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Virtual Locomotion Interface with Ground Surface Simulation

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Abstract

The current study presents a new locomotion interface that allows users to engage into a life-like walking experience within virtual environments while sensing and feeling terrain's topology such as slopes and uneven ground surfaces. The interface is composed of a turntable as walking platform within which four load sensors are embedded to track user's walking actions. Virtual ground surface is generated by a tilting mechanism that is based on three air cylinders mounted beneath the turntable. The usage of turntable is to keep users facing the screen center all the time. Such approach is necessary where projection system do not provide surrounding visual feedback (360°). The interface is proven to be simple and easy to use as demonstrated by an experimental evaluation. Such locomotion interface would be of interest to many human-scale virtual environments such as CAVE, DOME, and Display wall.

Key words: Virtual locomotion, walk-in-place, terrain rendering, turntable, and pressure sensors

1. Introduction

Walking or traveling in general is an important life enhancing activity which is initiated and sustained by the lower part of the human body and it is considered as a necessary daily behavior that human performs to get from place to place. Keeping the same natural mean to move around in VE with large display systems is of great interest for many applications demanding locomotion, such as building evaluation, urban planning, terrain exploration, rehabilitation, and military and vocational training. Though natural locomotion is accomplished in real life almost without conscious thought, it is a very difficult behavior to duplicate within a limited working space of any VE systems without the benefit of a control technique that can mimic human's walking. Therefore, some kind of "virtual locomotion" interface is needed to enable movements over large distances, while remaining within a relatively small physical space.

The present paper presents a new locomotion interface that can be integrated into a wide variety of VEs with large display system. The interface employs step-in-place technique with a smart-turntable mechanism to impart users with the ability to freely engage in a life-like walking experience into any direction without loosing sight of the displayed environment even when using limited screen size. Moreover, it is possible for users to feel terrain's feature by means of tilting mechanism implemented under the turntable.

2. System Overview

The proposed system as illustrated in figures 1 & 2, is composed of three main parts: turntable, Embedded load sensors, and tilting mechanism. The turntable is used as walking platform on top of which user will stand and interact with VEs. Initially user stands at the center of the turntable and face the center of the screen. User can engage into a virtual walking experience by stepping in place without propelling their body. Step-in-place movement will be detected by a sensing system and treated as a gesture of moving forward in the VE. To change the moving direction or to explore the surrounding environment in general, user is 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 hence the viewpoint in the VE. However, as large screens provide usually a limited projection area, a large turning action will put the displayed image outside

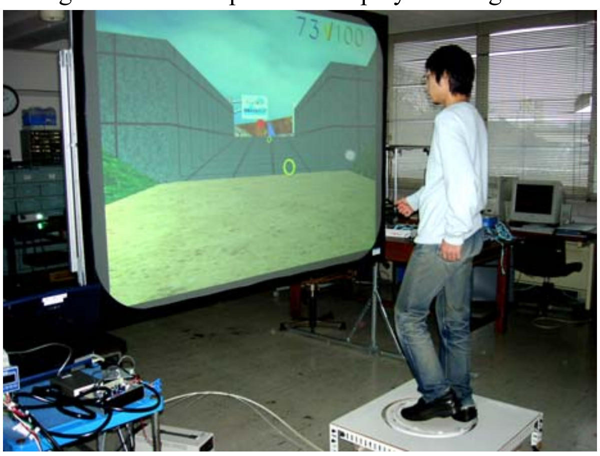

Fig. 1 Locomotion Interface

user's visual field of view. To overcome such limitation and keep user continuously oriented toward the screen and provided with enough visual display, the turntable platform will passively rotate in the opposite direction to cancel user's turning and bring him back to face the screen. The passive compensation of user's active turning starts slowly and continues until the user regains the initial orientation. The acceleration and deceleration applied to the turntable are well calculated in such a way they do not affect user's posture stability. Projected images will be update in real-time and accordingly to user's stepping and turning actions. Tilting mechanism is placed at the bottom part of the system, according to user's position and the slope of the ground surface, 3 air cylinders will generate appropriate slope that much the virtual terrain. In the following sub-sections, we describe in more details the functionality of each part.

