String Walker

Hiroo Iwata Hiroaki Yano Masaki Tomiyoshi
University of Tsukuba

Abstract

The String Walker is a locomotion interface using eight strings actuated by motor-pulley mechanisms mounted on a turntable. It enables the user to walk in virtual environment while his/her position is maintained. The mechanism enables omni-directional walking. The device allows the walker to various gait, such as side-walking.

CR Categories: H.5.1 [Information Systems]: Multimedia Information Systems – Artificial, augmented, and virtual realities ; H.5.2 [Information Systems]: User Interface – Haptic I/O

Keywords: locomotion interface, walking, string, turntable

1 Introduction ----- vision and goal

It has often been suggested that the best locomotion mechanism for virtual worlds would be walking. It is well known that the sense of distance or orientation while walking is much better than that while riding in a vehicle. However, the proprioceptive feedback of walking is not provided in most applications of virtual environments.

We have been developing various prototypes of interface devices for walking since 1989, including torus-shaped omni-directional treadmill, motion foot pad, and robot tiles. These locomotion interfaces create infinite surface by the use of motion floors. Realization of the motion floors needs bulky or complex drive mechanism, which restricts practical use of locomotion interfaces. We therefore started projects to develop locomotion interface using actuated shoes instead of motion floors. The Powered Shoes, which we demonstrated in SIGGRAPH2006, was a first example. It is a light weight wearable device but has several limitations in its function and durability. Considering these limitations, we developed a new locomotion interface named "String Walker". It employs actuated shoes using motor-driven strings.

The goal of this project is to develop a string-based locomotion interface that enables the user to omni-directional walking in various gaits, while the position is maintained. In order to achieve this goal, tension of the strings must be effectively generated.

Research on locomotion interfaces is still in a preliminary state, but some applications of virtual environment, such as training or visual simulation needs a good sensation of locomotion. The next decade will see effective devices of locomotion interface in these applications.

2 Technical Innovation of the Project

2.1 Basic design

The major innovation of this work is a new actuation mechanism that cancels the displacement of the walker. Existing locomotion interfaces employ motion floors for creation of infinite surface. The easiest way to realize an infinite floor is the use of a treadmill [1][2][3][4]. However, a treadmill has difficulty in realizing omni-directional walking [8][13]. Motion foot-pad for each foot is an alternative [14]. It has ability to simulate omni-directional walking as well as walking on uneven surface. The major limitation of this method is that severe accuracy is required for the foot-pad to trace the walker. Actually, the walker has to be careful about miss tracing of the foot-pad. The CirculaFloor was developed to overcome drawbacks of treadmills and foot-pads [15]. However, the system is too complicated to achieve sufficient walking speed.

The Powered Shoes employs roller skates instead of motion floor [16]. The roller skates are actuated by motors and flexible shafts. The major limitation in the system is that the direction of the traction force generated by the rollers is identical to the shoe, which only allows the walker in a straight gait.

The String Walker is a new locomotion interface that employs motor-driven strings. Four strings are connected to each shoe and they are actuated by motor-pulley mechanisms. Each motor is equipped with rotary encoder and the motor-pulley mechanisms can measure position and orientation of the shoe. The strings pull the shoe in opposite direction of walking, so that the step is canceled. The position of the walker is fixed in the real world by this computer-controlled tension of the strings. The motor-pulley mechanisms are mounted on a motor-driven turntable. It rotates according with the direction of the walker, which enables omni-directional walking. Figure 1 illustrates basic structure of the system and Figure 2 shows its overall view.

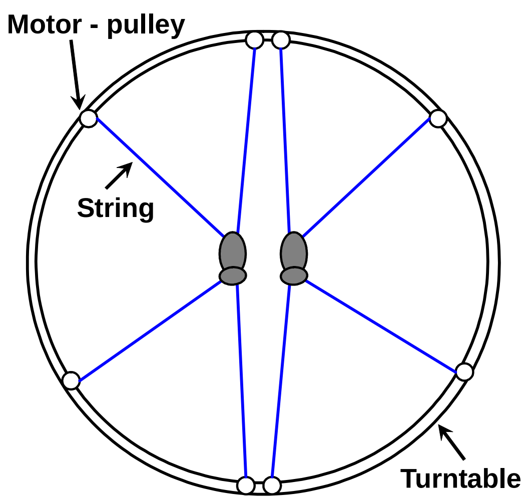

Figure 1. Basic structure of the string-based system

The four strings can pull the shoe in omni-direction, which enables the walker to various gaits such as side-walking or backward walking. This is the major advantage of the system compared to the Powered Shoes that we demonstrated in the SIGGRAPH 2006.

