Seven League Boots: A New Metaphor for Augmented Locomotion through Moderately Large Scale Immersive Virtual Environments

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ABSTRACT

When an immersive virtual environment represents a space that is larger than the available space within which a user can travel by directly walking, it becomes necessary to consider alternative methods for traveling through that space. The traditional solution is to require the user to travel 'indirectly', using a device that changes his viewpoint in the environment without actually requiring him to move – for example, a joystick. However, other solutions involving variations on direct walking are also possible. In this paper, we present a new metaphor for natural, augmented direct locomotion through moderately large-scale immersive virtual environments (IVEs) presented via head mounted display systems, which we call *seven league boots*. The key characteristic of this method is that it involves determining a user's intended direction of travel and then augmenting only the component of his or her motion that is aligned with that direction.

After reviewing previously proposed methods for enabling intuitive locomotion through large IVEs, we begin by describing the technical implementation details of our novel method, discussing the various alternative options that we explored and parameters that we varied in an attempt to attain optimal performance. We then present the results of a pilot observer experiment that we conducted in an attempt to obtain objective, qualitative insight into the relative strengths and weaknesses of our new method, in comparison to the three most commonly used alternative locomotion methods: flying, via use of a wand; normal walking, with a uniform gain applied to the output of the tracker; and normal walking without gain, but with the location and orientation of the larger virtual environment periodically adjusted relative to position of the participant in the real environment. In this study we found, among other things, that for travel down a long, straight virtual hallway, participants overwhelmingly preferred the seven league boots method to the other methods, overall.

CR Categories and Subject Descriptors: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism.

Additional Keywords: spatial perception, locomotion, immersive virtual environments.

1. INTRODUCTION AND MOTIVATION

Immersive virtual environments (IVEs) have the potential to be extraordinarily useful in a variety of applications, from architectural design to situational awareness training. By enabling a user to visually experience an environment from the point of view of directly 'being there', as opposed to just looking at pictures that could be coming from any arbitrary, indirectly manipulated, camera location, researchers envision the possibility to convey to the user a more accurate, intuitive and robust intrinsic appreciation of the spatial layout of the virtual environment, including providing a reliable understanding of the distances between objects or landmarks in the scene [26].

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Previous research [e.g. 18, 21, 23, 27] has indicated that participants' sense of presence in a virtual environment is enhanced when they are able to move through that environment using a method that is similar to one they would naturally use in the real world – such as walking – as opposed to having to rely on an *indirect* metaphor for locomotion, such as walking-in-place [20, 2], or an *abstract* metaphor, such as flying. These findings are consistent with new theories being formed in the field of psychology about the relationship between perception and action, and, in particular, between perception and the anticipated expenditure of effort [c.f. 15], and much work has been done to enable locomotion through large virtual environments as a result of naturalistic physical effort within confined physical spaces using custom-fabricated devices such as the omni-directional treadmill [5], the torus treadmill [9], the Sarcos treadport [8], the HapticWalker [17], and other walking devices, as well as various modifications of exercycles [e.g. 3], etc.

When one wants to use ordinary direct walking for locomotion through a virtual world, complications will arise when the potentially navigable space in the immersive virtual environment exceeds the physically available space for walking, e.g. in the lab where the VE equipment is installed. Inspired by the work of Mine *et al.* [12] and Razzaque *et al.* [16], one of the goals of our present research is to explore the use of alternative methods for locomotion that can retain the same sort of proprioceptive mapping to the user's physical actions that one gets with real walking. In this paper we introduce and discuss a new method for traveling through moderately large, immersive, HMD-based virtual environments that remains essentially based on walking, but in which the mapping between the user's actual movement in the real world and his apparent movement in the virtual environment is artificially manipulated through the use of various, hopefully intuitive, metaphors.

2. PREVIOUS AND RELATED WORK

Although our present focus is on direct, proprioceptively-faithful methods for immediate-mode navigation in moderately large immersive virtual environments presented via head-mounted display systems, these represent only a small subset of the space of possible navigational techniques and virtual environment scenarios.

