An Experiment to Characterize Head Motion in VR and RR Using MR

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Abstract

Virtual reality user interfaces usually use a Head-Mounted Display (HMD) for viewing a simulated virtual world. Typical HMD's are rigidly mounted on the user's head and supply a head-relative fixed viewport to the virtual world. The direction of view is supplied by a 6D position and orientation tracker, such as a Polhemus Isotrak. One characteristic of HMD use is that HMD's are heavy, and require that the user spend additional effort in turning the head. There can also be a significant lag between when the head moves and when the corresponding image appears on the HMD screens. This paper documents an experiment that we plan to perform with subjects wearing a HMD. The purpose of the experiment is to determine the characteristics of user head motion, with a view to designing a predictive filter that takes advantage of these characteristics. Initial ad hoc experience indicates that the user's head moves along a great-circle arc while undergoing orientation changes. The velocity of orientation motion seems also to be symmetric.

1 Introduction

In recent years, the virtual reality concept has been explored by many researchers [Brooks86] [Green90]. To provide real-time visualization of a 3-D space, a Polhemus Isotrak tracker is often used to determine the user's viewpoint and line of sight, and based on the measured data, stereoscopic images are generated and displayed to the user through the Head-Mounted Display (HMD). In this paradigm, two factors associated with tracking technology adversely affect the user's perception of the virtual world, namely, the jittering of images and the lag between head movement and visual feedback [Rebo89] [Wang90] [Liang91].

The jittering of images is caused by the noise in the measured data, and will not be considered further. The lag is due to three system components: The first component is the time taken by the tracker system to measure and calculate the position of its sensing unit. The second component is the time taken by the software system to convert sensor data into a usable format and to communicate it to all drawing processors. The third lag component is the time taken to draw the virtual world and display it to the user. These lags sum, and any effort spent reducing lag in any one area will directly affect overall lag.

There are three problems associated with the output part of the HMD: The limited viewing angle available to each eye, the low display resolution for each eye's screen, and the nontrivial mass of the HMD that the user's head must support. The viewing angle and the screen resolution probably do not affect the user's head motion, but the mass of the HMD does change how the user moves his/her head. HMD mass thus has some sort of effect on the amount of image lag the user experiences due to the increased head inertia.

Therefore, in designing a predictive filter to reduce the amount of image lag that the user experiences, both mechanical and cognitive components of head motion must be taken into account. This paper describes a series of experiments that we plan to perform with subjects wearing a HMD. The purpose of the experiment is to determine typical characteristics of user head motion, so as to intelligently design a predictive filter. In the following section, we discuss previous approaches to eliminating lag in Head-Mounted Display applications. Section 3 discusses the goals of the experiment. Section 4 describes the experiment, and section 5 mentions some initial results. Section 6 concludes the study.

2 Summary of Previous Work

Previous efforts at filtering head motion do not take into account any information about how one moves one's head to look around. Friedmann et al [Friedmann92] note that for HMD applications, head orientation is more important that position.

Our previous study [Liang91] also noted that head orientation was the most important component, and we therefore built a naive Kalman filter that predicted the user's head orientation. In the naive approach, the orientation quaternion is broken up into its 4 components, and then each component is filtered by a Kalman filter. Next, the filtered components are reassembled and the reassembled quaternion is normalized to preserve the its unit length. There are two reasons why this naive approach works: First, the random process model chosen for head motion was appropriate. Other researchers [Rebo89] chose an inappropriate model, and as a result, their filter oscillated and severely overshot. Second, the renormalization step minimizes overshoot by constraining the filtered output to once again lie upon the unit 4-sphere. Thus, while each Kalman-filtered component may overshoot, the normalized result may overshoot less due to normalization.

To make the naive filter work well, the Kalman filter must be parameterized properly. The appropriate parameterization depends only on the noise and delay properties of the tracking system. Thus, as long as basic assumptions about maximum angular acceleration and maximum angular speed are not violated, the naive filter will work for any object whose orientation is being tracked. This generality comes at a cost in prediction performance, however. It seems intuitively clear that one should be able to do better in the HMD situation simply because one can study not just tracker performance, but also human head performance, and therefore glean some specialized information to be used as the basis of a new HMD-based predictor.

