Making People Move – Walking Techniques in a CAVE

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ABSTRACT

Among navigation techniques in Virtual Environments (VEs) physical walking is most natural and intuitive. If we look at the performance of users in a CAVE though, we notice that they almost never leave their starting point. In this paper we investigate how walking can be stimulated for navigation in a CAVE. However, our goal is not merely to mimic walking as such – as in most approaches – but rather to encourage users to take advantage of the entire tracking space at their disposal. We combine our proposed walking elements with other components to create new metaphors for navigation in VEs and compile the evaluation carried out during our thorough, informal test phase.

Keywords: interaction techniques, CAVE, navigation, travel task, walking

1 INTRODUCTION

Being one of the primary interactions in Virtual Environments (VEs), navigation has been an area of intensive research since the beginnings of virtual reality. Hence a vast literature and many approaches for navigation in VEs exist. It is clearly true that physical walking is one of the most natural and intuitive ways to navigate (cf. the study by Ruddle et al. [11]). If we look at the performance of users (expecially novices to the system) in a CAVE however, we notice that they mostly seem to be pinpointed to the ground, almost never leaving their starting point even if the system offers an adequate space to move in. In this paper we investigate walking techniques that motivate the user to take advantage of the entire tracking space at their disposal. We combine these ideas with other navigation elements to create new metaphors for navigation in VEs. Here we concentrate on navigation in a CAVE with its easy and relatively unimpeded possibility for physical movement tracking (e.g. no cables or backpacks). The starting point for our research was to design navigation techniques for the exploration of machine models in a CAVE, that are moderately larger than the available physical volume. During our investigation we have developed a whole set of navigation techniques suitable for different travel tasks which we present here. Moreover we consider walking as a tool for building effective travel techniques and encouraging this natural movement. Our contribution consists in extending existing taxonomies by integrating the walking metaphor both in the theoretical concept as well as providing concrete practical travel techniques.

It is important to have our technical setup in mind since it is vital for our modes of navigation: We use a five-sided CAVE (only back side is missing) with rectangular back projection and a resolution of 1600x1200 pixels on screens of 3.6 meter length and 2.4 meter height each. This means, that the side walls exeed the floor and the ceiling projection. The stereo effect is achieved using the INFITEC filter technique. Tracking of the user is done via an infrared camera setup from ART with retroreflective markers on trackable objects. Examples are the master INFITEC glasses for tracking the main user's head position and orientation (which we take for the position of the user) or a flightstick – a 6DOF device with additional buttons.

The remainder of this paper is organized as follows: first we give an overview of relevant existing approaches concerning navigation in a CAVE and classify our contribution. Next we recapitulate the basic concepts of a taxonomy for navigation. Afterwards we describe our navigation elements separately, combining them to whole navigation techniques in the following section. Finally we give an overview of user experience with the new navigation techniques, summarize our contribution, and give an outlook to future investigation.

2 RELATED WORK

Concerning navigation techniques, Anthes et al. [1] distinguish between movement vector and gaze orientation and give a host of models for each one. Tan et al. [13] propose a rather complex task-based taxonomy. Based on what the user is supposed to do in the VE (task selection) the designer develops an abstract solution to the problem (travel control) within the boundaries of available hardware and similar restrictions (user interface). In this paper we work the other way around, using the travel tasks described in [4] to evaluate our travel techniques in the end (see section 3).

There has been extensive research into walking interfaces, offering a multitude of different approaches in order to overcome the physical limits of the restricted space of interaction. However, all remain single standing solutions, none of them relating their technique to a high level taxonomy. Moreover their goal generally seems to be to mimic walking as closely as possible within the confines of a small tracking space.

A common approach for building walking interfaces is to introduce specialized hardware. Darken et al. [5] proposed an omni-directional treadmill, using two perpendicular treadmills to allow travel in any direction. Jiung-yao et al. [9] developed the gait sensing disc, an 'omni-directional ball-bearing disc locomotion device'. The CirculaFloor by Iwata et al. [8] uses movable tiles to achieve the same effect. None of these approaches however work well in a CAVE environment: Since here, in contrast to an HMD scenario, the user is still aware of his real world surroundings, additional visible hardware severely detracts from his sense of presence while also blocking at least part of the floor projection.