There has been a large amount of previous work in the investigation of effective metaphors for general navigation in virtual environments, both immersive and non-immersive. For example, Ware and Osborne [22] compared three different metaphors for indirect viewpoint control in desktop virtual environments via a 6DOF input device and found that none was best overall but rather that each had various advantages and disadvantages, so that the choice of method should depend on the needs of the task. Also, Pausch *et al.* [13] proposed an indirect metaphor for navigation through large immersive virtual environments based on the direct manipulation of a tiny avatar within a hand-held miniature (WIM) of the occupied environment. In this method, the user repositions the avatar in the WIM, and then his point of view is transformed, via continuous translation/rotation/scaling, into the point of view of the avatar. Bowman *et al.* [1] proposed a control-based taxonomy of techniques for traveling through an immersive virtual environment, categorizing various possible approaches according to 1) the technique for selecting the direction of travel; 2) the method for defining the speed of motion; and 3) the ways in which the user or system controls the onset, duration and extent of the movement. They conducted a series of experiments comparing two different metaphors for selection of the direction of travel: gaze-directed and hand-directed, and found that the latter approach offered several ergonomic advantages and efficiencies over the former, particularly in situations where the required direction of travel was not in a straight line towards a sighted target. They also compared the effects on spatial awareness of using three different velocity/acceleration techniques: constant, slow-in/slow-out, and abrupt (jumping), and found that the abrupt change of view was particularly disorienting, but that there was no apparent difference in the effectiveness of using a constant velocity for travel versus ease-in/ease-out. Darken and Banker [4] compared the effectiveness with which participants could navigate through a real environment after training in the real world versus training using a desktop virtual environment versus training using only a map. While they found that task performance correlated more strongly with a participant's overall level of previous experience in orienteering than with the method of training he received for the particular course studied, and that the best results were generally obtained by the participants who were able to complete the training in the real world, they also found that training in the VE offered the particular advantage of time compression. Tan *et al.* [19] proposed a task-based taxonomy of techniques for navigating through generally non-immersive 3D virtual environments, and they used insights provided by this structure to come up with several effective new techniques for navigation in a desktop virtual environment, including 'speed-coupled flying' in which the speed of movement, controlled by the motion of the mouse, automatically determines the height and tilt of the camera that defines the point of view of the participant, resulting in the effect that when people travel quickly, they rise above the ground, and after they release the mouse button, they float back down. And, LaViola *et al.* [10] developed several hands-free metaphors for navigation in immersive virtual environments, including a leaning technique for traversing small and medium distances, the use of amplified rotations – which allow the user to be exposed to a 360° change in viewpoint across a three-sided CAVE – and a floor-based WIM. Other body-centric navigation methods have also been developed by Fuhrmann *et al.* [7], and others.

Perhaps closest in spirit to our work are the recent efforts of Williams *et al.* who have developed methods for using uniform tracker gain [24] and 'resetting' the position of the participant within the virtual environment [25] to enable participants to traverse moderately large virtual spaces by directly walking within a smaller real space.

3. Seven League Boots

The primary metaphor that we explored for augmented, walking-based locomotion in immersive virtual environments was inspired by the fairly-tale device of Seven League Boots [14]. With the Seven League Boots metaphor, our intention is to let each step that the user takes in the real world appear to have the same consequence as, for instance, that of taking seven steps in the virtual world. In a naïve implementation, this can be thought of as equivalent to applying a uniform scaling factor to the amount of displacement that occurs as a user moves through a space. However, unfortunately, a naïve implementation of seven league boots based on a uniform scaling of the user's displacement suffers from several serious drawbacks. The most disturbing of these is a consequence of the fact that when we walk in the real world, our head doesn't actually move in a straight line, but rather sways, ever so slightly, from side to side with each step. Although we are often not consciously aware of this motion, as an indication of its impact Lécuyer *et al.* [11] have recently shown that, in the context of desktop virtual environments, users report that when ordinary forward viewpoint translation is enhanced with oscillatory camera motions, this yields results that are perceived as being more evocative of real walking. Therefore, simply applying a uniform scaling to the displacement that is computed at each update of the user's position results in exaggerating not only the movement in the primary direction of travel but also the movement in the side-to-side directions. This typically causes the viewpoint to appear to sway excessively, which can be discomfiting in large open spaces and have disastrous consequences when one is traveling within closer spaces, such as when walking down a narrow alleyway.

The most obvious solution to this problem is to determine the direction of intended travel, and only scale the component of the movement that is aligned with this direction. For example, if the primary intentional direction of travel over a fixed ground plane is given by $\vec{u}$, then one can express any particular displacement $\vec{d}$ in terms of the basis vectors $\vec{u}$ and $\vec{v}$, where $\vec{v}$ is orthogonal to $\vec{u}$ and both $\vec{u}$ and $\vec{v}$ are parallel to the ground plane, obtaining the expression $\vec{d} = d_u\vec{u} + d_v\vec{v}$, and then apply the scaling only to the component d_u. This is the approach that we have taken, and we have informally observed that it results in vastly smoother and more natural feeling motion. We never scale movement in the direction orthogonal to the ground plane, since we don't ever want the user to feel as if he is getting taller or shorter, or bouncing excessively as he walks, and we never want to let the users' default resting foot position either rise above or fall below the ground plane, because of the well-known effect of eye height on users' spatial perception in immersive virtual environments [6].

