DISCRIMINATION OF CHANGES IN LATENCY DURING HEAD MOVEMENT

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1 Introduction

Human users of virtual environments (VE) are disturbed by system latency which reduces interactivity, user dexterity, and speed. Because latencies in VEs arise from rendering, switching and transmissions delays, they will continue to persist in systems involving satellite or space communication links even as computing speeds increase. Our previous work has focused on the precision, stability, efficiency and complexity of operator interaction in latency-plagued systems (e.g., Ellis, Bréant, Menges, Jacoby, & Adelstein, 1997). But there has been relatively little work on users' subjective response to changes in system latency which could cue impending degraded performance and also disturb users' sense of immersion in "virtual" tasks (see Uno & Slater, 1997). In particular, operators' psychophysical functions describing sensitivity to detection of the visual consequences of latency change have not been measured. We have measured these functions for the first time for head movement while users view nearby virtual objects.

The literature on manual control has long established that latency in displays or controls has a major negative impact on performance (Smith and Smith, 1962, Ferrell, 1965; Sheridan, 1992). In general, the effect involves a reduction in control accuracy which ultimately drives the operator to adopt a "move and wait" strategy when latency exceeds about 300 msec. Operator compensation for a delay usually requires the ability to predict the future state of a tracked element.

Display delays have also been shown to interfere with operator adaptation to other display imperfections such as static positional distortions in vision (e.g. Held, Efstathiou, Greene, 1966). Consequently, but not surprisingly, delays in visual displays have been shown to have major impact on overall operator productivity in the workplace (Doherty & Thadhani, 1982).

Interest has more recently moved away from the performance impact of delay and update rate onto their subjective impact. For example, delay and update rate have been considered as factors affecting the operators' sense of presence in the environment. (Sheridan, 1992; Barfield & Hendrix, 1995; Ellis, *et al,* 1997). These dynamic aspects of displays are particularly potent influences on users' sense of presence because they tend to swamp other factors influencing important VE parameters such as positional fidelity and dynamic registration error (Holloway, 1997).

Since transmission delay is inescapable in many VEs, teleoperation, or augmented reality applications, interest naturally is directed to how detectable differing levels of delay might be. Poulton (1974, p. 202) reports that manual tracking performance is reliably reduced with delays as low as 40 msec even though such delay may not be "appreciated" by the operator. But his book contains no specific reports of the differential discriminability of various levels of delay. In fact, we have not been able to find such data in the literature.

Accordingly, the following experiment has been designed to provide the first measures of human operators' discrimination of the consequences of latency during head movement in an immersing virtual environment. Subjects' psychophysical functions for the discrimination of latency were measured with a Two Alternative Forced Choice technique. Since the subjects were asked to only make a single stereotyped head movement, strictly speaking they are not discriminating latency, but only its visual consequences. These consequences appear as uncommanded movements of virtual objects that are observed.

2 Methods

The VE simulation used was produced with World Tool Kit on a SGI Onyx graphics computer with RE-2 graphics viewed through a Virtual Research V8 head-mounted display (HMD). FasTrak hand and head position sensors were used with a custom, low-latency dual-serial driver comparable to a previously described parallel driver (Jacoby et al, 1996). Because we use two Polhemus sources simultaneously, we are able to collect both head and hand position and orientation at 120 Hz. Notably for the simulation content that we used, the system has been able to maintain a regular 60 Hz simulation update rate for a stereoscopic display. Minimum full system latency has been measured to be 27±5 msec. Since the measurement technique we use contributes to some variability, the actual latency variation is less than 5 msec. The unique dynamic performance of our system make the following experiment possible.

An immersing VE simulation was used to present subjects with a simple VE giving the impression that they are looking at a multifaceted, neutrally colored, 10 cm diameter virtual ball located at arms length. The ball is lit by two virtual light sources, one ambient and one directed so as to make the facets visible and to appear somewhat like at 3/4 moon. Maximum luminance as seen by the subject was midphotopic, about 50 cd/m^2. No other environmental elements are simulated.

