Active Locomotion Interface for Virtual Environments

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Abstract

This paper presents a new locomotion interface that provides users with the ability to engage in a life-like walking experience by stepping in place. Stepping actions are performed on top of a flat platform with embedded grid of switch sensors that detect footfalls pressure. Based on data received from sensors, the system can compute different variables that represent user's walking behavior such walking direction, walking speed, standstill, jump, and walking. The overall platform status is scanned at a rate of 100Hz with which we can deliver real-time visual feedback reaction to user actions. The proposed system is portable and easy to integrate with major virtual environment with large projection feature such as CAVE and DOME systems. The overall weight of Walking-Pad is less than 5 Kg and can be connected to any computer via USB port, which make it even controllable via a portable computer.

Key words: Locomotion, Virtual environment, sensors, walking-pad, step-in-place

1. Introduction

This Walking or traveling in general is an important life enhancing activity, that is considered as a natural daily behavior that human performs to get from place to place. It is a fundamental requirement for action and navigation in our real life. Keeping such an active and dynamic ability to move through large-scale virtual environments (VEs) is of great interest for many applications demanding locomotion, such as building evaluation, urban planning, terrain exploration, etc. However, user movements in the VEs are usually restricted by a limited range of tracking sensors, and constrained by a small workspace in the real word. Therefore, some kind of virtual locomotion interface is needed to enable movements over large distances, while remaining within a relatively small physical space.

Iwata [9] and Carmen [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. Both systems used Head Mounted Display (HMD) for visual feedback, have a heavy weight (more than 100 Kg), and use a set of attachment to the user body related to tracking sensors and safety mechanisms. Iwata stated in [3] that the use of head mounted display (HMD) caused some safety concern and suggested that a large display system could be more suitable for their interface. In contrast to the use of complex mechanical systems, Slater [10][11] and Templeman [12] adopted a simpler approach that eliminates the need of moving platform to cancel user displacement, instead they used the step-in-place action to engage user into a walking experience, such action kept a very similar body movement to actual walking behavior but without body propulsion. However, both system were implemented with HMD and used a set of sensors to read user's stepping behavior, the attachment of the HMD and cabled sensor to the user body make them inconvenient for integration in VEs with large display where cables may disturb user's movement mainly during rotation. Sharif Razzaque et al. [7] used the stepping in place without the use of a HMD but with an interesting redirection technique that keeps user oriented toward the screen. That is letting user walk around virtual environment without loosing sight of projected images. Other linear locomotion systems have been developed to reproduce active walking experience within VE such as Bi-pedals interface, linear treadmill [6] …etc. but these interfaces do not provide users with the ability to use their active and natural body turning action to change their walking direction or in-place turning, instead the omni-directional locomotion is achieved by using an extra artificial interface to accomplish a rotation task.

The major shortcoming of nowadays VR systems with large screen, is the presence of an open area or a "dead angle" where no visual feedback cue can be available. This area is usually located at the opposite side of the center of the display and behind the user, figure 1. The missing of visual feedback in some direction puts the traveling experience of little advantage when users make a large physical turn in attempt to explore the rear environment behind them, such move will bring their visual field of view partially or totally outside the display area. Only few VR systems deliver surrounding visual feedback cue, but their bulky structure, space allocation, and price make them not so popular. CyberShpere [15], Cabine VR [16] systems are good examples.

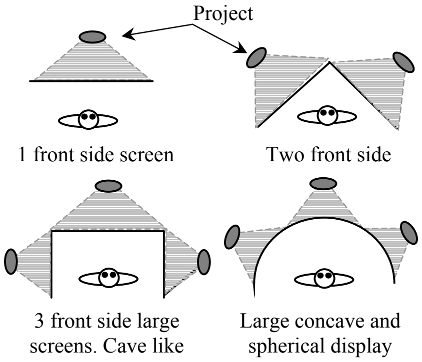

Fig. 1 Top view of some common large-display systems

The challenging part in integrating omni-directional locomotion interfaces for VE with large screen has been always how to let users perform comfortable and effective life-like navigation without being physically displaced outside the limited area of the interface and without loosing sight of the projected images during large rotation?