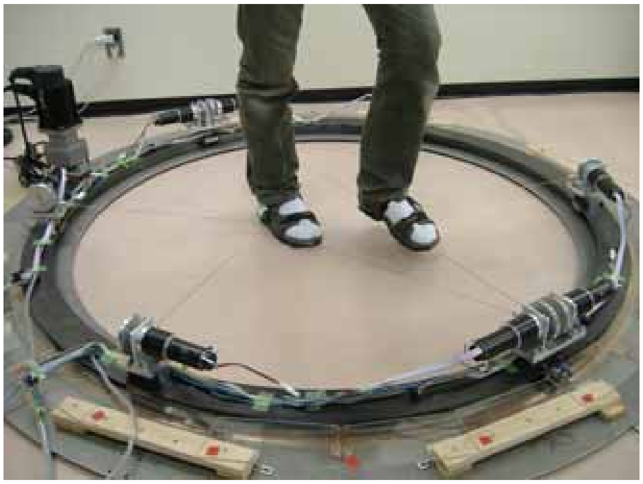

Figure 2. Overall view of the String Walker

2.2 Hardware configuration

Four strings are connected to each shoe (Figure 3). These strings apply force to the shoe in arbitrary direction. A motor-pulley mechanism generates tension of the string (Figure 4). It also measures position and orientation of the shoe. The maximum tension of each string is 25Kgf.

A touch sensor is equipped at the shoe (Figure 5). It detects stance phase and swing phase of walking. The signal is wirelessly transmitted to the host computer. The tension is not applied to the shoe while it is in the swing phase.

The motor-pulley mechanisms are mounted on a turntable driven by a motor (Figure 6). When the walker changes direction of walking, the turntable is activated to follow the direction of walker. This function enables omni-directional walking. Diameter of the turntable is 1800mm.

Figure 3. Strings attached to the shoes

Figure 4. Motor-pulley mechanism

Figure 5. Touch sensor

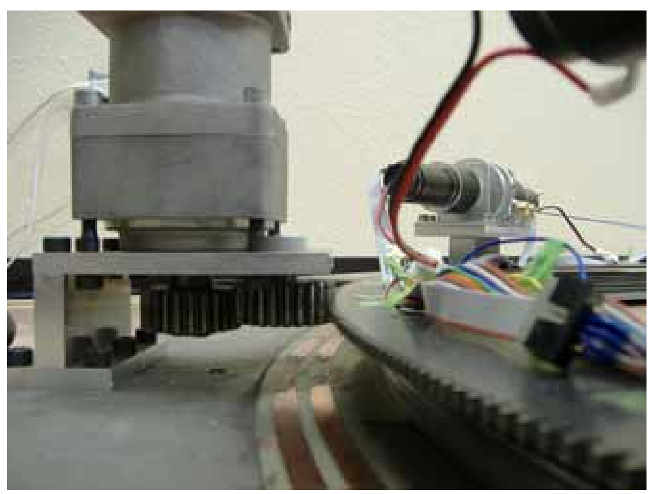

Figure 6. Motor-driven turntable

2.3 Method of walking

The user's position in virtual space is updated corresponding to the results of motion tracking of the feet.

Figure 7 illustrates basic idea of the detection of walking. A circular dead zone is placed in the center of the walking area. In this study, the dead zone is 200 mm diameter circle. The positions of the walker's feet are measured with motor-pulley mechanisms as described in the previous section. Point G in Figure 7 represents the projection of the central position of the walker. The strings don't apply force while the point G is inside the dead zone. If the point G leaves the dead zone, the strings pull the foot so that the point G returns to this area. The direction and distance between the point G and the circle determines the pulling back direction and velocity of the shoe respectively.

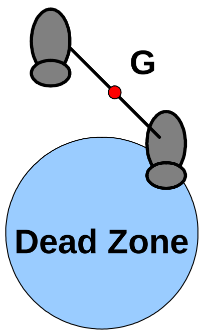

Figure 7. Detection of walking

The control algorithm must keep the position of the walker at the central position of the String Walker system. In order to keep the position maintained the strings have to cancel the motion of the feet. Figure 8 illustrates methods of cancellation. The principal of the cancellation is:

1) Suppose the left foot is at the forward position and right foot is at the backward position while walking.

2) When the walker steps forward the right foot, the weight of the walker is laid on the left foot.

3) The strings pull the left foot back in accordance with the displacement of the right foot, so that the position of the walker is maintained.

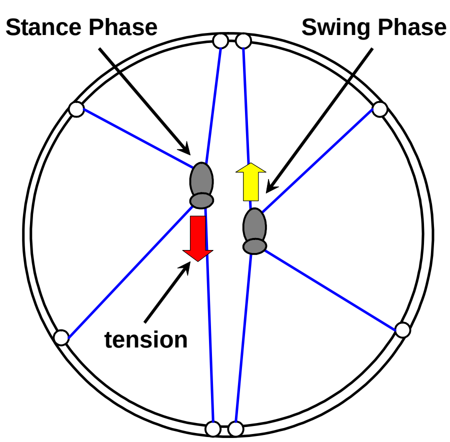

Figure 8. Cancellation of walking

The eight strings can generate force in arbitrary direction so that they can cancel various gait including backward walking and side stepping. Figure 9 illustrates cancellation method for side stepping.