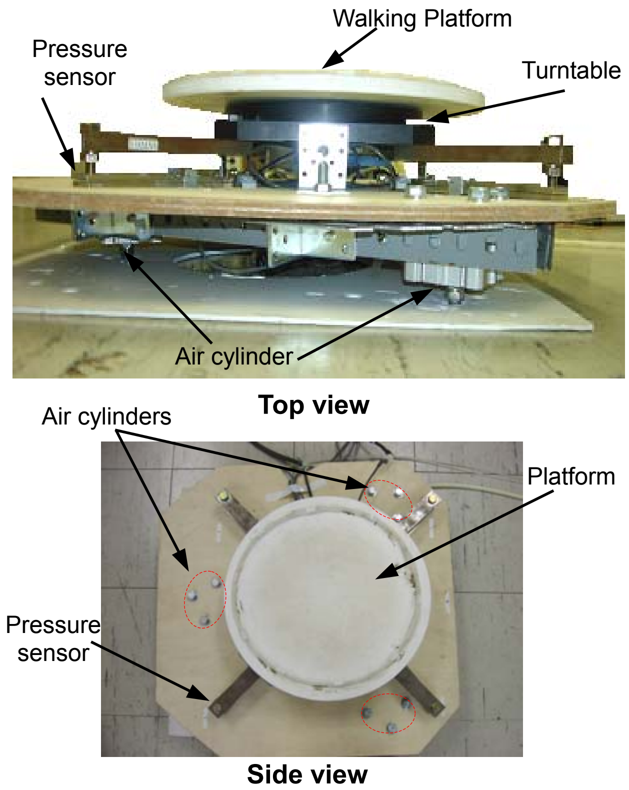

Fig. 2 Hardware structure of the interface

2.1 Tilting mechanism

Composed of three air cylinders fixed at the bottom of the system and placed at the apex of a triangle. Each cylinder has a stroke of 3cm. Depending on user's orientation and position in the VE, cylinders change their stroke lengths creating the necessary tilt that match the ground surface. Pneumatic servo-system, and collision detection techniques are used to achieve smooth and accurate terrain simulation while synchronized with the visual feedback.

The process of terrain rendering is achieved through three steps.

Step 1: *Find colliding polygon*; in most walk-through systems, VEs are represented by polygons. Thus, the tilting system determines its inclination from the polygons on top of which user is supposed stepping. We use GJK distance algorithm [1], which is incorporated in the Software Library for Interference Detection (SOLID) [2], to detect the colliding polygon.

Step 2: *Calculate the tilt of the floor from the polygon and user's direction*; from step 1, we get the normal of the polygon where the use is stepping. Then determine the direction of tilt by the interior angle between the direction of the user and that normal. The inclination of the tilt is calculated by the direction of that normal.

Step 3: *Filter the tilt for smooth motion of air cylinders*; when the user moves from one polygon to another, the shape of polygon changes suddenly. Therefore, we use low pass filter to create smooth and quiet motion of the platform.

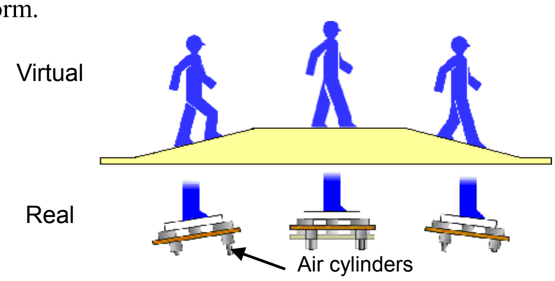

Fig. 3 Tilting mechanism

2.2 Embedded sensors

Embedded sensors are used to track user's stepping behavior on the walking platform. The different actions that the system can detect and treated as voluntary gestures are stepping, turning, jumping, and squatting as illustrated in figure 4. All these actions are tracked by analyzing the different forces interaction between the feet and the walking platform. In other term, analyzing the movement of center of gravity.

