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Development of Ground Surface Simulator for Tel-E-Merge System

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Abstract

In the paper, we describe a series of stages in the development of a new virtual locomotion device designed to enhance remote, interpersonal communications. The latest system, called GSS (Ground Surface Simulator) , inherits the features of two previous locomotion interfaces, i.e. ATLAS (ATR Locomotion Interface for Active Self Motion) and ALF (ALive Floor). GSS also incorporates two different features not found in ordinary treadmills: a movable belt and an active belt speed controller.

We built an initial prototype of GSS and developed a method that presents bumpy surfaces free from the mechanical limitations inherent in prior designs. Experimental results showed that the subject could distinguish a 1% difference in the virtual slope on the GSS.

1. Introduction

The Virtual Space Teleconferencing System (VSTS) [1], which provides a means of communications involving both virtual reality and teleconferencing, was proposed by ATR Communication Systems Laboratories and developed between April 1986 and March 1996. By using the system, people in different locations can participate in meetings or collaborative work while having the feeling of being together just as though they were sharing the same space via a communications system. In the case of the VSTS, the users enter a virtual space from their real spaces and conduct conversations in the virtual space.

Following the VSTS, we at ATR Media Integration & Communications Research Laboratories have been concerned with communication media, especially media for daily communications. Our primary consideration is when we want to have a chat. For example, when a person travels alone in a foreign country or when a person views an impressive picture alone, s/he may want to share this feeling with family members. We have therefore introduced “Tel-E-merge” as a new communication method for such a situation, i.e., "I wish you were here" [2].

We coined the term Tel-E-Merge with a double meaning, i.e., Tel-E-Merge and Tel-Emerge. More specifically, we want to make it possible to merge a remotely located person, a tel-visitor, into a tel-inviter’s space through VR systems.

One form of Tel-E-Merge that we can imagine is as shown in Fig. 1. In the figure, a friend (Tele-visitor) who is in a foreign country is invited into the communication booth of one's own home for a chat. In this case, the friend is invited into a scenic spot where the tele-inviter is, and the tele-visitor’s image is superimposed on some mobile robot. On the tele-visitor's side, too, the image may become an image of that person visiting the scenic spot with some VR devices.

In this research, we intend to shape Tel-E-Merge into a type of medium that allows conversations to take place between remotely separated persons while they walk together. In particular, our focus is on the sense of locomotion, the sense one feels while walking on the real ground.

Some VRML viewers called “walkthrough simulators,” allow a user to move around a virtual world on a screen, visually. The user merely controls the direction and speed of the viewing point by using a mouse. A typical MUD (multiple-user dungeon) system is a shared walkthrough simulator, and users can meet and hike in the world. However, it is difficult to feel where one’s partner is in the world with-

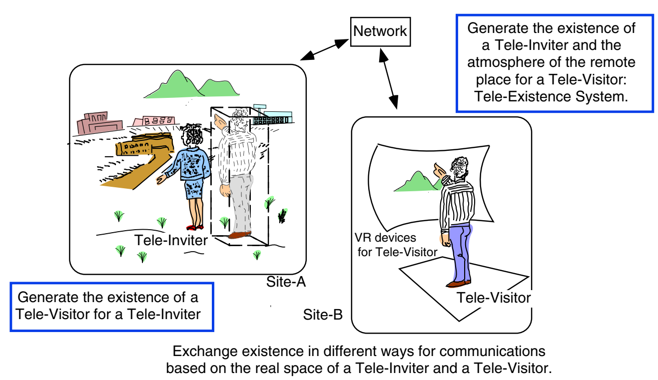


Figure 1. Concept of Tel-E-Merge

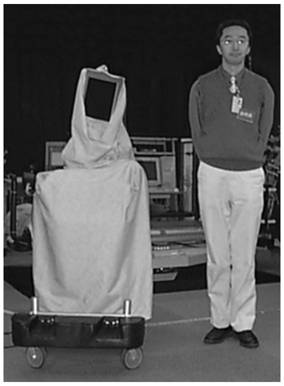


Figure 2. AIR: ATR Imaging Robot

out some special sensors like a radar set.

When people walk together, their walking motion is sometimes felt to be synchronous. Moreover, they can find out a lot of information, like the sound, scale, hardness, humidity, and so on of the space by walking on foot. People usually do such a complicated task unconsciously and can pay a great deal of attention to their partner. Such an unconscious interaction while walking on foot can be thought of as a key point for the enhancement of reality or the existence of one's partner.

