Design and Development of a Ground Surface Simulator

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Abstract

We describe a newly developed locomotion interface system, called the GSS (Ground Surface Simulator). The GSS system is a novel locomotion device that provides a ground surface simulation with an active treadmill. This ground surface simulation function achieves a more realistic virtual walking environment. In this paper, we describe the objective and background of the GSS development program, the basic concept of the GSS system, its technical basis of implementation, and an overview of the first prototype system development. The first prototype system has a 60cm X 150cm walking surface on its treadmill belt, and has a ground surface simulation function.

KeyWords: Virtual Environment, Locomotion Interface, Ground Surface Simulation, Active Treadmill, Design Methodology

1. Introduction

This paper describes a newly developed locomotion interface system, called the GSS (Ground Surface Simulator). The GSS system is a novel locomotion device that provides a ground surface simulation with an active treadmill. The GSS system can represent a simulated ground surfaces ranging from flat and smooth to rough and bumpy, such like a natural field, on a treadmill belt. In this paper, we describe the objective and background of the GSS development program, the basic concept of the GSS system, its technical basis of implementation and provide an overview of the first prototype system development.

2. Objective and Background

In recent years, we have developed numerous virtual reality (VR) devices and systems, aimed at creating more sophisticated virtual environments. Using current VR technology, many research and development programs are attempting to create high-fidelity simulated real worlds or enhance the reality of the real world in a virtual world. Most of these programs focus on the visual reality of a simulated world, because visual information is the most effective media for the human cognitive process and is relatively easy to generate using computing technologies such as three-dimensional computer graphics (3-D CG). However, humans also have other sensations, i.e., auditory, tactile, somatic and so on. These sensations are a very important part of the whole human sensory mechanism, but current VR technology is insufficient to stimulate the them. This is a major problem in creating high-fidelity simulated worlds. To cope with this problem, we intend to achieve a novel VR device that can stimulate these "non-visual" sensations. The GSS development program is one part of this aim. One aim of the GSS system itself is to achieve a novel locomotion device. Locomotion is a natural and ordinary motion for humans. And humans can sense complicated impressions about the environment, i.e., the feeling of distance, the feeling of spending time together with the feeling of distance, and the feeling of space from locomotion. Thus, locomotion plays an important role in recognizing the environment. This is one the of main reasons for developing the locomotion interface in VR technology. However, there are many restrictions on existing locomotion devices, i.e., they give unnnatural feelings to the user, they are not able to represent realistic natural fields or terrains, and so on. We intend to make a more sophisticated locomotion device and its application environment.

3. Basic Concept of the GSS System

The GSS is a locomotion interface that simulates ground surfaces. Users can walk around a virtual environment with simulated uneven ground, and there are no restrictions on the walking motion or distance. The system is a mechanical device and has two major technical points. One is an active treadmill with a natural synchronization function for the user's walking motion. The other is a ground surface simulation function. These features were originally developed in our previous related work, the ATLAS (ATR Locomotion Interface for Active Self-motion) system [1] and ALF (ALive Floor) system [2]. In this chapter, we briefly introduce the technical features of these two systems individually and also describe the technical points of the GSS system that have been applied from the development results of these two previous systems.

3.1 Locomotion Interface ATLAS

The ATLAS system is a locomotion device that consists of an active treadmill and a three-axis motion platform (figure 1). Here, the treadmill can cancel the user's forward motion to achieve an infinite walking path in a virtual environment. The motion platform is placed under the treadmill base and can drive the the treadmill part of the system. The motion platform can simulate the slope of the path, by tiliting the treadmill base. Likewise, it can correspond to the turning motions of the user, by turning the base.

