Scene Instability During Head Turns

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Abstract

Various experiments have shown scene-motion thresholds to be greater when the scene moves with the direction of the head turn than when the scene moves against the direction of the head turn. In fact, a virtual scene may appear to be more stable in space when moving slightly with the head turn than when the scne does not move. In this position paper, we discuss current investigations into this illusion and possible explanations.

Index Terms: H.1.2 [Models and Principles]: User/Machine Systems—Human Factors; I.3.6 [Computer Graphics]: Methodology and Techniques—Ergonomics and Interaction Techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; I.3.m [Computer Graphics]: Miscellaneous—Perception;

1 Introduction

It is known that users perceive immersive virtual environments (IVEs) differently than the real world. However, researchers do not fully understand why. For example, egocentric distances in IVEs are perceived to be compressed, even when geometrically correct, compared to the real world [6].

In this position paper, we describe a perceptual illusion that we unexpectedly found in our research:

> A scene can seem to move during a head turn when in fact it is not moving. The scene can appear to be more stable in space when it moves by a small amount in the same direction as a head turn than if the scene did not move.

We report our evidence for the illusion, possible explanations as to why it might occur, and future work that might be pursued to investigate the phenomena further.

2 Evidence of the Illusion

We unexpectedly discovered in pilot studies of a previous experiment, where subjects made scene-motion judgments after viewing a projected scene with only subject-relative cues, that scene-motion thresholds seemed to depend upon the direction of the scene motion relative to head motion. Due to this discovery, we added conditions to our experiment comparing scenes moving with the direction of head turns to scenes moving against the direction of head turns. The difference between these conditions was statistically significant. We found subjects' scene-motion thresholds when the scene moved with head turns to be twice that of scene-motion thresholds when the scene moved against head turns [4].

A later pilot study, with the first author serving as the subject, resulted in the data shown in Figure 1. The scene appeared more stable when moving at 0.1 m/s then when the scene did not move.

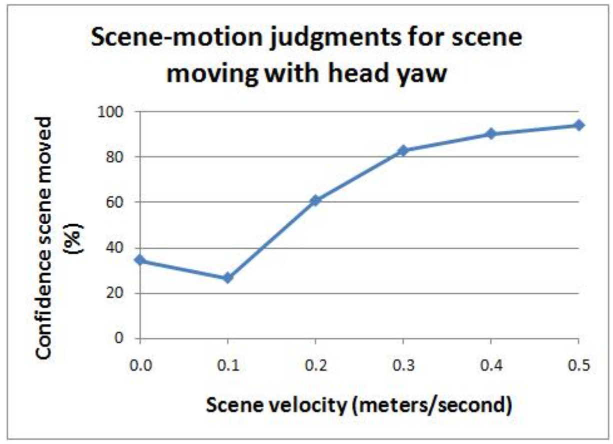

Figure 1: Results of a pilot study that included various head motions and presentation times (288 trials with each trial allowing a rating scale of 1 to 6). Confidence that the scene moved are plotted against six scene motions. Confidence that the scene moved is greater when the scene did not move than when the scene moved at 0.1 m/s.

We found a similar finding in a seperate study [8]. Rotational gains were added to a scene presented in a head-mounted display (HMD). When a rotation gain g_R is applied to a real world rotation α, the virtual camera is rotated by $\alpha \cdot g_R$ instead of α. This means that if $g_R = 1$ the virtual scene remains stable considering the head's orientation change. In the case $g_R > 1$ the virtual scene appears to move against the direction of the head turn, whereas a gain $g_R < 1$ causes the scene to rotate in the direction of the head turn. We found the point of subjective equality (PSE) to be at a gain of $g_R = 0.96$ meaning that, on average, subjects judged a scene to be moving slightly with the head to be the most stable.

After discovering this phenomena we went back and took a closer look at the literature. We found some researchers had mentioned similar findings.

In Wallach's review of his own work [9], he claimed scene-motion thresholds to be the same whether the scene moved with the head or against the head. However, in his original work [10], he stated subjects judged scenes to be stable when the scene moved with 1.5% of head turns. Wallach stated this 1.5% to be neglible, even though the result was statistically different from zero. He argued this was due to the scene being at a finite distance from the subjects and that this would be further investigated. We could find no later report of Wallach investigating this finding.

Jaekl et al. [3] found for a monoscopic HMD that the ratio of visual to physical motion most likely to be regarded as perceptually stable resulted in 1.2 times more visual movement against head turns than was geometrically necessary. This is in the opposite direction of our findings. This implies that the illusion can occur in either direction depending on conditions.

3 Possible Explanations

We propose that the following factors might contribute to the illusion.