We have been investigating a series of development programs for communication devices using locomotion for the Tel-E-Merge system. Our trial system consists of a tele-robot and a locomotion interface. Fig. 2 shows a trial tele-robot, AIR (ATR Imaging Robot), that was designed to represent the existence of a tele-visitor to his/her tele-inviter [3]. AIR can follow the tele-visitor's motion and act as a mobile TV phone to guide the tele-visitor to where s/he is invited.

In this paper, we propose our latest locomotion interface called GSS (Ground Surface Simulator), which allows a tele-visitor to get a true feel, even when walking on a remote uneven ground. In designing the GSS, we focused on two functions, a method for canceling user's free walking motion and a method of simulating natural terrain surfaces. Until now, we have achieved these functions on ATLAS (ATR Locomotion Interface for Active Self Motion; Fig. 3-a) [4] and ALF (ALive Floor; Fig. 3-c) [5], separately. Inheriting the results of ATLAS and ALF, we developed GSS to integrate their solutions.

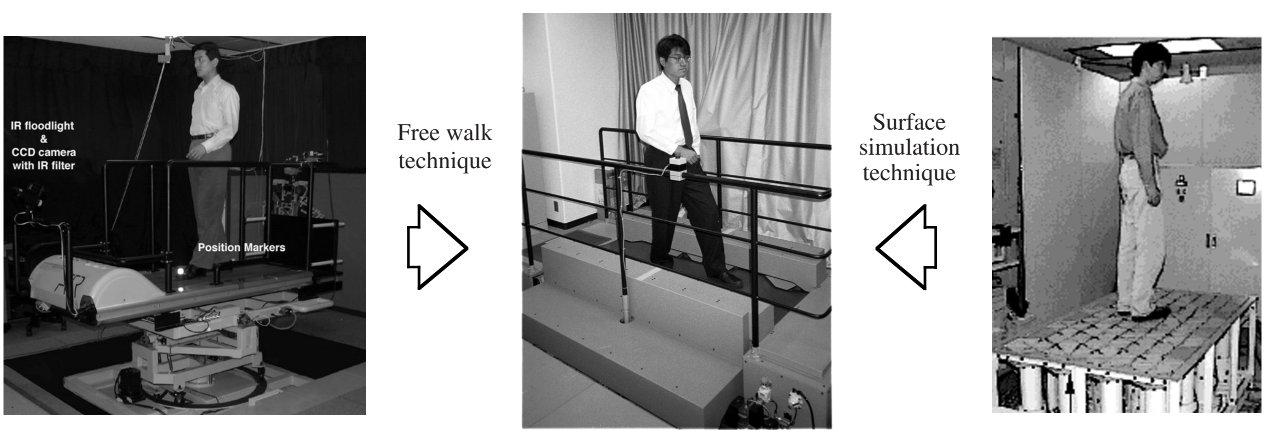
In the following sections, we mention related works on locomotion interface, and then give an overview of ATLAS and ALF. Finally, we present the GSS and experimental results to show the effectiveness of the method.

2. Related works and our design concept

When people want to go somewhere, they typically select the most suitable means of transportation: by foot, bicycle, car, or airplane. Many applications have been developed and a lot of research has been done to simulate such a feeling of locomotion. Most of them have used a vehicle simulator as a training tool or as entertainment, and they have been nearly complete. In this paper, we limit our discussion to a locomotion interface for walking or running motion. As a start, we describe previous research related to locomotion interfaces. Then, we present the design concept of our locomotion interface.

2.1. Locomotion interfaces in VR

Generally speaking, a locomotion interface should cancel a user's self motion in a location to allow the user to go to anywhere in a large virtual space on foot. Additionally, some of them can be designed to present textures of walking surface, i.e., slopes, roughness, hardness, and so on. Several devices have been studied up to now and we clas-



(a) ATLAS (b) GSS (c) ALF

Figure 3. A series of ATR locomotion interface: ATLAS, GSS, and ALF

sify them in the following.

2.1.1. Treadmill approach. In this approach a treadmill is used to cancel a user's motion by moving an infinite belt in the opposite direction. The main advantage of using a treadmill is that the user does not have to wear obstacle devices.

