head tracking).

Based on our experiment, we have the following recommendations for game designers:

- Make use of head tracking in first-person shooter (FPS) and air-combat games that have tasks that could benefit from head-tracking usage.
- Include instructions and hints during gameplay to guide gamers to make optimal use of head tracking. Most people are used to playing games with traditional button-based controllers, so most of the time they forget to use head tracking. Instructions and hints would remind them of the presence of head tracking.
- Limit head-tracking usage in racing games, where it could be distracting.

**Gestural Menus**

Menu techniques also play an important role in video games. Because a menu system’s response time and ease of use can significantly affect the user experience, it is essential that they be fast and efficient so as not to become a burden on the user during setup and gameplay.

People often use fingers to count or enumerate a list of items. Past studies have investigated using such finger-counting strategies for interaction with multitouch surfaces and distant displays. A gestural input system based on finger-count gestures (such as holding up two fingers) also has the potential to be a natural and intuitive approach for menu selection in gesture- and motion-based games. Menus designed to accommodate finger count are easy to understand, and finger-count gestures are fast to perform. Therefore, it is interesting to explore finger-count menus for video games. These menus could be useful for some in-game tasks (switching modes from first- to third-person view and vice versa in a racing game, selecting weapons in a FPS game, and so on).

Thus, we explored the utility of four menu techniques:

- **Hand-n-hold**: In this technique, users control a cursor by moving a hand in the air (see Figure 3a). The cursor’s position on the screen is directly related to the 2D position of the user’s hand in a virtual plane. Users select a menu item by holding the cursor over the desired item for a short duration (about one second).
- **Thumbs up**: A user holds a fist in front of the input device (see Figure 3b). The user then has to move the fist either horizontally, vertically, or radially in a virtual plane, depending on the layout, to highlight an item corresponding to the fist position and then give a thumbs-up gesture to confirm the selection.
- **Finger count**: All the menu items are numbered, and the user has to extend a corresponding number of fingers to select a given item (see Figure 3c). Items can be arranged in any layout and submenus appear in place. This option supports eyes-free selection because visual feedback is not needed as long as the user knows the corresponding number of the desired item.
- **3D marking**: The 3D marking menu design we selected is based on the multistroke marking menu because of its high selection accuracy. In this technique, the user performs a series of simple gestures instead of a compound stroke. Menu items are always presented to the user in a circular layout. To select an item, the user positions a fist in the center of the menu and moves it toward the desired item and then gives a thumbs-up gesture to finalize the selection.

**User Study**

We explored the utility of finger-count gestures in two user evaluations with 36 participants (31 males and 5 females, ranging in age from 18 to 33). First, we compared a finger-count-based menu selection approach with two gestural menu selection techniques (hand-n-hold and thumbs-up menu) adapted from existing motion-controlled video games. We examined both menu depth and different menu layouts. Second, we compared the finger-count menu with 3D marking menus
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Figure 3. Hand-gesture-based menu techniques: (a) hand-n-hold menu with vertical layout, (b) thumbs-up menu with horizontal layout, and (c) finger-count menu with circular layout.

We chose to conduct two experiments because 3D marking menus support only circular layouts and thus differed significantly from the hand-n-hold and thumbs-up menus. In both experiments, we examined selection time, accuracy, and user preference.

Lessons Learned

Our experiments indicate that finger-count menus let participants select items significantly faster than the hand-n-hold, thumbs-up, and 3D marking menus. This is primarily because finger-count menus do not require the user to move a hand in accordance with the items’ positions on the screen, resulting in a constant selection time for all items. The users preferred finger-count menus because of their faster selection time and natural interaction metaphor. Therefore, finger-count menus are a viable option for 3D menu selection tasks with fast response times and high accuracy and could be well-suited for gesture-controlled applications such as games.

Based on our experiment, we have the following recommendations for game designers:

- Gesture-controlled menus requiring cursor movement are slow and should be avoided, whenever possible, for games.
- Finger-count menus are fast, are layout-independent, and offer fixed selection time for each item. These menus could be a good choice for fast in-game menus or could potentially be used as shortcuts for some game tasks (such as selecting a weapon in a FPS game or switching between different camera modes in a racing game).

Effects of Simultaneous Usage

So far, we have discussed experiments that focused on exploring 3DUI technologies in isolation, but it is still unclear how the gaming experience might be affected if several 3DUI technologies are used simultaneously.

To explore this area, we custom designed an air-combat game that integrates several 3DUI technologies (stereoscopic 3D, head tracking, and finger-count gestures) to understand the interplay among them and study their combined effect on the gaming experience. Our game design was based on principles for optimizing the use of these technologies in isolation.