Another solution is to let the user mimic walking while actually staying in one place. Slater et al. [12] use a neural network to determine when the user is walking in place. In this approach the direction of travel is derived from the direction of the user's gaze while walking-in-place serves as the trigger for movement. The study concludes that Walking-in-Place yields a higher sense of presence than a pointing technique. Still, a later study (Usoh et al. [14]) pointed out '[...] that real walking is significantly better than both virtual walking and flying in ease (simplicity, straightforwardness, naturalness) as a mode of locomotion.' We do not think Walking-in-Place is particularly well suited for CAVEs since it tends to anchor the user in one place discouraging natural movement inside the projection space – a fact that we explicitely address in this paper.

Another answer to the problem of limited tracking space is the addition of translational or rotational gains to the user's movements in order to scale the virtual space or redirect the path the user is taking through the VE. Engel et al. [6] use a real-time controller to determine rotational gains on the fly and use these to redirect the user. However, since a CAVE is much smaller than the size of their tracking space (9x12 meters), this approach is not feasible for us. Interrante et al. [7] propose a metaphor of Seven League Boots similar to one of our ideas. Here, the covered walking distance is scaled in the VE but only in the direction the user is intending to walk. This is done by a weighted sum of gaze and walking direction. A study by Williams et al. [15] investigated how different translational gains affect performance for such techniques. They conluded that even the highest tested gain (10:1) did not have a significant effect on errors or latency.

An approach especially designed for the CAVE is 'Redirected Walking in Place' by Razzaque et al. [10]. In order to avoid the user looking at the very often inexistent back wall and keep him turned towards the front, the rotation of the VE is constantly changed to compensate for the user's movements. This approach relies heavily on the user not making abrupt turns and not realizing that he is being made to turn by the simulation.

3 BASIC TOOLS

Bowman et al. [3] presented a task decomposition concept for the classification of travel techniques. Since it is relevant for our contribution and – in our eyes – a good starting point for designing interaction techniques and analyzing them, we here state the main ideas of this taxonomy. They divided the travel task into three subtasks:

- **Direction or target selection** specifies how or where the user moves,
- **Velocity/acceleration selection** specifies the speed control,
- **Condition of input** specifies how the travel is started, continued, and terminated.

In each subtask the developer can choose from a variety of possible components to form a complete travel technique (see figure 1). All in all Bowman et al. present

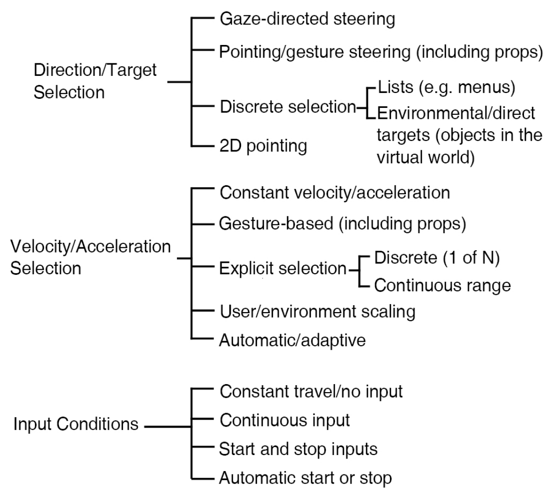

Figure 1: Taxonomy of travel techniques with travel subtasks (taken from [3]).

four different taxonomies to gain more complete understanding of the tasks and the techniques involved. However, none of these should be considered 'the correct one'. The one we have chosen presents the view on different components to form a whole technique.

4 EXTENDING THE TAXONOMY

When developing their taxonomy Bowman et al. explicitly do not take physical motion into account. Consequently we will describe in our first step how walking could be used in each component of the above taxonomy(for overview see figure 2).

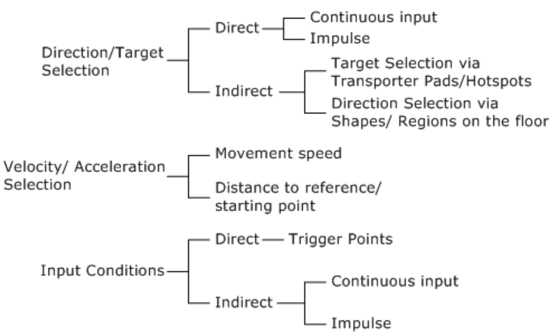

Figure 2: Extended Taxonomy with suggestions for walking interfaces

4.1 Direction/Target Selection

Generally speaking, there are two methods to determine the direction of travel via walking – direct and indirect.

In indirect approaches walking is only the means to reach certain key positions. The actual travel direction or target depends on the position of the user. A simple example are virtual transporter pads: if the user steps onto one he is automatically flown or teleported to his target. Of course this leaves him with little actual control. One might also assign certain directions of travel to certain positions or regions in the tracking space. In one of our techniques we assigned the direction of travel to each edge of the CAVE, respectively.