One major problem, however, concerns how to control the belt speed so as to keep the user from falling off. In the case of a motor driven treadmill, the system has to adjust the belt speed based on the user's motion [4,6]. With a passive treadmill, in contrast, the belt is driven by balancing the user's weight, so the user never falls off the belt. This approach, however, can generate a flat surface only.

Another major problem is how to change the walking direction. Brooks [7] and Hirose [8] employed a handle to change the direction. Some unique mechanical 2D treadmills have been proposed. As a motor driven one, Iwata [9] developed a 2D infinite plate that can be driven in any direction and Darken [10] proposed an Omni directional treadmill that uses a mechanical belt. As a passive treadmill, Eyre [11] proposed a 'Spherical Projection System' employing a huge semitransparent sphere. A user can walk inside of the sphere which also acts a visual screen for projectors.

2.1.2. Active footpad approach. This method also does not to require the user to wear obstacle devices and can simulate various terrains. Latham [12] is developing OmniTrek, which uses two footpads. These footpads track the feet of the user quickly and cancel the user's motion so that s/he does not go out of the device. Roston [13] proposed a 'Whole Body Display' that allows the user to walk on stairs, on sand, in mud and so on. Iwata [14] developed 'Gait Master' which consists of two three-DOF footpads and a turntable. Generally speaking, footpads have to support a user's whole weight and track the feet motion quickly; therefore, require sufficient rigidity and a wide bandwidth.

2.1.3. Sliding Interface. Iwata [15] developed a series of sliding interfaces. The user wears special shoes and a low friction film is put in the middle of the soles. Since the user's body is supported by a harness or rounded handrail, the foot motion is canceled passively when the user walks. The system measures the foot motion and changes the user's view together with the walking motion.

2.1.4. Pedal Interface. Using a bicycle, the user's motion is different from that when walking; however, the complicated walking motion is simplified and can be measured easily by computer. Brogan [16] developed a pedal interface for people training for bicycle road races. Ensor [17] developed a VRML based bicycle simulator.

2.1.5. Other Methods. Some research has related the gesture of walking to locomotion. Choi [18] developed CyberBoots. Four pressure sensors are put on the sole of each foot and a gesture detecting system using fuzzy logic outputs motion patterns. Kadobayashi [19] developed a gesture interface, called VISTA Walk, that detects the user's motion visually. Kobayashi [20] reported a similar device that measures the position of the center of balance by a sensor tile. They translate gestures into commands for moving in a virtual space, so the user has to learn how to walk in a virtual space in advance.

2.2. Design Concept of our Locomotion Interface

Our goal is to develop an intuitive locomotion interface that allows a user to get a feeling of walking around a natural terrain surface without any bothersome equipment. To achieve this goal, we divide the method into two parts: a method for canceling a user's free walking motion and a method for simulating natural terrain surfaces.

As the first subject, we employ a motor-powered active treadmill and turntable approach. Using the trial ATLAS, a user can get a feeling of walking in any direction on a flat floor or slope. As the second subject, we use a movable floor, ALF, that can move pieces of small panels on the floor to simulate a natural terrain surface.

ATLAS and ALF have solved specific problems separately, so we have integrated them into our latest system, i.e., GSS. Combining an active treadmill and movable floor, GSS can simulate endless virtual terrain surfaces beyond the restrictions of some mechanical limitations. In the following section, we summarize the solutions of ATLAS and ALF briefly. Then, we describe GSS and its method of simulating terrain surfaces.