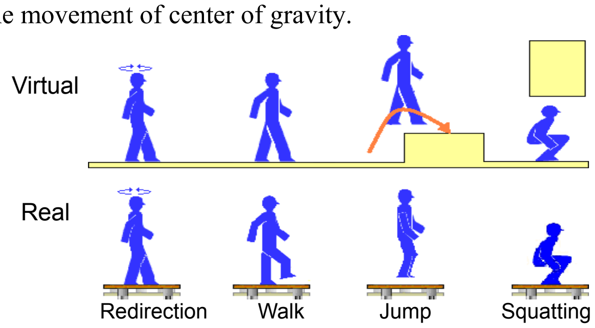

Fig. 4 Possible gestures for navigation

Sensors are very sensitive to any load changes on the platform. Load value collected from each sensor is denoted as U_n *(n=1,2,3,4)*. To normalize these values, a calibration process for each load sensor is necessary as mentioned by equation 1.

$$P_n = \frac{U_n - U_{n\_\min}}{U_{n\_\max} - U_{n\_\min}} \tag{1}$$

Where U_n is the load received from S_n; figure 5 U_{n_min} is the load received from S_n when the platform is free from any user, and U_{n_max} is the load value received from S_n when user stands just on top of it.

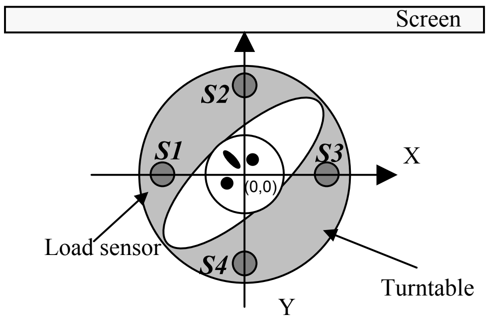

Fig. 5 Sensors placement

Once the calibration is done, the center of gravity (COG), which represents also user's position on the turntable, can be computed in real-time by equation 2.

$$P(t) = C_1P_1 + C_2P_2 + C_3P_3 + C_4P_4 \tag{2}$$

Where C_n represents the coordinate position (x,y) of sensor S_n. Position of sensors are fixed in reference to the center of the platform (0,0) as indicated in figure 5. Based on equation 2, it is possible to track user's stepping on the platform. Figure 6 shows a graph where user is exerting stepping action at an angle of 45° from initial position.

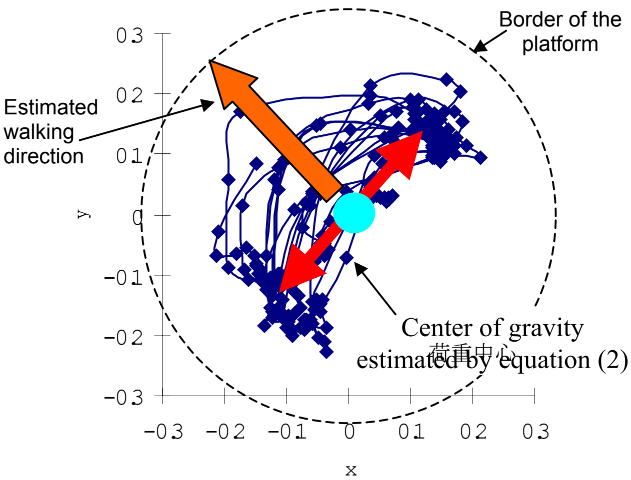

Fig. 6 changes of COG position during stepping action.