The direct approach records the actual movement direction of the user and applies it to the direction of travel in the VE. This works well as long as there is enough tracking space in the direction one wishes to travel. However, if the user is standing right beside a projection screen he will not be able to travel in this direction without first correcting his position. On the other hand, this approach allows for very natural relative travel (travel parallel to a reference point), because the user can look around freely while moving in another direction.

4.2 Velocity/Acceleration Selection

The first thought for a technique would be to use the speed of the user's movement to control the speed of travel. But since it is hard to estimate your own velocity, especially while the virtual world is being moved around you, we don't think this idea holds much potential, especially inside the cramped tracking space of a CAVE.

A more promising way to determine the speed of a travel technique through walking is to measure the distance from a specific point of interest (starting/reference point) to the actual position of the user. For example the velocity might increase if the user walks away from the center of the CAVE. Of course the starting point does not need to be fixed. One can also take the position of the user as a reference point when the technique is triggered. However, the longer the technique is active the higher the probality the user loses orientation and is unable to intuitively decelerate by walking back to where he came from.

4.3 Input Conditions

Walking can be used directly or indirectly to start or stop a travel technique. Indirectly by having the user move to or stand on special trigger points in the tracking space, and directly through movement itself. For example, a travel technique might be initiated or aborted by taking a step forward or backward respectively. However, since with this concept every movement would be considered a potential trigger, it effectively anchors the user in one spot – a problem we wanted to avoid. A travel technique might also be active as long as the user is actually walking around. For techniques that amplify movement this is a naturally occuring input condition (see our first proposed navigation technique in the next section).

5 NAVIGATION TECHNIQUES FOR A CAVE

Having expanded our toolbox with new walking elements, we now combine old and new elements of the taxonomy to give examples for new navigation techniques. These are intended to encourage users to move around inside the tracking space of a CAVE, opening the possibility for more intuitive navigation in a limited space of interaction.

5.1 Seven-league boots

Our first navigation technique is an exaggerated movement technique similar to the *Seven League Boots* proposed by Interrante et al. [7]. The user travels by walking around but his tracked movement in the real world is scaled to allow him to cover greater distances in the VE. To this end, we simply multiply the difference between the user's position in two successive frames by a (variable) gain.

Concerning taxonomy in this case we use movement direction to determine the direction of travel. Two input conditions have to be met for the travel technique to be active. First the user has to hold down a button while he is using the technique. Secondly he has to move around in order to get the desired effect. Of course one might consider the user's movement the only input condition

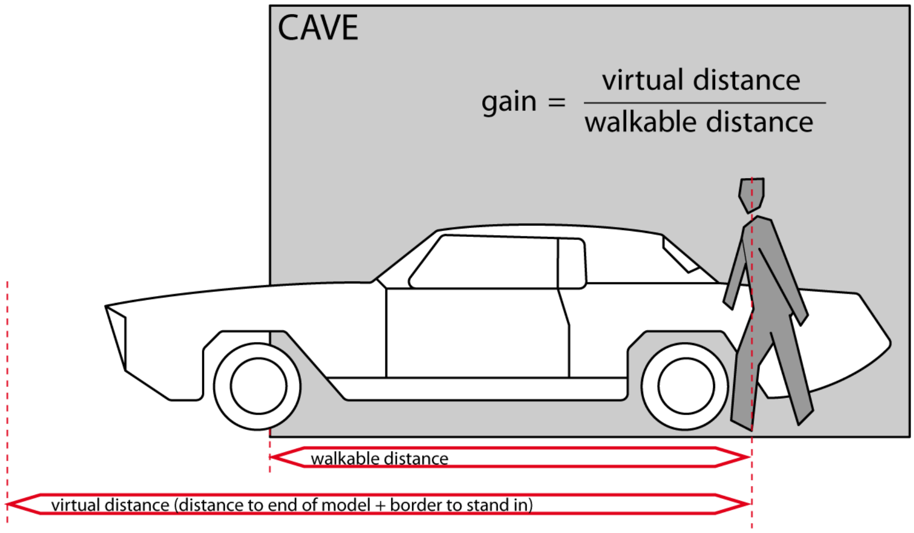

Figure 3: Automatic calculation of gain using virtual and walkable distance in our *Seven-league boots technique*

but this would make normal or even downscaled precision movement (without gain / not pressing the button) impossible (cf. exploration, search vs. maneuvering in section 6).