The most remarkable feature of the ATLAS system is a more accurate detection mechanism for the user's walking motion than those of previous works. This detection mechanism enables natural synchronization in the running belt control of the treadmill. The ATLAS system can naturally synchronize the running belt to the user's walking motion. The detection mechanism uses a computer vision (CV) method and is based on our physiological model of the walking motion. The detection mechanism processes the following procedures. First, the user's foot motion is captured by a CCD camera, as shown in figure 1, and the system analyzes the walking phases in the motion. Using the CV method, the walking motion can be divided into two phases; a stance duration and a swing duration. Then, the system estimates the walking speed from the duration time of the stance phase. This physiological model has been experimentally completed by using subjects. In previous work [1], we conducted a subjective experiment that observed the subjects' foot motion and measured the indexes that are concerned with the step length and transition timing of the walking motion. As a result of this experiment, we found that the duration time of the stance phase (tl) was in inverse proportion to the walking speed (V), with the following equation:

$$tl = 0.774/V$$

tl : duration time of the stance phase, V : walking speed

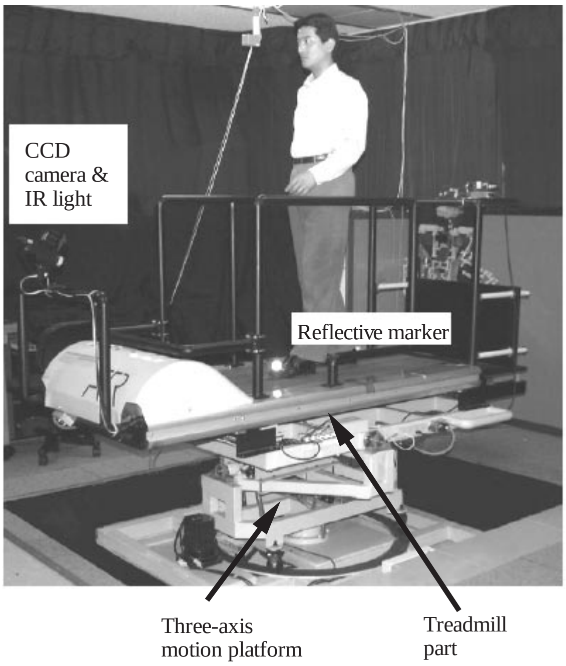


Figure 1: The ATLAS system

The ATLAS system uses the estimated walking speed of the user on the treadmill belt for its control information. Figure 2 is a block diagram of the control mechanism in the ATLAS system. As shown here, the system controls the running belt speed based on this estimated walking speed. It is a feedforward control method. This control mechanism naturally synchronizes the belt speed to the user's walking motion, and can achieve simultaneous start and stop or acceleration and retardation of the running belt with the user's foot motion. This running belt speed control mechanism has been applied to the GSS.