2.2.1 Moving direction: the 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. The middle point between left and right footfalls is estimated by the following equation.

$$\begin{cases} \hat{P}(t) = 0.9P(t-\Delta t) + 0.1P(t) \\ \hat{P}(0) = (0.0) \end{cases} \tag{3}$$

Once the middle point is computed, user direction ***B(t)*** at time *t* is estimated by the following equation 4.

$$\mathbf{H}(t) = P - \hat{P}(t)$$
$$\mathbf{D}(t) = \mathbf{H}(t)\begin{bmatrix} \cos\frac{\pi}{2} & -\sin\frac{\pi}{2} \\ \sin\frac{\pi}{2} & \cos\frac{\pi}{2} \end{bmatrix} \tag{4}$$
$$\begin{cases} \mathbf{B}(t) = 0.9\mathbf{B}(t-\Delta t) + 0.1\mathbf{D}(t) & (\mathbf{B}(t-\Delta t)\cdot\mathbf{D}(t) \geq 0 \text{のとき}) \\ \mathbf{B}(t) = 0.9\mathbf{B}(t-\Delta t) - 0.1\mathbf{D}(t) & (\mathbf{B}(t-\Delta t)\cdot\mathbf{D}(t) < 0 \text{のとき}) \end{cases}$$

2.2.2 Stepping detection: the system can estimate stepping status (on/off) by simply applying the following rule.

$$\{\mathbf{B}(t-\Delta t)\cdot\mathbf{D}(t-\Delta t)\}\cdot\{\mathbf{B}(t)\cdot\mathbf{D}(t)\} \leq 0 \tag{5}$$

For stepping speed, it is estimated based on a sampling of the last 5 steps and given by the following equation.

$$d = \frac{\sqrt{(\mathbf{H}(t) - \mathbf{H}(t-5\Delta t))^2}}{t-(t-5\Delta t)} \tag{6}$$
$$\mathbf{H}(t) = (0,0) \qquad (t \leq 0 \text{のとき})$$

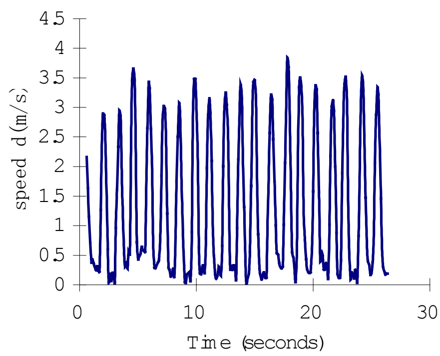

Fig. 7 Walking speed variation during walk experience

2.3 Turntable

Ideally, if the system can rotate the turntable at a speed equal to user turnings without time delay and without misbalancing, all turning actions would be immediately canceled and users could be kept facing the screen all the time. However, it is difficult to achieve such synchronization because a sudden rotation of the turntable with certain speed may disturb standing and stepping actions, hence shifting temporarily user interest from the walking experience to their balance and posture stability. Therefore, the passive rotation of the turntable must be kept smooth and within a limited speed that the user can withstand with no safety fears, and more importantly and preferably a speed that can hide as much as possible the passive rotation from users. Although as human, our vestibular system, in particular the semicircular canal, is sensitive to body rotation, we believe that a smooth and well-calibrated control of the passive rotation speed might be hided or ignored during virtual interaction. Hence an optimum cancellation would try to satisfy the following two conditions:

a- Cancel users turnings as soon as possible. Real-time cancellation would be the optimum.

b- Minimize as much as possible user awareness about the passive rotation of turntable. Zero awareness would be the optimum.

It is nearly impossible to satisfy both conditions with their optimum during the cancellation of natural turnings, which are usually carried at a speed ranging between 45°/s and 90°/s, though smaller turnings are quite possible. At such turning speeds, a condition would require immediate and fast rotation, whereas b condition would require slow and smooth rotation. To maintain a balanced tradeoff between the two conditions while canceling user turnings, two parameters regarding turntable rotation and its perceptual effect were studied and determined. Turntable acceleration "*a*" is fixed to 2.0 (rad/s^2) and the coefficient "*k*" to 2.0. Then the turntable will readjust user orientation based on the following algorithm.