The present paper presents a new omni-directional locomotion interface that can be integrated into a wide variety of VR systems equipped with large display system. The interface employs 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 without loosing sight of projected images even in case of limited screen size.

Taking into consideration the shortcomings of other locomotion systems, the proposed interface is designed to promote the following points:

- Body centered: the locomotive 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.
- Omni-directional: users can guide their traveling in any direction.
- Attachments free: no cable or bulky devices attached to user. Such as HMD and/or sensors.
- Simplicity: the walking interface is easy to set up, easy to learn, and easy to use, decreasing the mental workload due to the interface and therefore increasing the sense of presence in the VEs.
- Compact: the hardware system is relatively compact and fit most of VR system with large display.
- USB based interface. Making it a plug-and-play interface.

2. System Overview

Table. The proposed system as illustrated in figure 2, is composed of three main parts: a walking platform, a sensing system, and a large display. A wooden pad with embedded sensors is used as walking platform on top of which users will stand and interact with virtual environment being projected on the large screen. Initially users will stand at the center of the pad and face the screen center. In order to engage into a virtual walking experience, users need to perform a stepping in place actions without propelling their body. Stepping actions are detected in real-time through a series of embedded sensors and treated as a gesture of moving forward in the VE. To change the walking direction, or to explore the surrounding environment in general, users are required to turn or rotate their body about its vertical axis while remaining at the same position, the same natural turning action they perform in real life. The turn-in-place action is treated as a gesture changing the walking direction, therefore the viewpoint. However, as large screens provide usually a limited projection area, a large turning action will put the displayed image outside users' visual field of view. To overcome such limitation and keep users continuously oriented toward the screen and provided with enough visual display, users are instructed to perform navigational actions in a certain manner as follow:

1. Stepping action is used only to move forward in VE
2. Rotation action is used to rotate in VE
3. Rotation in VE is stopped only if user regains his/her initial direction. That is toward the screen center.
4. Walking speed is proportional to stepping frequency
5. Jumping action is permitted. Jump height is proportional to the time spent off the walking-pad. That is in the air.

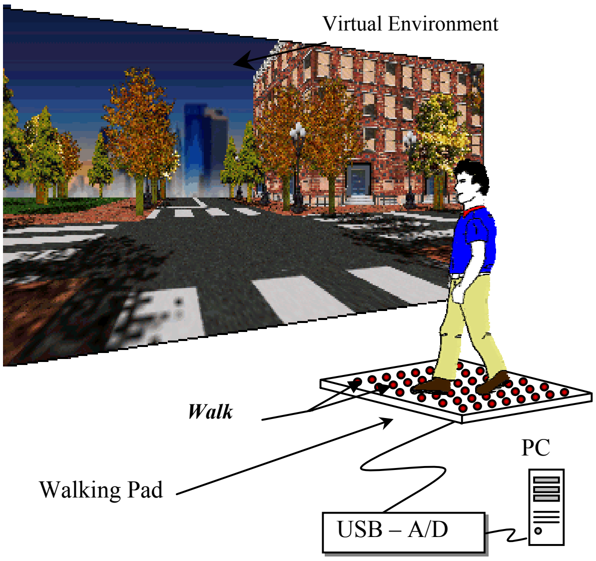

Fig. 2 Overall Walking-Pad system

Embedded sensors are scanned at a rate of 100Hz allowing therefore a real-time tracking of user's walking behavior on the walking-pad. As soon as the system recognizes a moving pattern, projected images representing VE will be update in accordingly

2.1 The Pad Platform

The platform illustrated in figure 3 has a compact size of 45cm x 45cm and weights less than 5Kg. 64 switch sensors (8 x 8) are embedded on its surface, they are placed in matrix form to allow locating footfalls and walking direction during stepping actions. Sensors are very sensitive to any pressure applied to their bottom side, which make it useable by children as well. All sensors are connected to a computer through an USB AD box produced by Turtle Co. 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.