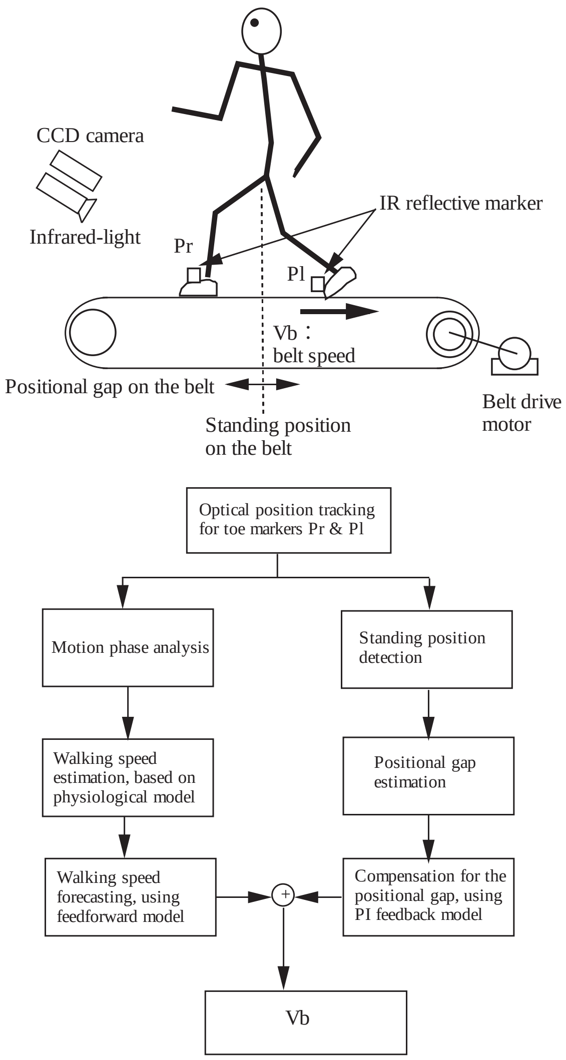


Figure 2: Block diagram of the control mechanism in the ATLAS

3.2 The Terrain Surface Simulator ALF

As mentioned previously, another important technical point of the GSS system is the ground surface simulation function. This function was originally developed in the terrain surface simulator ALF system. The ALF system can simulate a terrain surface as a replacement for a real surface in a simulated world. This is also a novel device in VR technology. In the ALF development program, we assumed that the stepping surface was an important point in somatic sensation, because the shape of the stepping surface strongly influenced or restricted human posture and motion. Therefore, the stepping surface simulation plays an important role in stimulating the somatic sensation. The main objective of the ALF system was to achieve this function. Likewise, in the GSS program, we assume that the ground surface simulation function of the GSS system is a key factor in stimulating the somatic sensation.

The ALF system is a mechanical device for simulating a natural ground surface. The ALF system can simulate ground surfaces ranging from flat and smooth to rough and bumpy, similar to a natural field. Users can walk on this simulated ground. Figure 3 shows the basic concept of the ALF system.

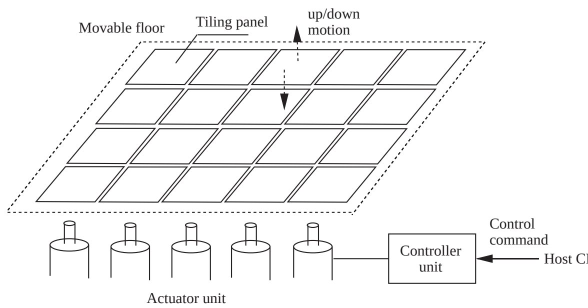


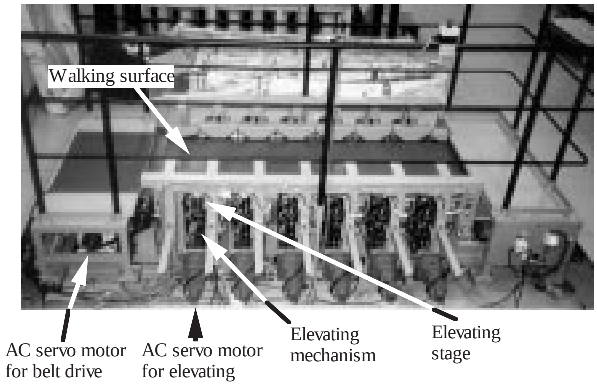
Figure 3: Basic concept of the ALF system

As shown in figure 3, the ALF system consists of a movable floor, actuator units and a controller unit. The movable floor consists of many pieces of small tiling panels in a matrix, and these tiling panels can be levated to a designated height when driven by the actuator units, under the control of the controller unit. The ALF system is also designed as a peripheral device for personal computer or workstation (PC/WS) systems. In other words, the ALF system is a display device that can represent a three-dimensional (3-D) surface shape. The controller unit receives control commands from the system's host PC/WS, and adjusts each actuator unit to the appropriate position of tiling panel height. For example, the system's host PC/WS CPU may use real surface data captured from a natural terrain or virtual surface data generated by 3-D computer graphics, and issue control commands to the controller unit. Then, the system can represent the 3-D shape of these terrain surfaces. This surface simulation function has also been applied to the GSS. In the GSS, this ALF type surface simulating mechanism is installed under the treadmill belt that synchronizes the user's walking motion. The basic concept of the GSS system is therefore a combination of the natural synchronization function of the ATLAS system and the surface simulation function of the ALF system.

4. System Development

4.1 Overview of the First Prototype GSS System

We have already developed the first prototype GSS system (figure 4). This system has a 60cm X 150cm walking surface on its treadmill belt, and has six elevating stages under the treadmill belt. The maximum stroke of each elevating height is 6cm and the maximum speed of the elevation is 6cm/sec. It can control the running speed of the belt from a halt to 2.5m/sec (9km/h).