Eye stabilizing motions. The vestibular ocular reflex and optokinetic reflex causes the eyes to rotate in the opposite direction the head turns so that the visual representation of an object remains stabilized on the retinas. For an object at an infinite distance the eyes rotate in an equal and opposite direction of the head (a gain of 1.0). For closer objects, the eyes must rotate by a greater amount (a gain greater than 1.0) for the visual representation of the object to remain stabilized on the retina. Misinterpreting vestibular cues and other cues might cause a bias resulting in apparent motion when no motion exists.

Pivot hypothesis. The pivot hypothesis [2] states that a point stimulus at a distance will appear to move as the head moves if it's perceived distance is different from its actual distance. A related effect is demonstrated by focusing on a finger held in front of the eyes and noticing that the background further in the distance seems to move with the head. Likewise if one focuses on the background then the finger seems to move against the direction of the head. For the case that objects appear to be closer to users than they should, as is the case for HMDs [6], the scene should appear to move with the head. In this case, the scene would have to move against the direction of the head turn to appear stable in space. This is consistent with the findings of Jaekl [3] but in the opposite direction of our measurements.

Spatial Frequnecy, Brightness, and/or Contrast. It is possible that our results could be a function of spatial frequency, brightness, and/or contrast. Freeman and Banks [1] found that the Filehne illusion (when tracking a moving object with the eyes, the background appears to move against eye motion) and the Aubert-Fleischl illusion (the false impression that objects move slower when they are pursued with the eyes as compared to when the eyes are kept stationary) could be reversed by manipuluating spatial frequency. Manipulating spatial frequency, brightness, and/or contrast might be able to reverse the illusion we found.

Edge of HMD. The edge of an HMD may cause subjects to judge scene motion relative to the head instead of relative to the world. I.e., subjects could be biased towards greater thresholds when the scene moves with the head since the edge of the HMD serves as an object-relative cue.

Scene size Our scene in our previous experiment [4] had a 20° horizontal span. We expect larger scenes to appear to be more stable and to reduce the illusion.

Magnitude of relative motions. It is possible the mind biases us to see scene motion in the opposite direction we are turning our head. If the eyes follow the scene, the difference between head motion and eye motion is larger when the scene moves against the direction of the head turn. If the eyes remains stabilized in space, the difference between head motion and motion on the retina is greatest when the scene moves against the direction of the head turn.

Latency. Latency in an HMD causes the scene to move with the head as the head accelerates and to move against the head as the head decelerates. This could cause bias if subjects pay more attention to scene motion as the head is accelerating or decelerating. However, in our original study [4], the scene was presented by a projector so that latency caused no scene motion.

4 Discussion and Future Work

Our current study emulates an HMD by using a projector and removing all object-relative cues. This was done to remove all confouding motion that occurs due to error inherent in HMDs (e.g., due to latency, incorrect field of view, incorrect accomodation, etc). The casing of an HMD was used so that the field of view was similar to a real HMD.

We presented a large stable scene (∼100 lux) that showed the true display surface between trials so that subjects could have a reference of a stable world.

The study investigates the illusion under different conditions:

- **Head Phase** Different phases of head turns (beginning, center, and end of single left-to-right / right-to-left head turns)

- **Brightness** One dark condition (∼1 lux) and one bright condition (∼400 lux) such that subjects might perceive the darker scene to be behind the display surface and the brighter scene in front of the display surface. We thought this might reverse the illusion due to the pivot hypothesis or find a result similar to Freeman and Banks [1].

Preliminary analysis suggests the illusion holds across all tested conditions. We suspect the differences in brightness did not cause subjects to perceive the scenes to be at different depths and/or the pivot hypothesis and brightness/contrast does not significantly affect the illusion.

In this study all scene motion was a constant velocity for each trial. However, at least one subjects perceived changes in velocity:

> "It sometimes feels still up to the end then it moves when you stop your head" (Subject ID415).

This illusion makes sense since scene-motion thresholds increase as head motion increases [5].

4.1 Future Work

Future studies might include the following

- Binocular disparity in order to vary the perceived distance to further test the Pivot Hypothesis.

- Removal of the HMD casing such that subjects cannot use the edge of the HMD in peripheral vision as an object-relative cue. It may be the case that this illusion only occurs in HMDs due to this cue.

- Different scene sizes or different field of views. The illusion may decrease as the field of view in newer HMDs increase.

- Varying latency to determine if latency could have contributed to the results of Jaekl [3].

4.2 Discussion

We are curious as to why the results of Jaekl et al. [3] are the opposite of our results. We suspect the reasons are due to different conditions such as the monoscopic display, latency, etc. If we can determine the important factors of when the illusion can be reversed, then this would be very useful to control perception of scene motion in virtual environments.

Specifically, We believe understanding such illusions and under what conditions they occur will allow us to create better redirected walking systems. For example, our results suggest distractors used for reorientation purposes [7] could be used most effectively by moving the distractor in the same direction we wish to rotate the world. We also suspect the thresholds would be larger if subjects pay attention to a distractor or some distracting task.

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