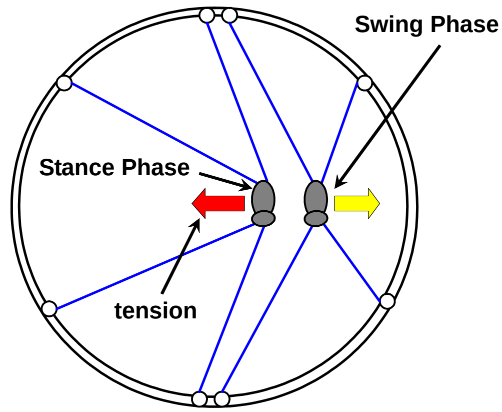

Figure 9. Cancellation of side stepping

3 Experience for the SIGGRAPH 2007 attendees

The experience of the String Walker is simple. The attendees only put the shoes on and walk. The participant of the system can enjoy omni-directional walking while his/her position is localized in the real world. We can demonstrate the performance of the system in 3 minute. One person can participate at one time, but waiting people can enjoy seeing motion of the shoes. Considering individual differences, we are going to prepare several sizes of the shoes. Since most of SIGGRAPH attendees are novice user of the system, a safety bar mounted on the turntable will be provided to support the walker.

Setup of the system is easy. We bring all the apparatus from Japan. Only turntable is set on the floor of the booth. It will need half day for setup. Required space is 13ft X 20ft.

4 How does this work expand on prior work?

We have been developing prototypes of locomotion interfaces for virtual environments since 1989. The first project was named Virtual Perambulator[12]. A user of the system wore parachute-like harness and omni-directional roller skates. The trunk of the walker was fixed to the framework of the system by the harness. Omni-directional sliding device is used for changing direction by feet. We developed specialized roller skate equipped with four casters which enabled two-dimensional motion. The walker could freely move his/her feet in any direction. This is the first locomotion interface in the world.

Later, the harness was removed and a hoop was set around the walker's waist in which he/she can physically walk and turn about. We demonstrated it at the Interactive Communities venue in the SIGGRAPH'95. During five days conference, 235 people experienced the device. We observed behavior of the walkers and 94% of them succeeded in rhythmical walking. However, walkers had to slide their feet by themselves. In other words, the device was passive. Walkers had to get accustomed to the sliding action. We therefore aimed to develop an active device which moves corresponding to motion of the walker.

In order to achieve an omni-directional active floor, we developed a specialized treadmill named "Torus Treadmill" in

1997[13]. The device employed 12 treadmills connected side-by-side. They rotate in perpendicular direction. Thus, each treadmill cancels back-and-forth motion of the walker, and rotation of 12 treadmills cancels his/her left-and-right motion. The device enables natural walking on a flat surface. However the hardware is very large and complex. We could not bring it out from the laboratory.

In 1999, we developed a new locomotion interface named "GaitMaster[14]." It was equipped with two motion platforms to support the walker's feet. The foot-pads trace position of the feet to provide an infinite floor. The device could simulate uneven surface such as staircases. We managed to demonstrate it at the Emerging Technologies venue of the SIGGRAPH 2000. The demonstration was successful but the device has limitation in tracing accuracy of the feet. We therefore put safety strap to prevent the walker to fall off from the foot-pad.

The CirculaFloor, developed in 2002, takes advantage both from treadmill and foot-pad [15]. It creates omni-directional infinite surface by the use of a group of movable tiles. Combination of the tiles provides sufficient area for walking, thus precision tracing of the foot position is not required. The CirculaFloor was demonstrated at the Emerging Technologies venue of the SIGGRAPH 2003. The system requires high-level implementation of actuation mechanism of the tiles and wireless controller. It has difficulty in improving its performance.

The Powered Shoes, which we demonstrated in SIGGRAPH2006, is a light weight wearable device. It has several limitations in its function and durability. Traction of the roller skate is limited in one direction. Thus gait of the walker is limited. Side stepping is not allowed, for example. Another problem in the Powered Shoes is durability of the flexible shafts. They were frequently broken during the SIGGRAPH demo. The flexible shafts are specialized parts so that we had problems in logistics.

Based on these experiences in locomotion interface, we propose the String Walker to solve all the difficulties in implementation as mentioned above.

5 Larger implications of the project beyond this demonstration phase

Walking on foot is the most intuitive way to move about the real world. Although advanced visual simulation often requires good sense of locomotion, existing systems do not provide sense of walking. The String Walker is a practical solution to allow the user to natural walking. It has wide application areas including training simulators or entertainment.

One of the serious applications will be training simulator for dismounted infantry. The String Walker allows the user to various gaits including side-stepping or backward walking. These capabilities contribute to training in urban space or buildings. Another serious application may be an "evacuation simulator." Analysis of evacuation of people in disasters is important in social safety. However, it is impossible to carry out experiments with human subjects during an actual disaster. Virtual environment is inevitable for such experiments. Since evacuation is done by walking or running, the String Walker will be an indispensable interface device for the experiments.

Combination of the String Walker and an immersive image display may provide ultimate sense of presence. The integrated system can greatly contribute to teleoperation or virtual travel.

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