However, it is known that successive stepping in place actions doesn't keep user from staying at the same place. To overcome this situation a ring is place around sensors to limit the stepping area. Therefore a feedback could be given to user whenever they attempt to step outside the ring. The ring is thick and could be easily sensed upon contact with foot (shoes).

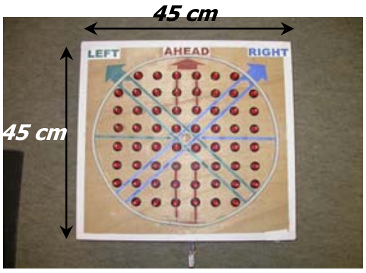

Fig. 3 The Pad platform and its walking area

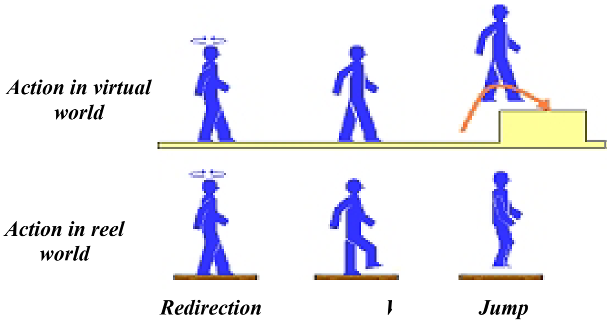

Fig. 4 Possible actions

2.2 The pad platform

The different actions that the system can detect and treats as voluntary moving gestures are: stepping, turning, and jumping as illustrated in figure 4. All these actions are tracked by analyzing the different contact interaction between the feet and the walking-pad platform. In other term, matching the patterns presented by active sensors and user actions. For this aim, finding the center of gravity (CoG) of the activated sensors is a consistent and reliable indicator that can be used to predict user's stepping behavior on top of the pad. Furthermore, CoG gives also an idea on the placement of footfalls on the platform.

Values collected from each sensor are denoted as Wn (n=1,2…64) and can be 0 or 1, which represent the sensor weight. To compute the CoG, only activated sensors are taken into account. Therefore, after fetching all sensors values, the COG is computed based on the following equation.

$$\begin{aligned} P(t) &= (0,0) \qquad if \sum W_{ij} = 0 \\ P(t) &= \sum W_{ij} P_{ij} \Big/ \sum W_{ij} \end{aligned} \qquad (1)$$

Where P (t) represents the CoG coordinate and Pij represents the coordinate position (x,y) of sensor Sij. Positions of sensors are fix on the pad and placed in the form of an 8x8 matrix as indicated in figure 5.

A data output sample obtained by applying CoG approach to values received from sensors is shown in figure 5. The plotted data were recorded during a straightforward walking task. It is very clear that during stepping movements CoG is moving in accordance with footfalls position on the pad, that is shifting from left to right.

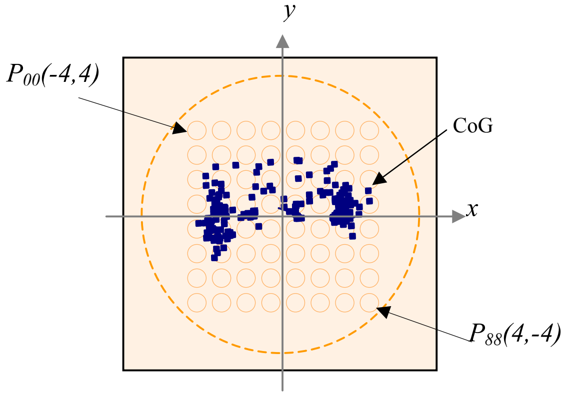

Fig. 5 CoG computation and its significance

2.3 Moving direction

Changing walking direction with the Walking-Pad interface is very intuitive since it keeps the same movement that we use in daily life to change the course or our displacement that is rotating mainly our body about its vertical axis. Since the sensing resolution of the walking pad is not too high, few thresholds are set to signal changes on walking direction. CoG data is the main input that is used to monitor such changes. Moving direction can be 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 6 shows an overview of two different walking directions and their respective CoG plotting.