(1) Photo of the mechanical part

(2) The user walks on the treadmill of the GSS system

Figure 4: Photo of the first prototype GSS system

This 1st prototype system can work in real-time.

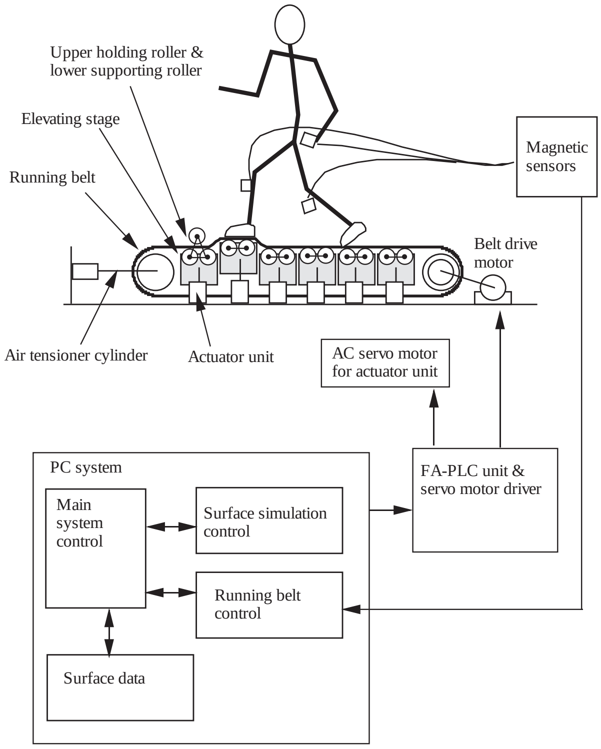


Figure 5: Block diagram of the 1st prototype

Figure 5 is a block diagram of the first prototype GSS. The system contains a treadmill part and a controller part. The treadmill part consists of a running belt, elevating stages, actuator units, an air cylinder tensioner and AC servo motors. The running belt provides the walking surface and enables an infinite path a the virtual environment. The elevating stage plays the same role as the elevating panels in the ALF system. In the GSS system, the running belt runs on the elevating stages. To reduce mechanical friction, the elevating stage has five lower supporting rollers under the belt. The elevating stage also has upper holding rollers on each side of the running belt. Therefore, both the lower supporting rollers and the upper holding rollers cramp the running belt. The elevating stages are driven by the actuator units. In the first prototype system, there are six elevating stages under the belt. The actuator unit is powered by an electric motor, and strokes vertically. With the up and down motion of the elevating stages, the running belt may become loose. To cope with this, the system has a belt tensioner, which is an air cylinder that automatically pulls the belt. AC servo motors serve as the power source of the running belt and the actuator units. The elevating stage is 25cm long in the forward direction of the running belt. This length is shorter than the average foot size of an adult male, and is considered to be sufficient to represent a realistic ground surface.

4.2 Control Method in the First Prototype

As shown in figure 5, The controller part of the system consists of a personal computer (PC), a factory automation (FA) programmable logic controller (PLC) unit, servo motor drivers and magnetic sensors. The main control mechanism is implemented by software running on the PC system. As mentioned previously, the belt speed control mechanism is transplanted from the ATLAS system. This PC system captures the user's walking motion using the magnetic sensors, and estimates the walking speed. Then, it calculates the belt speed and the elevating height of each elevating stage, and issues a control command to the FA-PLC unit. The FA-PLC unit drives the AC servo motors. Basically, the system uses a voltage control method for the servo motor control.

Another important point in the controller part is the ground surface simulation, corresponding to the user's walking motion. In the first prototype system, as mentioned previously, the maximum stroke of each elevating stage is 6cm. This simply means that the system has a mechanical limitation which only allows an uneven surface on the running belt within this 6cm stroke. If there is a sparse bump or basin that is less than 6cm high in the simulated world, the system can represent the shape without any difficulties in the surface simulation, because it clears the constraint of that mechanical limitation. In the real world, however there are many other surface shapes, i.e., taller bumps, continuous rough surfaces, slopes, steps and so on. Sometimes, these shapes exceed the mechanical limitation of the first prototype system. However, to make a realistic simulated world, it is necessary to generate these shapes in the surface simulation. Here, we propose a surface simulation method that can give a slope or step feeling to the user in this simulated world. This method provides a more complicated surface simulation function to the system. In this section, we discuss this method using an example. As shown in figure 6, there is a virtual slope in the simulated world.