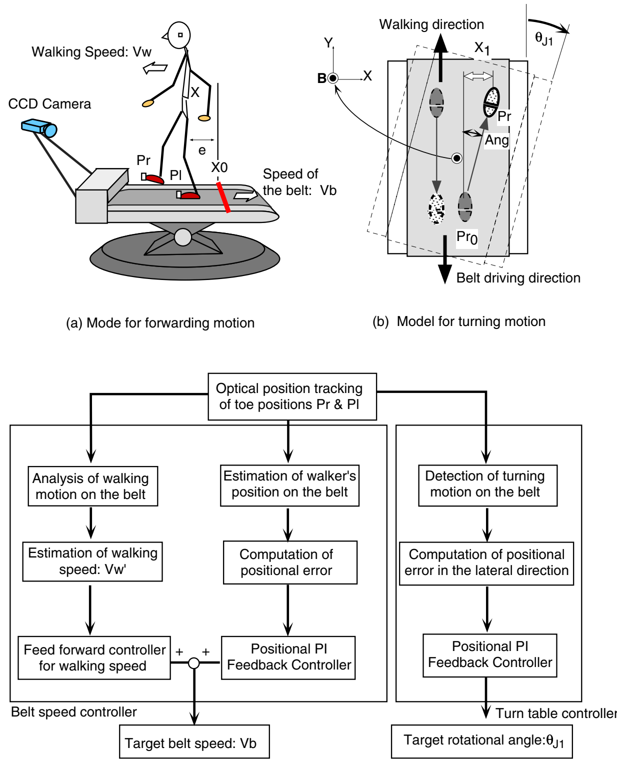
3. Locomotion Interface ATLAS

Using ATLAS, a user can get a feeling of walking on a flat ground or slope. The main advantage of the treadmill approach is that it gives the user a very natural feeling of walking without any bothersome equipment. However, as mentioned in section 2.1.1, we are confronted by two difficulties in this approach: how to keep the walker from falling off, and how to allow the walker to change directions.

On a solution for the first point, we have reported an effective method that integrates a motor-powered active treadmill with a visual motion detecting method. We arranged a CCD camera with an infrared light filter and an infrared lamp in front of the treadmill (Fig. 4-a). Putting small IR reflection markers on each toe of the walker, these positions could be measured with a video tracking unit. Comparing them and the belt speed, the walking phase, stance, and swing phases, could be detected automatically. By observing ordinary walking motion on a flat floor, we could see that the duration of stance phase is almost in inverse proportion to the walking speed [3,21,22].

Using this relation, the system can estimate the walking speed on the belt. As shown in Fig. 4-c, the belt speed controller adjusts the belt speed to keep the walker on the belt using a combination of a feedforward controller for the walking speed and a PI-feedback controller as the user's position .

Next, we discuss the second point of allowing a user to turn to any direction while walking. If a walker makes a turn on an ordinary treadmill, s/he will lose her/his footing and fall off of the belt. To keep the user's foot on the belt at that time, we have considered a method that would cancel the turning motion by rotating the treadmill [3]. Fig. 4-b shows the top view of a treadmill with this method when a walker starts to turn to the right. The next step is supposed to be taken with the right foot, and the foot will be placed down at Pr. At that time, if the belt is rotated in the clockwise direction by the turntable, by synchronizing with the foot motion as shown by the dotted line, Pr will look to move only forward in the coordinate B fixed on the treadmill.



(a) Mode for forwarding motion (b) Model for turning motion

(c) Diagram of controllers of ATLAS

Figure 4. Control method of ATLAS

We applied this method to the trial ATLAS. When the visual motion detecting system found that a swinging foot moved in the lateral direction more than a certain threshold, it reported that the turning motion could be detected. Simultaneously, the turntable rotated the treadmill to keep the swinging foot on the center of the belt.

Fig. 5 gives an overview of the trial ATLAS. It employs a video tracking system, QuickMug™ manufactured by OKK. It can track bright markers at 60 Hz. Furthermore, it uses Fastrack™ to measure the walker's head direction, to support head-tracked visual display as an optional extension.

Our altered treadmill is a commercially-available product. The walking area of the belt is 145 cm (D) x 55 cm (W). The belt speed can be controlled by a PC, from 0 to 4 m/s continuously, the time delay is 0.09 sec, and the time constant is 0.10 sec within the walking speed. The treadmill is mounted on a custom made three-axis motion platform. It can tilt and rotate the walking surface in any direction. The maximum rotational speed is 1.0 rad/s.

Two computers, a PC and a SGI ONYX™ control these devices. The PC acts as an interface I/O for the video tracker, the magnetic tracker, the treadmill, and the motion platform. All data is exchanged via ethernet. The motion analyzing subsystem and belt speed controller are built in the ONYX™. These subsystems operate at 60 Hz. The virtual world simulator subsystem is also implemented in the ONYX™. A visual image feedback subsystem generates images of the world on a projector screen in front of the walker.