In this technique the velocity of travel is directly dependent on the user's velocity and the gain used to scale the movement. The easiest way to determine speed is to just assign a fixed value to the gain. Of course with a gain that is too small one constantly has to double back inside the tracking space in order to travel a significant distance in a specific direction. If the gain is too high one risks reaching points far beyond the actual content, making exact travel to a specific target nearly impossible. One could try to give dynamic speed control to the user via hand input (e.g. velocity scales with the distance from the hand to the body) or even by taking walking speed into accout. But since it is hard for users to get a good feeling for distance and speed in VEs this could easily overburden them.

Instead we propose to automatically calculate and set the gain every time the technique is triggered. The goal is to automatically allow the user to walk to every point in the VE at every time no matter where his starting position might be. To achieve this two variables have to be taken into account (see figure 3). The first is the distance from the user's position to the 'edges' of the VE. Secondly one has to account for the user's position inside the CAVE itself i.e. the distance the user can freely walk before hitting a projection screen. We now take the ratio of virtual and walkable distance for every direction as gain whenever the technique is triggered. If the user is standing very close to a wall, the corresponding direction is not considered because of the potentially unnaturally high gain owing to a very small trackable distance. Of course we also assumed that the user does not intend to walk into a wall.

In particular for rooms or objects that are slightly larger than the tracking space of the CAVE we think this approach is very promising because the gains tend to remain near the value one. For example, previewing the design of a new car or construction machine can easily be accomplished with this technique even though its dimensions are generally larger than the 3.6 x 2.4 meters of our CAVE. We will report on users' experience in the next section.

5.2 Other techniques

While we think the *Seven-league boots* are the most highly developed of our techniques, there are other ideas that warrant further investigation.

In our *scrolling technique* we used walking solely as the trigger for movement. Whenever the user steps near a projection wall (e.g. less than one meter distance – see figure 4) he starts to travel with constant speed in the direction of the wall. Much like scrolling with the

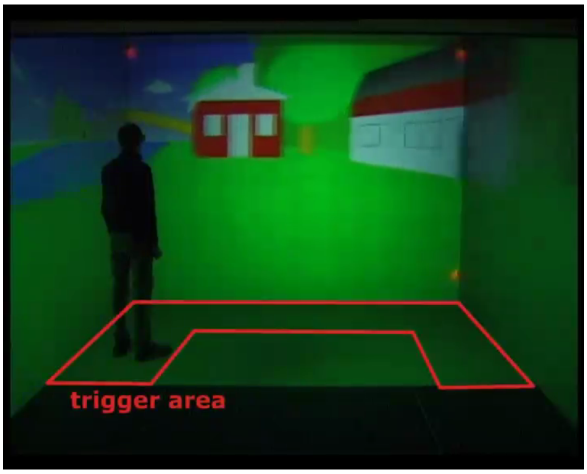

Figure 4: Area the user has to stand in to initiate travel in our *scrolling technique*

mouse on a desktop (often applied in computer games) the user can 'scroll' the VE by stepping to the appropriate side. Unfortunately this can become tedious very fast, especially if the speed of the travel technique is high. If you overshoot your target you have to move to the opposite side to reverse the direction. In case that happens more than once the user gets tired or irritated very quickly.

Hence we modified the above technique by using the direction of his gaze as the travel direction. This approach has two advantages. Areas of the tracking space that are otherwise rarely visited are assigned a practical use. Furthermore, the only input condition for this technique is the position of the user, leaving hands and possible input devices free for other actions. However, one should somehow visualize the area (eg. on the floor or as a virtual transparent curtain in space) that triggers the technique to avoid having it triggered by accident.

The *directed stepping technique* also uses movement to determine direction. However, it does not depend on continuous input. By taking a step in any direction while holding down a button the user can trigger travelling in that direction with a constant speed (see figure 5). Whenever he steps in another direction while the technique is active the direction of travel is changed accordingly. This allows for very fast, albeit potentially disconcerting course corrections. The user can instantaneously reverse direction by simply stepping in the opposite direction.

