Enactive Navigation in Virtual Environments: Evaluation of the Walking PAD

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Abstract

This paper presents a human performance evaluation of a low-cost enactive locomotion interface, the walking-PAD, that provides users with the ability to engage in a life-like walking experience in virtual environments (VEs) by stepping in place. Stepping actions are performed on top of a platform with embedded grid of switch sensors that detect footfalls pressure. Based on data received from sensors, the system computes different variables that represent user’s walking behavior such as walking direction and walking speed. Twelve human subjects were instructed to reach the exit of a virtual labyrinth as quickly as possible and memorize as many information as they can. Two navigation techniques were compared: a mouse-based technique and the walking-PAD technique. Results revealed that more information was memorized when using the walking PAD.

1. Introduction

How users move from one virtual place to another within limited tracked space is one of the most difficult and persistent problems for immersive virtual environments (VEs). Flying by pushing a button or joystick has none of the naturalness of really walking because it doesn’t make users tired or stimulate users proprioceptive and vestibular systems. Real walking overcomes those problems, but introduces the problem of how to move in VEs that is larger than the area covered by the tracking system. Iwata [6] and Darken [4] proposed two different locomotion interfaces with similar principle of omni-directional treadmill systems, which can cancel users’ displacement and keep them located at the same place while being able to walk into any direction. Slater [13], Templeman [14] and Usoh [15] adopted a simpler approach that eliminates the need of moving platform to cancel user displacement.

They used the step-in-place technique to engage user into a walking experience. Such action keeps a very similar body movement to actual walking behavior but without body propulsion.

Razzaque et al. [10,11] and Bouguila et al. [7] have used the stepping in place with interesting redirection techniques that keep user oriented toward the screen in a non-immersive configuration. Other locomotion systems have been developed to reproduce active walking experience within VE such as bi-pedals interface or linear treadmill [2]. These interfaces do not provide users with the ability to use their active and natural body turning action to change their walking direction. Instead omni-directional locomotion is achieved by using an extra artificial interface to accomplish a rotation task.

This paper presents a human performance evaluation of a low-cost omni-directional enactive locomotion interface that can be integrated into a wide variety of VR systems equipped with any visual display. The interface employ step-in-place technique and a sensitive walking platform to impart users with
the ability to freely engage in a life-like walking experience into any direction.

The proposed interface was designed to promote the following points:

- Body centered: the locomotive omni-directional actions controlling the navigation are initiated and sustained by the lower part of the body as in real life. This approach will preserve user’s natural reflexes and navigational control skills. Moreover, the system lets user’s hands free for manual interaction.

- Simplicity: the walking interface is easy to set up, easy to learn, and easy to use, decreasing the mental workload due to the interface.

2. System overview

A human-scale multi-modal VR platform was developed to provide users with the ability to both navigate and manipulate virtual objects. The platform promotes enaction by supporting both multi-sensory (visual, auditory, haptic, and olfactory) modalities and real world based interaction techniques. In particular, haptic interaction is realized using a bimanual human-scale stringed-based haptic interface [12]. Locomotion is achieved using a low-cost easy-to-use enactive interface that permits users to control both their speed and direction of walking in virtual worlds [8].

2.1. The PAD platform

The platform illustrated in figure 2 has a compact size of 45cm x 45cm and weights less than 7kg. A total of 60 iron switch sensors are embedded on a plexiglas surface. The sensors are placed in matrix form to allow locating footfalls and walking direction during stepping actions. The PAD is connected to a PC computer through an NI DAQ board. A second PC computer is used for graphics and receives computed data such as walking speed and direction. Taking into account real-time interaction, the system is set to scan all sensors at a rate of 100Hz. Values that can take each sensor is either “0” or “1”, the equivalent of “on” and “off”. “0” indicating a free status whereas “1” reflects the presence of the foot on top of the sensor. Values collected from each sensor are denoted as \( W_n \) (n=1,2…60) and can be 0 or 1, which represent the sensor weight. To compute the center of gravity (CoG), only activated sensors are taken into account. Therefore, after fetching all sensors values, the CoG is computed based on equation 1.

\[
P(t) = (0,0) \quad \text{if} \quad \sum W_n = 0
\]

\[
P(t) = \frac{\sum W_n P_y / \sum W_n}{\sum W_n}
\]

Where \( P(t) \) represents the CoG coordinate and \( P_y \) represents the coordinate position \((x,y)\) of sensor \( S_y \).