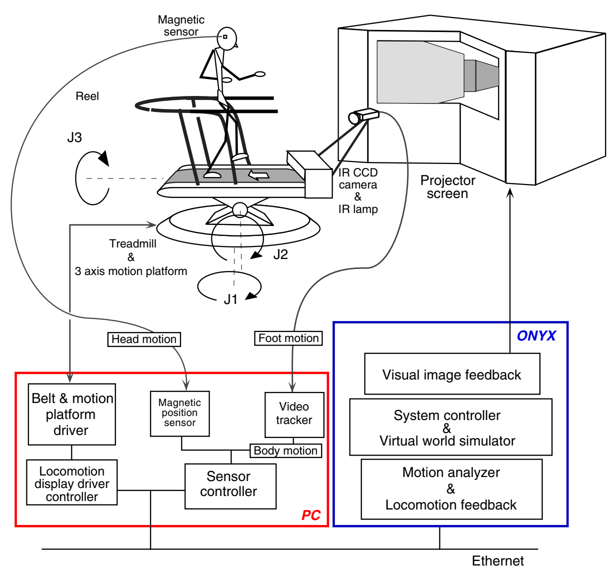


Figure 5. Overview of trial ATLAS

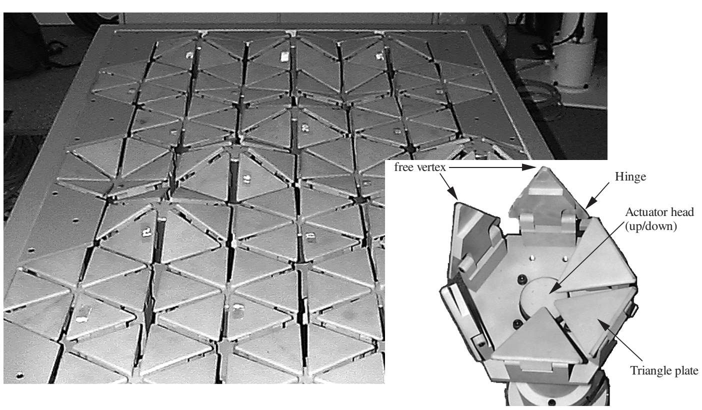
4. Terrain Surface Simulator ALF

The ALF system is a mechanical device for simulating natural terrain surfaces from flat and smooth to rough and bumpy, similar to a natural field on which a user can walk.

The basic idea of the ALF system is very simple. As shown in Fig. 6, the trial ALF system consists of many combinations of vertically moving small tiling panels and actuator units. These tiling panels can elevate to a designated height when driven by the actuator units, under the control of the actuators controller. The system's host PC/WS can accommodate real surface data captured from natural terrains or virtual surface data generated by 3-D computer graphics, and issue control commands to the actuators' controller. Then, the system can represent the 3-D shape of each of these terrain surfaces.

In the development of ALF, we intended to make a practical device. To achieve this, we focused on the following points: (1) small tiling panels, to enable a high-resolution device, (2) large maximum and small unit strokes of the elevation height, to enhance the capability of shape representation, and (3) real-time operation. These were important points for making realistic simulated terrain surfaces, and were reflected in our implementation.

To cope with these points, we proposed a surface patching methodology. In this proposed methodology, each tiling panel is an equilateral triangle plate, and six of these plates are gathered into a hexagon as a drive unit. This hexagonal unit is arranged in a matrix to fill the movable floor surface (Fig. 6). Each hexagonal unit is driven by an actuator unit. The actuator unit can push up or pull down the center of the hexagonal unit. This mechanical configuration can represent a smooth contour. The trial system has 168 tiling panels and 28 actuator units in a 1m x 2m area. Each triangle plate is made of machined aluminum, and the pull down motion is done by its dead load. It uses electrical actuator units and a PC based controller. The system also has a projection system that can project texture graphics onto the tiling panels to form a more realistic terrain surface.



Close up of the actuator unit.

Figure 6. Movable floor surface of trial ALF

As shown in Fig. 7, the controller unit is based on a PC system, and uses a factory automation programmable logic controller (PLC) unit for its stepping motor. The control logic for the controller unit is implemented by software run on a built-in PC system. Here, the system's host CPU gives surface data to the controller unit, and the control software interprets the data and issues PLC control commands. The PLC unit drives each stepping motor in the actuator cylinder. In this first prototype system, an actuator unit can drive a 100 mm stroke vertically.

5. Ground surface simulation for locomotion interface

5.1. Object and basic Idea of GSS

The trial ATLAS can display in an infinite tilted way using its three axis motion platform below the treadmill, but a user always walks on a flat slope such as a paved concrete road or a board. On the other hand, the trial ALF system can simulate terrain surfaces ranging from flat and smooth to rough and bumpy, but each surface is limited within the movable floor. By solving these limitations, we designed GSS to have the mutual advantages of both ATLAS and ALF.