3 Head Motion

The special properties of head motion are that the head is a large mass which is moved by a motor system that is controlled by muscle feedback, visual feedback, and vestibular feedback. Adding a Head-Mounted Display significantly increases the mass and thus the rotational inertia of the head. Thus, the mechanical aspects of the system are significantly changed, although the feedback pathways remain the same. The HMD also changes the visual environment such that the visual feedback does not temporally match what is really happening. Visual lag adds a new element in the control loop, which changes the transformation function of the visual control loop. As a result, the HMD wearer tries to compensate for this extra lag, usually expending a nontrivial amount of cognitive energy in the process.

4 Head Motion Experiment

We plan to perform a series of experiments to determine the properties of head motion in the VR context. The basic procedure is to log head position and orientation while the the subject moves his/her head to look about the room. The experimental setup is as follows.

The subject sits in a chair and looks at a series of targets arrayed about the seat in the room. The subject is free to move his/her upper torso, but the chair is fixed to the floor, and his/her bottom remains stationary on the chair. There are six targets arrayed about the subject: five targets are at eye level; one is in front of the subject, one each to the left and right at 45 degrees, and one each at 90 degrees to the left and right. The sixth target is in front of the subject, raised 45 degrees above eye level.

To perform one trial of the experiment, the subject gazes at the center of one of the targets, designated the *start target* for this trial. The location of the *goal target* is displayed on the start target along with a countdown display. When the countdown reaches zero, the timer clock starts and the start target goes blank, signaling the subject to start moving towards the goal target. Also at time zero, the goal target displays one of two possible characters. The subject must discriminate between which of the two characters is displayed, entering the choice by pressing one of two buttons. The end of the trial is signaled by the subject entering the choice of character.

The data collected during the trial is the subject's head position and orientation throughout the trial, along with the time at which the subject made the discrimination choice, and whether the choice was right or not. The start target can be either the previous trial's goal target, or the target that is directly in front of the user. The goal target is chosen pseudorandomly in such a way that all pairwise combinations of targets are tried. Between each trial is a five second rest period, and between each set of 50 trials is a five minute rest period, for a total of 200 trails per hour.

In order to minimize the effects of training, and in order to get people who are practiced at performing these trials, we plan to have each subject execute 1000 trials over a period of five days at one hour of trials per day.

There are three experimental conditions: The first is where the subject wears only a Polhemus Isotrak on his/her head with no HMD. The subject looks through *blinders* which limit the subject's field of view equal to that of the HMD. The targets in condition 1 are graphics CRT's arranged in a semicircle about the user.

Condition 2 is where the subject wears an Isotrak mounted on a HMD, but the subject does not use the displays of the HMD, but instead looks at graphics CRT's through blinders. The purpose of this condition is to increase the inertia of the head without changing the visual stimulus.

In condition 3, the subject wears the HMD, tracked by an Isotrak, and the targets are virtual CRT's in the virtual world displayed on the HMD. The targets have the same location in the virtual world as in the real world, but in this condition there is an added visual lag caused by the sensor, system and display lags outlined above.

With these three conditions, we hope to be able to identify how the use of a HMD in the VR context changes head motion. We anticipate that there is a mechanical component, caused by the added inertia of the HMD, and a cognitive component, caused by the lag in visual stimulus. As a side benefit, we also plan to get mean reaction times for character recognition using a HMD versus reaction times of the same characters in the real world. Finally, we hope to identify typical motion curves for head motion while a HMD is worn.

5 Preliminary Results

Ad hoc testing of condition 3 with one subject looking at randomly self-chosen targets indicates that the head undergoes great-circle motion. In other words, the arc traced by the head in moving from the start target to the goal target is of minimum length.

Also, speed traces of orientation change indicate that the speed of head motion is symmetric. That is, speedup time equals slowdown time. This matches findings in the psychological literature [Jeannerod88].

6 Conclusions

This paper outlines the motivation for a series of psychological experiments that we plan to perform. The experiment was outlined, along with some preliminary results.

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