Figure 2. Top view of the Walking-PAD Platform

2.2. Moving direction

Moving direction is obtained by getting the perpendicular axe that passes through the middle of left and right foot falls. As stepping action has certain frequency, it is useful to take the average position during certain interval of time. Figure 3 shows an overview of two different walking directions and their respective CoG plotting.

Figure 3. Moving direction based on CoG data

3. Experiment

This section reports an experimental study that aims to compare a mouse-based navigation technique with the walking-PAD navigation technique. Our assumption is that the walking-PAD navigation technique supports enactive knowledge through intuitive movements and involves a better memorization of information from the VE.

3.1. Virtual environment

The experimental VE consists of a labyrinth (Fig. 4). Four amphoras, numerated from 1 to 4 are placed in the labyrinth in order to help the subjects by providing intermediate target. The last amphora is considered as the exit. Five “Star Wars” movies posters and two aubade posters were placed onto the walls of the labyrinth.
3.2. Participants

A total of twelve volunteers’ male students from ISTIA (Angers University) participated in the experiment. They were aged from 20 to 26 years old and they never experienced VR before.

![Figure 4. Top view of the labyrinth: a printed path shows a direct way from the entrance to the exit](image)

3.4. Task

The participants were asked to reach as quickly as possible the exit of the virtual labyrinth, while passing through the three intermediate targets (amphoras). They were also asked to memorise as many information as they can from the VE.

3.5. Design

Participants were separated in two groups of six each. The first group (G1) performed the task using the mouse-based navigation technique, while the second group (G2) performed the task using the step-in-place technique.

3.5. Procedure

Before the experiment started, and after looking for 30 seconds to the top view of the labyrinth, each subjects performed the task one time to get acquainted with the navigation technique they were to use in the experiment. All participants were positioned at 2.5 meters from the large screen. Experimental session consisted in three trials. At the end of the experiment, all participants were asked to fill a questionnaire. Questions were about the preferred navigation technique, the number of posters and information on the posters.

![Figure 5. View of the entrance of the labyrinth with the first amphora and a “Star Wars” movie poster](image)

4. Results

Results are presented and analysed according to two criteria: task completion time and information recall.

4.1. Completion time

Task completion time was recorded for each single trial. This data was analysed using ANOVA. Results illustrated in Figure 6, revealed a statistical significant time difference between conditions $F(11,1) = 13.34; p < 0.005$. The mouse-based navigation technique gave better results. Participants of group G1 have reached the exit of the labyrinth in an average completion time of about 3.6 min. (std: 0.57), while participants of group G2 performed the task in an average of about 5.0 min. (std: 0.60 min.). This result shows that the mouse-based navigation technique was easier to use than the other to navigate in a virtual labyrinth. However, data from the questionnaire reveals that the subjects found the step-in-place technique more intuitive and immersive.

![Figure 6. Mean task completion time vs. navigation technique](image)

4.2. Memorisation

The number and type of information memorised were obtained from the questionnaire and analysed
using ANOVA. Results illustrated in Figure 7, revealed a significant difference between conditions $F(11,1) = 7.50; p <0.005$. The step-in-place technique gave better results. Participants of group G1 had an average of 3.33 good results (std: 0.52), while participants of group G2 had an average of 4.33 good results (std: 0.51).

Figure 7. Mean number of information memorized vs. navigation technique

5. Conclusion

This paper presents a human performance evaluation of a low-cost enactive locomotion interface that provides users with the ability to engage in a life-like walking experience in virtual environments (VEs) by stepping in place. A total of twelve volunteers’ male students aged from 20 to 26 years were instructed to reach the exit of a virtual labyrinth as quickly as possible and memorize as many information as they can. Two navigation techniques were compared: a mouse-based technique and the walking-PAD step-in-place technique. Results showed that the mouse-based navigation technique was easier and to use and faster than the other. However, subjects found the step-in-place technique more intuitive and immersive. Indeed, this technique gave better results for memorisation of information from the VE.

References


