The Cognitive Impact of Head Tracking Latency in Immersive Simulations

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Abstract

This research presents an immersive Virtual Environment (VE) of minimum tracking latency. Subsequently, we quantify the cognitive impact of head-tracking latency by investigating the effect of latency on spatial cognition, awareness states and mental imagery. Both the quantification of perceptual sensitivity to latency and description of the mechanism by which VE latency is perceived and controlled will be essential to guide system countermeasures such as predictive compensation.

Methodology

End-to-end simulation latency is the time lag between a user's action in a synthetic simulation environment and the system's response to this action. System latency and its visible consequences are fundamental VE deficiencies that can hamper user perception and degrade manual performance [Mania et al. 2004]. While users can exhibit sensorimotor adaptation that might improve manual performance to time delays in situations where task preview is available, the presence of delay hinders operator adaptation to other display distortions such as static displacement offset. Previous studies investigating perceptual sensitivity to latency through formal psychophysical testing revealed that the Just Noticeable Difference (JND) for latency discrimination averages ~15 ms or less, independent of scene complexity and real-world meaning. Such studies were far-removed from ecologically-valid training situations, demanding long exposures to Head Mounted Displays (HMDs) and repetitive head movements in order to acquire psychophysical judgments. The work presented in this poster explores the effect of tracking latency on spatial awareness and spatial cognition while users are immersed in a simulated real-world scene representing an apartment, utilizing a well-established methodology from memory research which explores how spatial awareness is perceived from a cognitive rather than a pure performance point-of-view.

A radiosity-rendered VE presenting a single-room apartment was created (Fig. 1) and displayed on a stereoscopic HMD. Head movement tracking was accomplished using a 3DOF head tracker. The typical end-to-end head tracking latency of the system was premeasured using a custom-made Data Acquisition Card (DAQ) instead of the oscilloscope utlilized in previous studies [Mania et al. 2004]. The card was capable of monitoring analog and digital inputs and reporting them to a PC through a USB connection. This provided freedom of creating software that statistically analyzed the inputs as intended for our study. A swing arm motor equipped with a rotary encoder repeatedly rotated the tracker back-and-forth through a pre-set threshold angle and the encoder reported crosses of the threshold to the DAQ. Passing through the threshold angle was resulting in VE changes. More specifically, polygons located at a corner of the screen were changing color from black to white and vice versa. A photodiode attached to the front of the monitor was used to detect brightness changes of these polygons and to transmit them to the DAQ. The two signals were compared, and the time shift between the passing of the tracker through the threshold and the black-to white transition of the polygons was the assessed end-to-end latency of the system. After measuring the typical latency of our system, latency-inducing features of the graphics subsystem (V-sync, triple buffering) were disabled. This resulted in reduction of overall latency but also image tearing. A steady frame rate was reestablished by reconnecting the VGA v-sync signal to the computer's parallel port and having the VE application poll the port. Addition of a constant amount of latency was achieved using a circular buffer for storing tracker positions and reporting them to the rendering thread on a later frame.

Accuracy of performance per se is an imperfect reflection of the cognitive activity that underlies user performance [Mania et al. 2006]. Accurate memory recollections can be linked with the subjective awareness states "Remember", e.g. recollections based on a mental image or a prior experience, "Know", as a general sense of knowing with no or little recollection, "Familiar", if something feels like it has been encountered recently without recollection, and "Guess". Participants across three conditions of latency (minimized, increased and extreme) were exposed to the VE and completed an object-based memory recognition task reporting associated awareness states. The apartment scene comprised of real-world objects consistent with the context of the room, or primitive geometrical objects (boxes, pyramids and spheres) substituting the real-world objects.

Preliminary results indicate that those immersive environments that are distinctive because of their variation from 'real', such as scenes which included primitive objects rather than objects with real-world 'meaning' or are presented in high latency but not extreme to the point of making navigation impossible, induce recollections linked with the "Remember" awareness state. Memory psychology has established that awareness states based on visual imagery ("Remember") require stronger attentional processing in the first instance than those based on familiarity. It could be deducted that the functional fidelity of the scene utilized is higher when it varies from expectations of photorealism or 'normal' scene context and therefore, a low fidelity simulation could be adequate for spatial awareness in this sense. Future work should include real-world comparisons.

Figure 1: The experimental scene

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