We chose to design an air-combat game (see Figure 4) because it requires depth perception to locate enemies around the aircraft and to avoid crashing into other objects. Furthermore, an air-combat game scene has a lot of depth and using stereoscopic 3D makes the game more immersive. Additionally, we wanted to include a 3DUI input mechanism in our game to create a more inclusive 3D user interface experience. We used finger-count gestures as an alternate to using buttons for switching weapons.

The game is controlled using the Logitech Extreme 3D Pro joystick. The head of the player’s avatar in the game can be controlled by using either head tracking (a TrackIR 5 device) or a combination of the hat switch and buttons on the joystick. The game features several stereoscopic 3D and head-tracking-specific optimizations including optimal GUI elements, no postprocessing effects, dynamic stereo optimizations, no awkward head movements, and nonisomorphic head rotations.
**User Study**

We conducted a within-subject experiment with our air-combat game to evaluate the combined effect of stereoscopic 3D, head-tracking, and finger-count shortcuts on the gaming experience. Additionally, we looked at the effects of the individual technologies to understand their contribution to the overall gaming experience. We recruited 32 participants (29 males and three females, ranging in age from 18 to 30) for this experiment. We recorded survival time, the number of enemies killed, and head-tracking usage data for each gaming condition presented during experiment.

**Lessons Learned**

Our study found significant performance benefits, in terms of the number of enemies killed, for the combined use of stereoscopic 3D, head-tracking, and finger-count shortcuts. Survival time was similar when compared with the monoscopic display, no head tracking, and button-based weapon switch condition. Essentially, that means that gamers killed more enemies in the same amount of time as in the condition with none of these technologies present. Therefore, the combined use of the three technologies improved user performance.

Our experiment indicates that participants performed significantly better, in terms of enemies killed and survival time, when head tracking was present. The availability of head tracking helped participants find enemies faster in the environment, without needing to rotate the whole aircraft. When they were using button-based head controls, it was not as easy to control the player’s head as it was with head tracking, which allows natural head movements.

The users’ performances with finger-count shortcuts were as fast as with buttons. We expected these results based on the fact that the recognition time for our finger-count gestures (under a second) was approximately the same as that of a button press. Interestingly, people were divided about their views on finger-count shortcuts. About half the participants preferred using finger-count shortcuts. Most people play games using button-based game controllers, so familiarity could be the reason for this result. Some of the participants like motion-controlled games and some don’t.

Based on our experiment, we have the following recommendations for game designers:

- Consider incorporating 3DUI technologies during the game design phase to provide a better gaming experience. Games should include elements/tasks that could be improved using 3DUI technologies.
- Consider interactions between different 3DUI technologies when used simultaneously in a game. One 3DUI technology could dominate the other, depending on the game genre or task.
- Train gamers for any new 3DUI technology used in a game. This helps users take advantage of a new technology and improves their gaming experience. This could be achieved by implementing a training/tutorial level in the game. In addition, a user could be reminded during gameplay of the presence of new technology and how to use it for better performance. Furthermore, it might help to include some challenges in the game that require the use of a 3DUI technology.

**Discussion**

Not all games could be optimized for a given 3D user interface technology. Our studies with stereoscopic 3D display and head tracking indicate that game genre is an important factor in the choice of 3DUI technology. We saw that participants performed better with stereoscopic 3D display only in games that have 3D tasks where the user is manipulating a single object at a time and the scene is more or less static (Hustle Kings and Tumble). A game with only 2D tasks will probably never benefit from the presence of stereoscopic 3D. In addition, the 3D tasks should require depth perception. Other 3DUI technologies, when present simultaneously, could also affect the role played...
by stereoscopic 3D. In our experiment with simultaneous usage, we found that head tracking was a dominant factor in user performance. Although users performed slightly better with stereoscopic 3D, the presence of head tracking helped them perform significantly better.

A user's gaming expertise could significantly affect performance when 3DUI technologies are present. For games that are relatively easy to play (such as Microsoft Flight), 3DUI technologies may not provide any additional benefits to expert gamers. Because expert gamers play often, they can perform equally well without the presence of 3DUI technology (such as head tracking) in such cases. However, casual gamers may learn faster in such easy games when 3DUI technology is present.

3DUI technologies and spatial user interaction could make gaming experiences better if used effectively.

In the case of moderately complex games (such as Arma II), experts have an edge over casuals. Expert users can learn to play the game faster and can make better use of additional 3DUI technology to their advantage. Meanwhile, casual gamers appear to focus more on game basics and do not pay much attention to the 3DUI technology present.

Our experiments indicate that 3DUI technologies and spatial user interaction could make gaming experiences better if used effectively. However, the games must be designed to make use of the 3DUI technologies available in order to provide a better gaming experience. Our results show that it is important to integrate game tasks, during the design phase, that could benefit from the 3DUI technologies.

As 3DUI technology advances, new technologies will continue to hit the market, and further exploration on how they affect the gaming experience will be required. We hope that our work will serve as a framework for these future explorations.

References
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