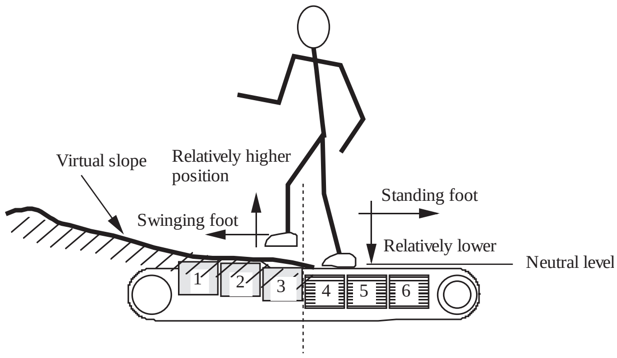


Figure 6: Schematic of the virtual slope

Here, we focus on the relative position of each foot in the transition of the walking motion. This example is an upward slope. In this case, the swinging foot always lands at a relatively higher position than the standing foot. Another important point is that walking is a mutual motion of both feet. Therefore, after the swinging foot lands at a higher position, each foot changes its walking phase. The landing foot will assume a standing phase, and the other foot will assume the swinging phase. Our proposed method can use this topological information, such as the locus of the foot motion, for control. The basic idea of our proposed method is that the system drives the elevating panel simultaneously with the walking motion. This method can give a continuous slope or step feeling to the user and represent more than a 6cm difference in the level. This method repeats the following (1) to (3) control steps:

(1) While the swinging foot moves forward, the system lifts the elevating stages in front of the user. The swinging foot will then be able to land at a higher position.

(2) When the walking phase changes, that is, during the transition when the landed foot changes into the standing phase, the landed foot moves backward. The system changes the elevating stage for the landed foot to a neutral height simultaneously with the backward motion of the running belt.

(3) Then, the other foot changes to the swinging phase, and the system lifts the elevating stage in the same way as step (1).

Metaphorically speaking, this method allows an infinite stairway.

5. Conclusion

In this paper, we describe the design and development of th newly developed GSS system. The GSS system simulates ground surfaces with an active treadmill. It is a novel locomotion device that achieves a more realistic virtual walking environment. The system can effectively stimulate the bodily sensations of the user. These technical features offer an advantage in creating a highly sophisticated virtual environment. In this development program, we have already achieved the first prototype system., and confirmed that it functions appropriately. Although the first prototype system has a mechanical limitation, our proposed surface simulation method can hide the limitation from the human sensory mechanism. This feature allows more complicated surface shapes in the simulated world, and that is a remarkable advantage of the GSS system.

Furthermore, we expect that the GSS system will find applications in the fields of medicine and amusement. As a medical application, the GSS system may be used in a rehabilitation environment for physically challenged people. In such an application, using surface simulation, the GSS system can provide patient with a proper physical load. Since each patient has different physical problems, the proper level of training load is also different for each. The GSS system can adjust the load to a proper level, e.g., the roughness of the surface. As an amusement application, the GSS system can create an entirely unique unnatural or unreal environment. This is a real advantage in a VR device, and the GSS system can make the best use of this feature in amusement applications. We expect that the system to find users in a communication environment. Our focus is to utilize a virtual world for communications media [3]. As we mentioned in chapter-2, one aim of our research and development program, including the GSS system, is to create a novel VR device that can stimulate the non-visual sensations. It can offer a virtual world constructed by non-visual information. Thus, such a virtual world can transfer non-visual information to the user. This would be a richer media than conventional media. In the GSS application system, the system can offer the feeling of distance, the feeling of spending time and the feeling of space by means of the user's bodily sensations. These are non-visual and non-verbal information, and are difficult to transmit by convenntional media.

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