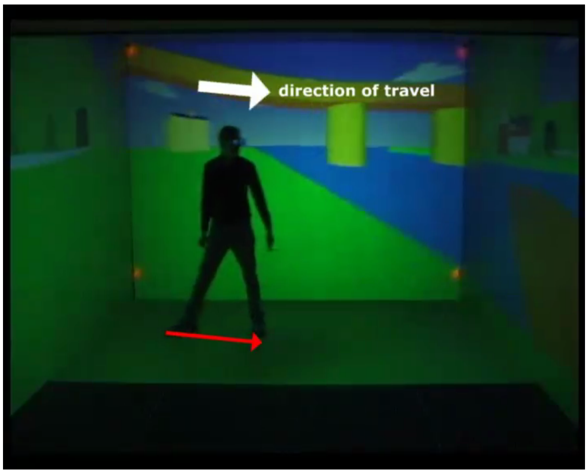

Figure 5: *directed stepping* – a step in a direction triggers movement in that direction

6 RESULTS

In order to analyze our results we again refer to Bowman et al. [4] who distinguish three main travel tasks:

- **Exploration:** Browsing the environment without a goal, obtaining information about the objects and locations within the world. This task is typical for (but not limited to) the beginning of an interaction with an environment.
- **Search:** Travel to a specific target location.
- **Maneuvering:** Subtle positioning (e.g. of the viewpoint) in a local area with precise movements involved.

We here analyze our techniques in relation to these three task types, while also taking into account factors like size or structure of the VE.

Exploration of small to medium sized VEs was our main goal when designing *Seven-league boots*. The idea was to give a designer or mechanical engineer an easy to use tool to examine models of cars or machines in the CAVE that do not fit in the captured volume. To that end the technique proved to be uniquely effective. Generally it could be argued that this technique is well suited for all three task types as long as the VE is relatively small. Manoeuvering to exact locations is as easy as literally walking there (with or without pressed button, i.e. scaling gain). Since the technique is very similar to a pure walking interface (like the one Ruddle and Lessels [11] use) it stands to reason that searching should be equally as effective. Moreover we have not met problems with the scaling of the lateral movements to result in excessive swaying, discomfiting feeling in open space, and disastrous effects in case of closed spaces reported in [7]. Some questions (in parts related with the results in [7]) remain to be answered. One is how well the performance of *Seven-league boots* scales with the size of the VE. How high can the gain get before the technique becomes unusable? How does the structure of the VE (e.g. object clutter) factor into this?

Our *scrolling technique* on the other hand is more suited for travel in large VEs, especially if accuracy and relative travel is not a concern. We observed that most often the user walks to a trigger region in the direction he wishes to travel even though he does not have to since the determination of direction is based on gaze. Since when starting travel he is generally looking at his target this is still quite intuitive. However, we found that actions like correcting the course after overshooting do not come naturally to most users. Furthermore in our case, the user might have to stare at a projection wall he is standing directly in front of, resulting in a view of only a sea of pixels rather than a clear image.

Directed stepping is still work in progress and needs further investigation. Especially with this technique, the step length to change direction has to be chosen carefully. If it is too short, small (unintentional) movements of the body might render the technique unstable. If it is too long starting travel at all might be virtually impossible. Because this technique is much less dependent on available tracking space it seems especially suited for travel in larger VEs. Similar to pointing techniques it allows for relative movement meaning the user can freely look around while travelling in any direction. However it still has to be determined how this technique performs for small course corrections during travel.

Finally we did not address the case of critical information being located in the direction of the missing back wall of the CAVE. We deliberately did not allow for rotation of the VE in any of our techniques since we wanted to keep them simple and not disorient the user.

In general we believe that navigation techniques should be customized to the requirements of the particular VE. We want to stress that walking should not be overlooked in this design process, especially when looking for a way to determine the direction of travel (be it directly or indirectly). There is also some potential for walking as an input condition. For now, we did not find a satisfying way to use walking for determining velocity and leave this open to further research.

7 CONCLUSION AND FUTURE WORK

We considered walking to be combined to new navigation techniques according to the taxonomy of Bowman et al. [3]. We believe our extension of the taxonomy can be a valid starting point for designing walking interfaces. Especially in a CAVE such techniques allow us to utilize the available tracking space as an additional input device. Of course the examples we gave for the different components of the taxonomy are far from complete. We still carry on with our research looking at different ways walking can be used for navigation.

Moreover, the navigation techniques we proposed are issue of further investigation. For the *Seven-league boots* we plan to experiment with ways for segmenting the VE into compartments to keep gains small while using this technique. This might be done beforehand or dynamically by the user. The *scrolling technique* might work better with an alternative method for determining direction. We also want to test different ways for rotating the VE (starting from the results of [10]) to make up for the missing back wall of the CAVE.

After an informal testing phase in order to optimize the techniques more generalized user tests for our different approaches have to be carried out to obtain more objective results about their performance. By using testbed evaluation as suggested by Bowman et al. [2] we hope to gain important knowledge of how well our navigation techniques work in relation to other options.

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