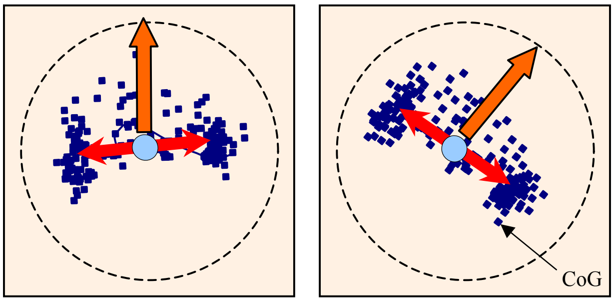

Fig. 6 Moving direction based on CoG data

The system is stable in detecting turning action, however because of screen size limitation, a continuous rotation might put user's visual field of view away from the projected images. Therefore, users are instructed to turn back toward the screen center as soon as they finish making the desired rotation. Moreover, users do not need to think about such maneuver since they react naturally by turning back toward the screen otherwise they will miss the desired moving direction. The following example illustrates the situation.

Assume that the user in figure 7 is instructed to walk along the traced path from point ***O*** to point ***V***. to successfully reach the destination, there are 3 actions ***a***, ***b***, and ***c*** to perform while stepping. Arriving close to the curved section of the path, the user will attempt to negotiate the curve by turning his body to the right. Once the turn is completed, it is required to regain the initial body orientation to continue walking as planned on the path. If the user do not adjust back his body orientation toward the screen after section b, and continue stepping, then the walked path will no longer match the original intention as illustrated by ***X*** in figure 7. So, even if the user forget to adjust his position, the visual feedback will push him to do so in order to stay focused on his goal. This is approach is very similar to steering a car.

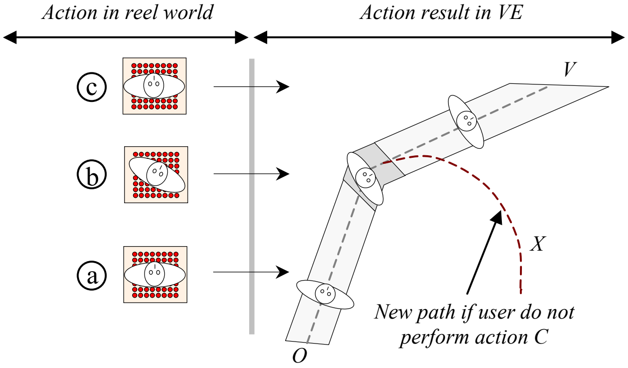

Fig. 7 steering locomotion

3. Software Implementation and Experimental Evaluation

A software GUI is developed to monitor the overall behavior of the system. Figure 8 presents a screenshot of the GUI. It contains the status of all switches, walking direction, CoG position, walking action, walking speed, and other parameters for managing the interface.

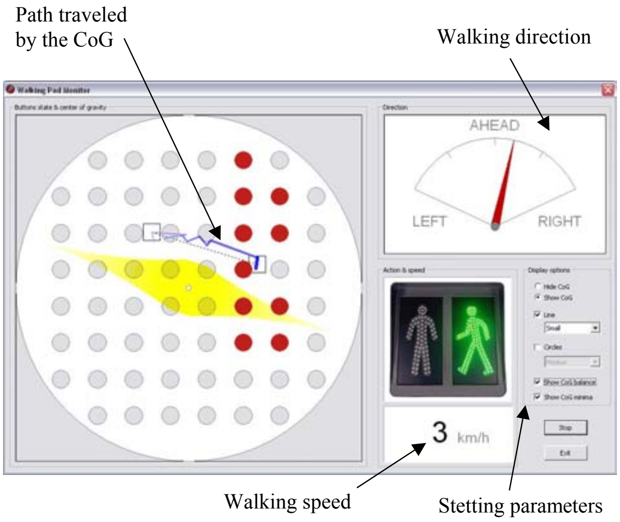

Fig. 8 Walking-Pad's GUI

To demonstrate the usability of the proposed interface for a life-like walking experience, we designed a VE that consist of a simple labyrinth and asked users to walk through it following a predefined path drawn on the floor. Walking-Pad interface was provided as mean of locomotion. The experimental setup and the simulated environment are shown in figure 8.