However we still have the problem that we need to determine the intended direction of travel. One possible approach is to predict the primary direction of intended motion based on the average direction of motion over the past n seconds, where n is some small number, such as 2. This method for predicting the intended direction of travel can be used with reasonable success if it is activated after the user begins to walk, but, if used exclusively, it has the serious drawback of requiring an initial m second onset delay, where $m<=n$, because it will produce estimates based completely on noise if it is activated while the user is in a stationary position. An alternative approach is to predict the primary intended direction of travel based on the direction of the user's gaze. We have informally determined that this works pretty well when the user wants to activate the boots from a standing position and then walk in a straight line towards an intended target, however problems can arise with the use of this method when the user wants to look around while he walks. In that case, using the gaze direction to predict the direction of travel results in a path that deviates from the path that is desired.

We believe that best solution is to use a hybrid approach, in which the direction of travel is determined as a weighted combination of the gaze direction and the direction of previous displacement (integrated over a reasonable time period), where the weight assigned to the gaze direction is nearly 1 when the total magnitude of displacement over the previous n seconds is small, i.e. equivalent to what occurs when a person is just standing around, but quickly falls to 0 as the cumulative magnitude of immediately prior displacement increases to an amount that is more typical of when the person is purposively moving.

There are several possible approaches for activating the boots. In the simplest approach, the user can carry a wand, and indicate via a button press on the wand when he wants to make the boots active. This has the advantage of providing an easy way to allow the user to walk quickly from one part of the virtual environment to another, and then walk around naturally when he gets to his desired area of the environment, without having to use an AI technique to try to guess when the user wants to travel quickly and when he doesn't. An alternative approach is to define the boots as always active, but to employ an ease-in/ease-out technique to ramp up the amount of scaling from 1.0 to 7.0 according to an exponential function of the speed at which the user is walking. With this approach, when the user is just standing around, even if his head is casually bobbing about, the scaling factor will remain pretty close to 1.0. As he starts to walk, the scaling factor will smoothly increase, then decrease as he slows down and prepares to stop. We have tried both of these approaches, and have informally observed that the former seems easier to use, because the user is always in control, while the latter tends to induce a sensation of lag in the tracking system, though the overall effect is not unnatural, despite the fact that the speed of movement is varying almost all of the time. It remains to be seen, however, how users' metric perception of the distance traveled might be affected by the experience of a non-constant speed of travel as compared to conditions of constant velocity.

4. EXPERIMENT 0

We next conducted a pilot observer experiment to subjectively assess the relative usability of the seven league boots metaphor in comparison with the three most commonly previously discussed alternative methods for navigating through moderately large immersive environments: augmented walking using uniform gain [24], ordinary walking, with 180° real and 360° virtual turns at the boundaries of the walkable space [25], and flying, using a wand. In this experiment, we used a simplified form of seven league boots in which the direction of travel was always defined to be the same as the direction of regard, and all augmentation (for boots and gain) was enabled/disabled via a button press on a hand-held wand. Through this pilot study we sought to gain insight into the following particular questions: 1) to what extent do users prefer the smoother apparent gait enabled by seven league boots over the exaggerated swaying motion that occurs with ordinary gain? Does the boots technique provide only a moderate improvement, or does it take a formerly nearly unusable method and make it now usable? 2) how favorably will users compare augmented walking, of any kind, with real walking, which is considered to be the gold standard? 3) once we give up the realism associated with real walking, to what extent do augmented walking techniques retain any perceived advantages over purely virtual locomotion (e.g. flying using a wand)?