The basic design of the GSS is quite simple. We employ a movable supporting stage under the belt of an active treadmill. When the supporting stage changes into some shape,

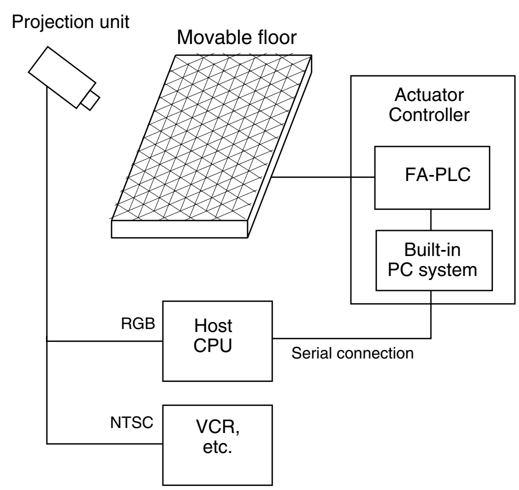


Figure 7. Overview of trial ALF

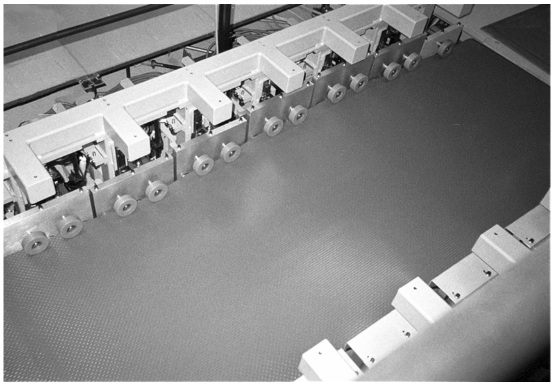


Figure 8. Photo of the deformed belt

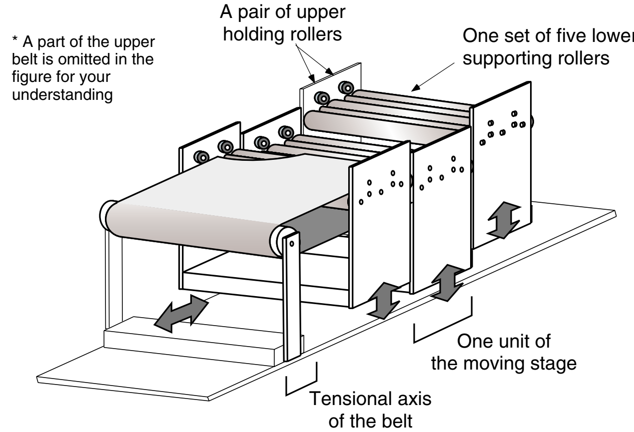


Figure 9. Sketch of belt stage structure

the belt is moved in accordance with this change. Using the techniques of ATLAS, GSS can simulate where a walker is walking. Therefore, if there is a small bump in a virtual world, GSS bulges a part of the belt. Furthermore, GSS can simulate a higher bulge or a lower hollow than the deformations possible with mechanical limited "offset compensation" method. The details of the simulation method are described in a later section.

5.2. Overview of the trial GSS

We have built a first-trial GSS (Fig. 3-b). As this system appears to be an ordinary treadmill, its supporting stage consists of six sub stages that can be moved up and down individually. Fig. 8 shows a close-up of the belt in the shape of a sine wave. The belt size is 1.5 m (D) x 0.6 m (W), and each sub stage is 0.25 m(D) x 0.6 m(W).

The detailed structure of the stages is represented in Fig. 9. Each of the sub stage has nine rollers: five of them are lower supporting rollers and the rest are upper holding rollers. The lower rollers support the weight of the user, so they are made of machined metal. Three of them have a radius of 3 cm and the rest have a radius of 1.5 cm. They are arranged alternately to minimize the gaps between them. The upper rollers are made of engineered plastic and have a radius of 3 cm. The belt is held between the upper and lower rollers. Therefore, the belt rotates along the sub stages when they are up and down. One AC servo motor drives one stage, so the trial GSS has six servo motors. The stroke of the stage is 6 cm and the maximum speed is 6 cm/s.