Fig. 9 Walking-Pad prototype

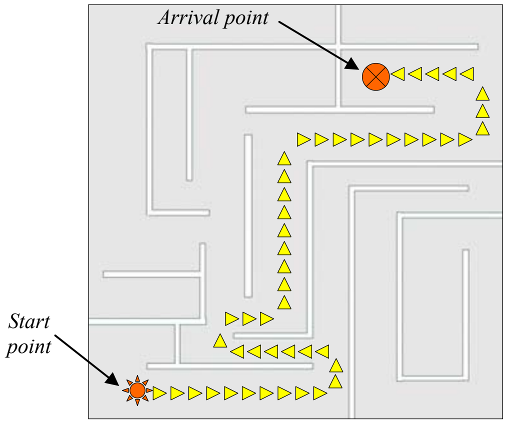

Fig. 10 Simulated environment of labyrinth for experimental evaluation

Five students were invited to take part in the experiment, each of them walked freely through the labyrinth for few minutes to get accustomed to the interface. At the beginning of each trial users are positioned at the start point and asked to maintain their walking position as much as possible closer to the drawn path, which was designed in such a way to evaluate the traveling performance in a narrow space and wide space.

During each trial, user position in VE was recorded every half a second for later analysis. For clarity raison, figure 10 present the recorded path of one student.

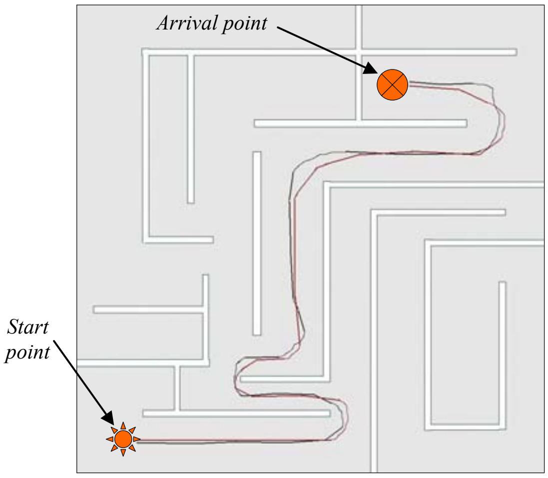

Fig. 11 Experiment result for 2 walking trials

At first we have to notice that all students performed very well to move from the start point till the arrival goal. As shown in the above graph the walk was close to the painted path on the floor. During all experiments there wasn't collision with the labyrinth's walls even when the turns were tight.

After asking student about their impression about the interface, all responded to find the interaction easy to control and do not bothered by the limitation of the screen size. However 3 of them complained about the limited size of the pad itself and suggested to provide larger space for the stepping area.

3. Conclusion and Future work

The proposed interface has few advantages that easily distinguish it from precedent locomotion devices such as omni-directional treadmills [1][2], slide and pedal interfaces [3][4], gesture-based pads [5][6], and other stepping-in-place interface [10][7][2]. Though its compact and simple structure, it allows users to intuitively carry out a life-like traveling experience within VEs. Furthermore, the interface imparts users with the ability to make jumps. Another advantage of the device is its portability feature since it uses USB port to communicate with computer making it suitable for integration within most of nowadays VR systems with large projection display like CAVE, DOME, …etc. Preliminary evaluation tests showed encouraging results and feedback from users.

As future work we would like to investigate the ability to integrate haptic interface with the current system so as to impart users with the ability to physically interact with VE during their traveling.

For future work, we are planning to make the walking-pad a wireless interface and adding other locomotion features such as sidestepping and backward movement. Another interesting improvement will be to dynamically control the rate of displacement and rotation. For now step size and rotation rate are both fixed in advance. A possible approach is to use footfall size and increase the resolution of the matrix of sensors.

Indeed, the walking-pad will be integrated to PREVISE (VR platform that provides multi-sensorial immersion using visual, auditory, haptic and olfactory displays) [14]. PREVISE is used to study the effect of sensorial immersion on user performance in different tasks/activities (tracking, navigation, manipulation).

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