Subjects were seated within 60 cm of the FasTrak transmitters and asked to rock back and forth once through an arc subtending 48° of visual angle, the full HMD binocular field of view. The virtual ball they viewed appeared fixed in virtual space 60 cm in front of them. System latency in the rendering of the virtual ball produced a transient mismatch in the visual position of the virtual ball and the felt position/direction of their head. Initial adjustment made the virtual ball coincident with the room-referenced straight ahead. In the actual experiment subjects were presented with one of three reference latencies which were followed by a test latency that could either be shorter or longer by a number of 16.7 msec steps. The increase or decrease in latency was intended to simulate a realistic graphics environment in which latency could change either way. Subjects indicated whether the two conditions were the same or different by pressing buttons on a hand-held response device. For each subject's latency comparison the detection/false alarms probabilities reported below were based on 64 trials /condition in which 25% presented a difference and 75% were catch trials. One to seven 16.7 msec. increments of latency were randomly presented for each of the base latencies. All tests were blocked by base latency and increments and blocks were randomized.

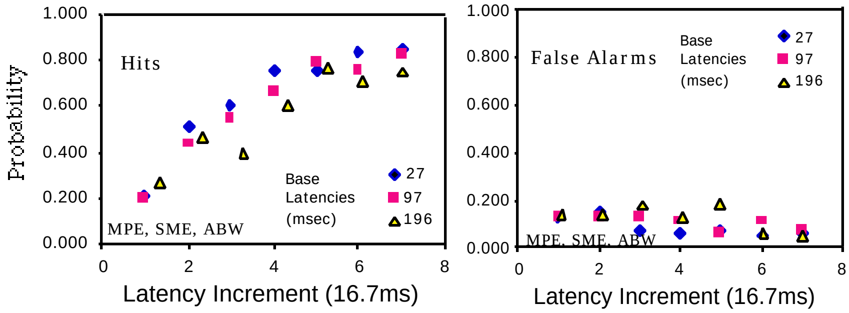

Figure 1. Mean data from three practiced subjects.

All subjects were trained on the discrimination task for at least 1 hour of familiarization, experiencing all experimental conditions. Subjects were laboratory personnel and paid volunteers who could tolerate the one day of automated data collection. They were blind to the specific experimental conditions and took rest breaks every 20-30 minutes. All were right handed.

3 Results

Complete data for three practiced subjects are presented above. Results show detection probability (Hits) increasing to an asympotote around 80% The false alarm rate remains relatively constant indicating a genuine change in stimulus detectability as the number of steps latency change increases. Three subjects have been completed.

4 Discussion

The most striking feature of the measured psychophysical functions is that neither the correct detections of latency differences nor the false detections of difference were affected by the differing base latencies. The observers' judgment criteria also appears to have been fairly constant for the different conditions. The discrimination, in fact, does not appear to follow Weber's Law. If a Weber's Law were in effect, the curves for the three base latencies should separate since at threshold each fixed increment would be a fixed proportion of the different bases. These results are similar for psychophysical functions measured for the discriminability of latency changes during hand movement of virtual objects (Ellis, Young, Ehrlich, & Adelstein, 1999).

The essentially identical threshold for the different base latencies means that users of long latency VE systems will be as sensitive to changes in latency as those who use prompter, systems. Designers will not be able to count on long latency interactivity per se to "smear over" variations in latency. However, the lower discriminability of the larger latency differences, when compared to discriminability of hand movement of virtua objects, suggests that users will not be less able to detect changes in latency before other effects such as motion sickness or reduced depth sensitivity from degradation of motion parallax manifest themselves (McCandless, Ellis, & Adelstein, 1998).

As in the case with hand movements, the stereotyped head movements used preclude interpretation that subjects are detecting changes of latency per se. They may only be responding to the latency's fixed visual consequence. Future studies will examine whether latency itself may be discriminated by forcing subjects to randomly move at different speeds.

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