θ: user angular position

If $|\theta| > 5^o$ then

$$\begin{cases} V_t = V_{t-\Delta t} + a \cdot \Delta t & (V_{t-\Delta t} < -k \cdot \theta) \\ V_t = V_{t-\Delta t} - a \cdot \Delta t & (V_{t-\Delta t} \geq -k \cdot \theta) \end{cases}$$

If $|\theta| < 5^o$ then

$$\begin{cases} V_t = 0 & (|V_{t-\Delta t}| \leq a \cdot \Delta t) \\ V_t = V_{t-\Delta t} + a \cdot \Delta t & (V_{t-\Delta t} < -a \cdot \Delta t) \\ V_t = V_{t-\Delta t} - a \cdot \Delta t & (V_{t-\Delta t} > a \cdot \Delta t) \end{cases}$$

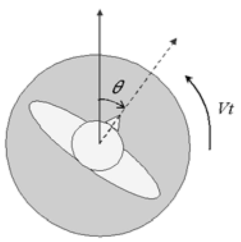

Fig. 8 Turntable rotation to adjust user orientation

Passive rotation should not interfere with user's visual focus or interest. Otherwise a conflicting situation will rise up between the proprioceptive, vestibular, and visual cues. To avoid such situation the projected virtual environment must be rotated with the same speed and direction as the turntable. Figure 9, shows that user's viewing direction remained unchanged within the virtual environment though the turntable was moving.

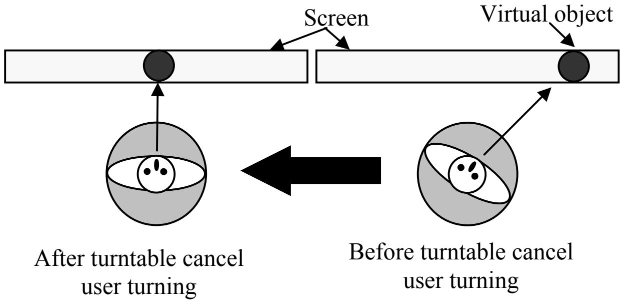

Fig. 9 User regains initial orientation without loosing visual focus

3. Experimental evaluation

For evaluation purpose we used the locomotion interface with a large screen laid on the floor as illustrated in figure 10. Such setting is due mainly to the nature of application that will be used to evaluate the interface, which is about walking through a simple labyrinth.

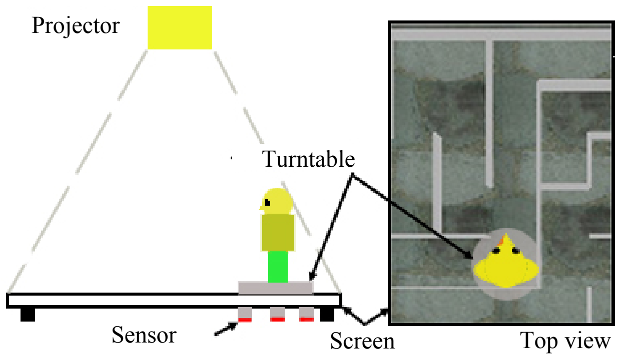

Fig. 10 Experimental environment

The system was brought for demonstration during an international workshop where tens of visitors tried the interface. Users were asked to walk through the labyrinth following a pre-marked path as indicated in figure 11. At the end of the walking experience, users are asked to fill-in a questionnaire to rate the easiness and simplicity of the interface along with their suggestions.

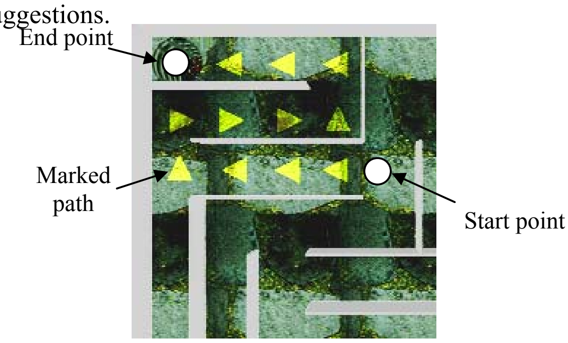

Fig. 11 Experimental labyrinth

Among filled questionnaires we selected 50 documents randomly. Most users stated that they mastered navigation. However, many suggestions were mentioned such as "adding back stepping would be helpful", "feel daisy when rotating, it's boring", "enjoyable", "side stepping is missing"…etc. Table 1 presents the overall result of the questionnaire.