4.1 Methods

Eight students from the departments of architecture or computer science at the University of Minnesota participated in this experiment and were compensated with $5 gift certificates for their efforts. We used a within-subjects design with one independent variable: navigation method. We chose as our test environment a high fidelity 3D model of a long, straight hallway that we had been using for other studies of distance perception in IVEs, which is shown in figure 1. We presented the environment via an nVisorSX head mounted display, which was tracked over the 30′ x 25′ extent of our lab space using a HiBall 3000 optical ceiling tracker from 3rd Tech. Each participant was asked to travel from one end of the hallway to the other, and back, using each of the four navigation methods, which were identified to them solely by the initials J (for travel using the wand), B (for walking with seven league boots), G (for walking with ordinary gain) and W (for ordinary walking). The navigation methods were presented in a balanced order between subjects using Latin squares and we explicitly avoided describing the methods in any way, not even by name, to avoid inadvertently biasing or otherwise influencing participants' opinions or ratings. At the beginning of each trial, participants were simply instructed to point the wand, which was also tracked with the HiBall system, in the direction they wished to travel, press the trigger (which activated the augmentation of the tracker output in modes B and G, and controlled the direction and duration of travel in mode J), and, except in the case of method J, to begin walking. After traversing the hallway from end to end using each navigation method, participants were given a short survey in which they were asked to 1) identify the methods that they liked best and least overall; 2) rate each of the methods on a seven point scale according to various criteria; and 3) provide written comments relating what they liked and didn't like about each navigation method. We created separate surveys for each possible presentation order, so that each participant would answer the questions about the methods in the order that s/he had experienced them (to minimize any opportunity for confusion between methods).

Figure 1: the virtual hallway environment used in the experiment.

4.2 Results

On the first page of the survey, participants were asked to: identify, by letter, the method that they "liked best, overall", and that they "liked least, overall"; to rate each method on a 7 point scale; and to describe what, in particular, they liked or didn't like about each method. Seven of the eight participants chose method B as their most preferred method; one chose method G. The main reasons given for liking B were that it felt "easy to use" and was "like walking, but faster"; the reason given for liking G was that it felt "like the fun houses at carnivals". Five of the eight participants chose G as their *least* preferred method; two chose W and one chose J. The main reasons given for disliking G were that it felt "out-of-control", "too fast", "too hard to balance" and "too outside of reality"; the main complaints with W were that it "took too long" and that "it was odd to turn around"; the complaint with J was that it "didn't feel immersive since you don't move". In the overall numerical subjective scoring, participants clearly rated the Boots method highest. Overall ratings of the other three methods did not differ to a statistically significant extent from each other.

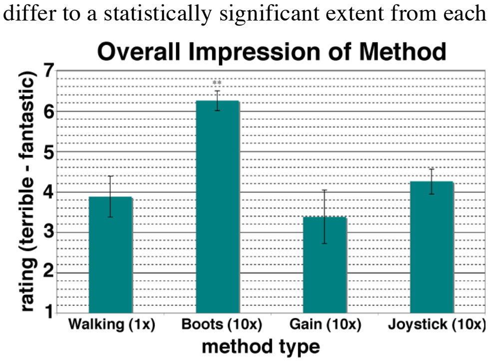

Figure 2: overall subjective ratings of the four methods tested.

On the second page of the survey, participants were asked to rate each of the methods, in the order that they were experienced, on a seven point scale according to various specific criteria. The results of these ratings are shown in figure 3.

Specifically considering *ease of use* and *naturalness*, participants rated the Gain method significantly lower than the other three methods, among which the rating differences were not statistically significant. Participants felt that ordinary Walking provided the most *accurate impression of traversed distance*, followed by Boots and Joystick (wand), which were rated as equivalent, and then by Gain, which was rated significantly worse. Finally, the Gain method was rated as significantly more *inducing of cybersickness* than any of the other methods.

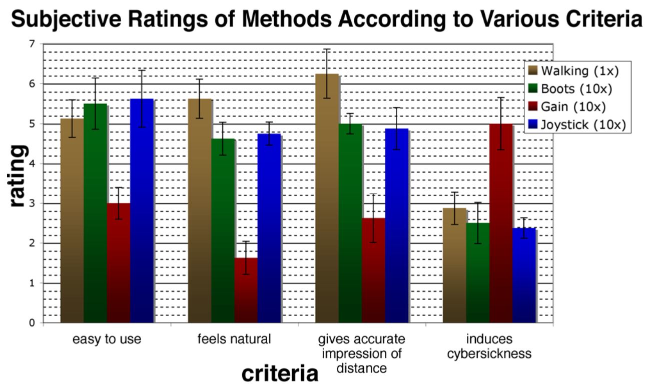

Figure 3: Users' subjective ratings of various specific aspects of the methods. Error bars specify the extent of the 95% confidence interval around the mean.

5. Discussion and Future Work

Our pilot study clearly indicates that the Seven League Boots method of locomotion offers a significant *qualitative* improvement over ordinary gain, and that it is nearly equivalent in usability to ordinary walking and/or locomotion via a joystick, at least for travel through the simple environment tested. In future work, we plan to follow up with a *quantitative* performance study that objectively evaluates the accuracy with which participants can identify the locations of landmarks in a more complex IVE when it is explored using augmented real walking with seven league boots vs. using virtual flight via a wand/button interface.

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