Locomotion in Virtual Environments: Comparing Techniques and Using Redirection

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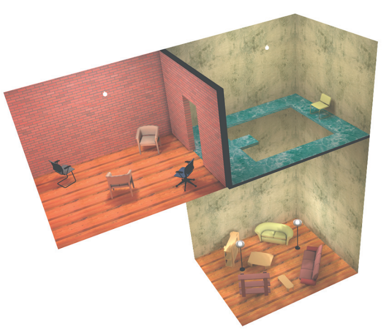
The Challenge

How users on foot move from one virtual place to another within limited tracked space is one of the most persistent and difficult user interface problems for immersive virtual environments. Flying by pushing a button or joystick has none of the naturalness of really walking: flying doesn't make you tired or stimulate your proprioceptive and vestibular systems, which is your body's way of "feeling" motion. Really walking overcomes those problems, but introduces the problem of how to move in a virtual environment that is larger than the area covered by your trackers.

Since 1998 the Effective Virtual Environments (EVE) research team has been developing and evaluating locomotion techniques for use in virtual environments.

Comparing Walking, Walking-in-Place, and Flying

Our earliest work in locomotion was done in collaboration with University College London. We replicated their results showing that walking-in-place (standing still while marching the feet) induces a higher sense of presence than flying with a joystick. Because we have a 6.7m x 9m wide-area tracker, we were able to add a *really walking* condition to the study. The results showed that really walking is also significantly better than flying, and showed a strong trend that it is better than walking-in-place.



This locomotion work was done in our "Pit" environment, Figure 1 (left), and the measures were post-experience questionnaires. This work led to later work establishing the validity of physiological measures as correlates of presence and the use of physiological measures to evaluate VE systems on several dimensions, e.g., frame rate, field-of-view, rendering quality, and audio quality.

Comparing Motion Paths

In our current work on locomotion, our goals are to develop metrics that let us compare motion paths—how the user moves in space and time—so that we can then apply those measures to see whether users move differently using different locomotion techniques. Our motivating issue is to determine whether or not locomotion interface adversly affects training and the transfer of skills learned in VR to the real world.

Highlights

- **Different locomotion techniques result in different user space-time movement patterns. We are using those patterns to compare locomotion technqiues.**
- **Redirection allows users to really walk through virtual spaces larger than the tracked space.**
- **Redirection, applied as redirected walking-in-place, keeps users from seeing the open back wall of a three sided CAVE.**

In our early studies, users walked to targets on walls and stopped as close to them as they could without making contact, Figure 2 (left). They did this in five experimental conditions that included one of three locomotion interfaces (really walking, walking-in-place, and joystick flying), and one of three visual conditions (head-mounted display, unrestricted natural vision, or field-of-view-restricted natural vision). We used principal component analysis to find the most important characteristics of the motion paths and collected data that captured task performance and the underlying kinematics of the task.

Our results show: 1) Over 95% of the variance in simple motion paths is captured in three critical values: peak velocity; when, in the course of a motion, the peak velocity occurs; and peak deceleration. 2) Correlations of those critical value data for the conditions taken pairwise suggest a coarse ordering of locomotion interfaces by "naturalness." 3) Task performance varies with interface condition, but correlations of that value for conditions taken pairwise do not cluster by naturalness.

Another goal of this research is to see if our metrics correlate with the perceptual variable τ, which is defined, for a person approaching something in front of them, as the time-to-contact (distance-to-object / velocity). Such a correlation would be valuable because, in the psychology literature, τ has been shown to relate perception and motor control of motion.

Redirected Walking

Real walking is more natural and invokes a greater sense of presence in the user, but limits the size of the virtual scene to the size of the tracked area. Redirected Walking allows users to really walk in a virtual scene larger than the tracked area, by interactively and imperceptibly rotating the scene about the user. This causes users to walk along an arc when they think they are walking in a straight line. When users are turning in place, it causes them to turn faster than they think they are. By continually rotating the visual and auditory scene, it causes users to continually walk towards the farthest wall of the lab (Figure 3).

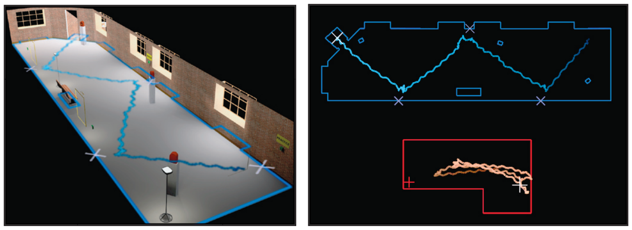


Figure 3: Path thru virtual scene and overhead view (in red outline) of path in laboratory.

Redirected Walking-in-Place: The vast majority of CAVEs® and CAVE-like systems, have three vertical display surfaces (walls) and an opening on the fourth, back, side. Having the open wall come into view reduces the user's sense of presence in the VE. We have successfully applied the Redirection to locomotion in a 3-walled CAVEs. Users can turn naturally and in any direction in the virtual scene, using their body rather than a hand-controller. Compared to using a hand-controller, users see the open back wall less often and suffer less simulator sickness Figure 4 shows one user's path in the virtual scene—she is able to walk in all directions without seeing the open back wall.

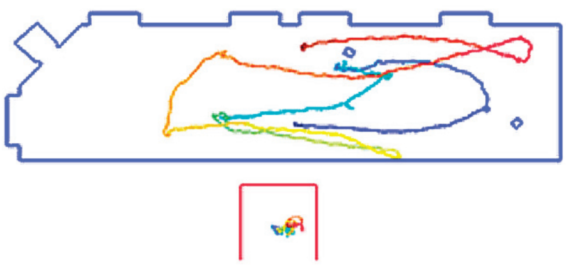


Figure 4: Top - Virtual path in the VE. Bottom - Corresponding real path in a three-wall CAVE.

Future Opportunities: Simulations based on theory and user studies describe the minimum size tracked space needed to allow the user to walk along an arbitrarily long, straight, virtual path. Algorithms have been proposed for steering users away from the lab walls while they freely explore a large virtual scene. The hardware components to build a system which implements all of this are now available. This would enable testing and refining the theoretical work and deploying it in practical applications. Also the effects of Redirection on users' spatial understanding, task performance and training have not been explored.

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Selected Publications

Whitton, M., J. Cohn, J. Feasel, P. Zimmons, S. Razzaque, S. Poulton, B. McLeod, and F. Brooks. "Comparing VE Locomotion Interfaces," *Proceedings of IEEE Virtual Reality 2005* (Bonn, Germany March 2005), IEEE Computer Society.

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Usoh, Martin, K. Arthur, M. Whitton, A. Steed, M. Slater, and F. Brooks, "Walking>Virtual Walking>Flying, in Virtual Environments" *Proceedings of SIGGRAPH'99* (Los Angeles, CA, August 11-13), Computer Graphics Annual Conference Series, 1999, pp. 359-364.

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