Additionally, GSS has a belt tension regulator. When the six sub stages are up and down, the treadmill needs a longer belt length than when they are level. In other words, the belt is driven by a frictionally coupled-motor powered axis, therefore the belt tension should be kept constant. In the trial GSS, an air piston and an air pressure regulator move the other end of the belt axis to maintain the belt tension. In the configuration, the maximum belt speed is 2.3 m/s.

Fig. 10 shows a block diagram of the trial GSS. In the system, we employ magnetic position sensors to measure user's foot position and estimate his/her motion. The belt speed controller of GSS uses the same results as ATLAS. GSS also manages a terrain map that contains height data on the simulated world. Using these results, GSS finds the shape of the ground surface where the user is walking, and changes the height of each sub stage to simulate the surface.

5.3. Design of ground surface simulation

In this section, we describe how the system simulates a terrain shape. The maximum stroke of a sub stage is 6 cm in the trial GSS. If the defences in height between the top and the bottom in the simulation world is within this mechanical limitation, the system merely reflects the surface shape

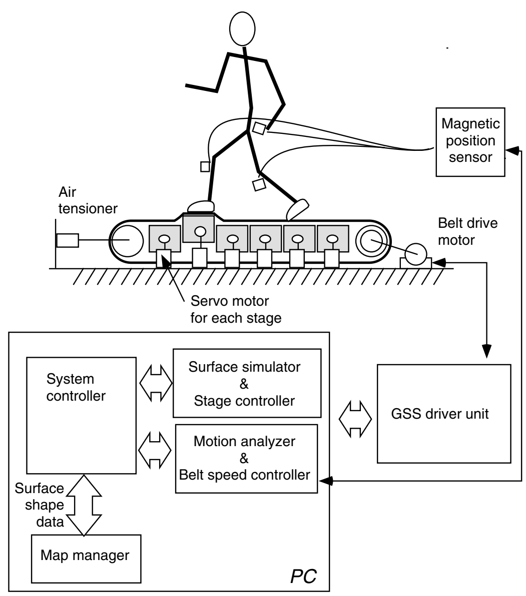


Figure 10. Overview of trial GSS

on the stage where the user is in the world. However, when a bulge is higher than the mechanical limitation, like a long slope, all of the sub stages are raised to their uppermost position.

We applied new method called “offset compensation” to prevent such a saturation condition. The term offset indicates how high the level of GSS is in the simulated world. When GSS needs to simulate a higher terrain shape than the mechanical saturation, the system compensates the surface shape with the offset. This offset is revised in the standing phase.

For example, for the user who is going up a long uneven slope in Fig. 11., there are two control modes running simultaneously: “simulation mode” and “offset control mode”. The sub stages in front of the standing foot (No. 1, 2, 3 in Fig.) are controlled according to the former mode. They simulate the terrain surface in front of the user identical to the simple simulation. One point of difference is that the terrain shape data is compensated by the offset. On the other hand, the remaining stages are controlled under the offset control mode. These motions are synchronized and lower the standing foot gradually in the case of an upper slope. The amount of lowered motions is added up to give the offset.

As a result, a user always has to step relatively higher location than the standing foot. Using the proposed method, the trial GSS can display a 5% infinite slope while walking speed is within 1 m/s.

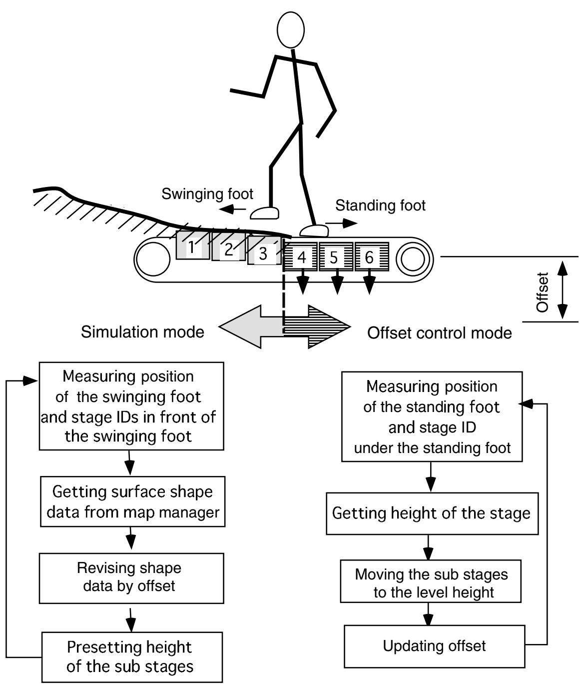


Figure 11 Control method for a large slope

6. Results of slope simulation

We conducted a simple experiment to examine the surface simulating method.