Mastered the walkthrough task	43
Did not master the walkthrough task	7

Table 1 Result of the questionnaire

During the demonstration some walking experience were randomly registered for later analysis. Such data will give an idea about the users' ability to reach the goal; a skillful walking will go directly to the goal without making extra navigation maneuver. From the dataset we selected 10 walking experience and we compared their accuracy of reaching the goal. We divided them into two categories, straight reach and not straight reach. Table 2 resumes about the result.

Straight walk to the goal	8
Not straight walk to the goal	2

Table 2 Navigational accuracy

80% of the successful walks were straight to the goal indicating that the interface was easy to control and matched user navigational control and intention. Figure 12 presents two kinds of navigation, straight and not straight.

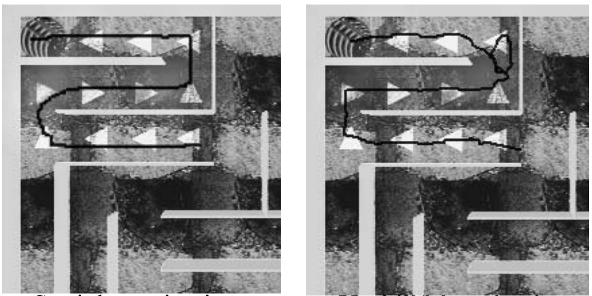
Straight navigation Unskillful navigation

Fig. 12 Skillful and Unskillful navigation

4. Conclusion

The proposed interface has few advantages that easily distinguish it from precedent locomotion devices such as omni-directional treadmills [3][4], slide and pedal interfaces [5][6], and gesture-based pads [7][8]. Though it is compact and simple, it allows users to intuitively carry out a life-like traveling experience within VEs. Beside normal walking it provide users with the ability to make jumps or squatting. Moreover, with its size, weight, and turntable features it can be accommodated within most of nowadays projection environment like CAVE, DOME, …etc, unlike most other omni-directional locomotion interfaces, which require surrounding projection. Preliminary evaluation tests showed encouraging results and feedback from users. As future work we would 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.

References

1. Gilbert, E.G., Johnson, D.W., and Keerthi, S.S., "A fast procedure for computing the distance between complex objects in three-dimensional space", IEEE Journal of Robotics and Automation, 4(2): pp193-203, 1998
2. Gino van den Bergen, "A Fast and Robust GJK Implementation for Collision Detection of Convex Objects", Journal of Graphics Tools, 4(2): pp7-25, 1999
3. Darken R., Cockayne W., & Carmein D. "The Omni-Directional treadmill: a locomotion device for virtual worlds" Proc. of UIST'97. pp:213-222, 1997
4. Iwata H., & Fuji T. "Virtual perambulator: a novel interface device for locomotion in virtual environment". Proc. of IEEE VRAIS'96, pp: 60-65, 1996
5. Ensor, J. R., Carraro, G. U., "Pelton: A VRML-based bicycling simulator" In SIGGRAPH'97 Visual Proc., p.198. 1997
6. Brogan, D. C., Metoyer, R. A., & Hodgins, J. K. "Dynamically simulated characters in virtual environments", SIGGRAPH7 Visual Proc., p.216., 1997
7. I. Choi and C. Ricci, "Foot-Mounted Gesture Detection and its Application in Virtual Enbironments," Proc. of IEEE int'l conf. on System, Man and Cyber-netics, vol.5, pp.4248-4253, 1997.
8. W. Couvillion, R. Lopez, J. Ling, "The Pressure Mat: A New Device for Travering Virtual Environments Using Natural Motion," Proc. of the Interservice/Industry Training Simulation and Education Conference, pp.199-211, 2001.