6.1. Experimental setup

Our subjects were asked to walk two virtual slopes on the trial GSS in succession, and to provide an answer which slope was steeper by "former", "latter", or "the same". As shown in Fig. 12, we employed four virtual slopes at inclines of 1%, 2%, 3%, and 4% using the previously mentioned method. In each trial, the subject tried the first slope with ten steps at first. Then, GSS presented a flat surface for five steps, and generated the second slope until the subject gave ab answer. We did not fix the number of steps for the second slope. Each of the subjects got 80 trials (twelve pairs of different slopes and four pairs of the same slope; five trials in each pair). The stimulus pairs were randomly selected. We had six subjects (22-39 years old, male), so we obtained results on 480 trials in total. Before the trials, all of the subjects experienced a training phase for GSS.

6.2. Result and discussion

Table 1 indicates the rates of right answers added up for all trials for each pair of slopes. The best rate was obtained for the 1% versus 4% slope pair. The worst rate was obtained for the in 4% versus 4% slope pair. The table shows that the rates of right answers increase difference between stimuli forming a pair. On the other hand, the rates for pairs with the same slope were worse than the rates for the oth-

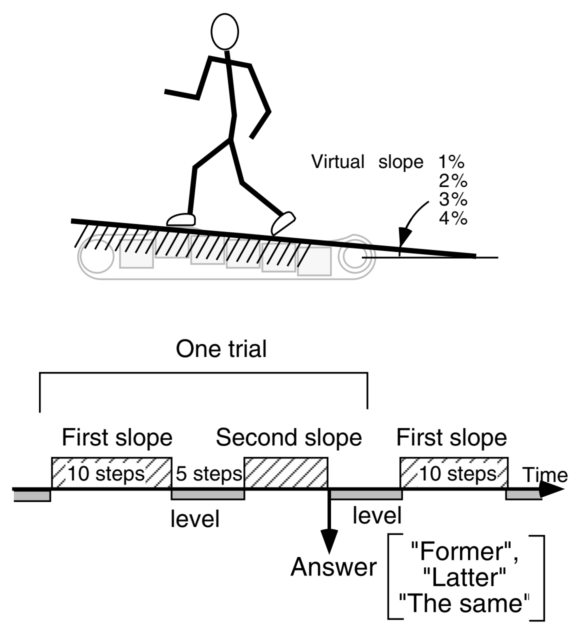


Figure. 12 Procedure of the experiment

Table 1. Experimental Results

	1%	2%	3%	4%
1%	0.767			
2%	0.817	0.500		
3%	0.950	0.667	0.467	
4%	0.983	0.850	0.550	0.400

ers. As a result, the trial GSS could present some stimulus that the subjects could feel. Moreover, the results tell us that the subjects could distinguish a difference of 1% on GSS.

In the experiment, we just compared stimuli on GSS. We have yet to compare real walking motions on slopes or bumpy grounds and motions on GSS.

7. Conclusion

In this paper, we described a series of development programs for communication devices using locomotion. The latest system called GSS inherits the advantages of locomotion interface ATLAS and terrain surface simulator ALF. GSS differ in two ways from an ordinary treadmill, i.e., it has a movable belt and an active belt speed controller.

We built the 1st trial GSS and developed a method that presents bumpy surfaces free from mechanical limitations. Experimental results showed that our subjects could distinguish a virtual slope difference of 1% on GSS.

At the beginning of the paper, we presented our new communication style "Tel-E-Merge" and then proposed a conversation tool between people separated but having the feel of walking together. As future work, we intend to built GSS into the Tel-E-Merge system.

Furthermore, we expect GSS to be applied for rehabilitation purposes, especially for training machines that teaches people walking skills. GSS can dynamically generate any shape of a walkable surface on a belt as walking motion. A patient can therefore select a suitable training course according to his/her skills and training level. For a doctor, GSS can generate and test a variety of walking ways dynamically, enabling the therapist easily and objectively find out the level of treatment a patient will require.

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