THE GAIT SENSING DISC -- A COMPACT LOCOMOTION DEVICE FOR THE VIRTUAL ENVIRONMENT

[+]Jiung-yao Huang, Wen-hsin Chiu, Yung-ting Lin, Ming-tien Tsai, Hua-hseng Bai
Department of Information Engineering, Tamkang University, Tamsui 251, Taiwan
[+]E-Mail : jhuang@mail.tku.edu.tw

Chi-fu Tai and *__Chung-yun Gau__
Institute of Occupational Safety and Health, Council of Labor Affairs, Executive Yuan, Taipei, Taiwan
*E-mail : gau@mail.cla.gov.tw

Hwa-teng Lee
Department of Mechanical Engineering
Cheng Kung University, Tainan 70101, Taiwan
E-Mail : htlee@mail.ncku.edu.tw

ABSTRACT

The locomotion device is an input interface, which can sense the walking pace and direction of the user, for the virtual reality system. This paper presents a new type of locomotion device called Omni-direction Ball-bearing Disc Platform(OBDP), which allows the user to walk naturally inside the virtual environment. Instead of using the 3D tracker, arrays of ball-bearing sensors on a disc are used to detect the pace and an orbiting frame to identify the walking direction. No other sensor, except the head tracker to detect the user's head rotation, is required on the user's body. In addition, the ball-bearing on the sensor slips the user's foot back to the center position of the disc. A prototype of the overhead crane training simulator that fully explores the advantage of the OBDP is also designed and introduced in this paper.

Keywords: Virtual Reality, Locomotion, Overhead crane, Gait analysis, Ball-bearing sensor, Interactive visual simulator.

1. INTRODUCTION

The virtual reality technique has been developed over the years and is widely used in various realms. Most significantly, the virtual reality technique is not an invention of a new technology. Instead, it is an integration of the existing technologies, such as 3D computer graphics, image processing, sound, network and real-time control. With the help of these integrated technologies, the virtual reality technique creates an user friendly interface for the existing applications, such as surgical training, military drill, merchandise advertising, and recreation.

Interactive visual simulator[Tucke98, Stytz96] for training adds mechanical control and dynamic computation to the virtual reality technique to create a more realistic simulation environment for the trainee. In addition, the interactive virtual simulator is often equipped with a cabin to emulate the training device for the trainee to be fully immersed into the simulated environment. The interactive visual simulator has the benefit of providing a safe and realistic environment for the trainee to exercise his skill repeatedly. Furthermore, the interactive visual simulator can help to integrate training procedure with the data acquisition for the drillmaster to ameliorate the training courses. Hence, different virtual simulators have been developed over the years, such as flight simulator[Tucke98] or tank simulator.[DIS] However, various machineries may be required for different training purposes. For example, a motion platform and a fly cockpit are often used for the flight simulator.

The overhead crane is a portage device used in the factory that requires the user to follow the crane on foot. Hence, a different type of mechanism is required when an overhead crane training simulator is built. The training simulator for the overhead crane requires an input device to detect the walking pace and direction of the trainee, so that the user can follow the simulated crane, inside the virtual scene, on foot. The locomotion device is an input interface, which can sense the walking distance and direction of the user, for the virtual reality system. The treadmill was the first device that was used to design the locomotion interface for the virtual environment.[Brook86] However, the legacy treadmill only can support one directional movement, which constraint the freedom of navigation inside the virtual environment. Darken[Darke97] and Iwata[Iwata99] both proposed omni-directional treadmills to relieve the directional constraint to the user. The Uniport, on the other hand, is a different type of locomotion device that uses a modified exercise-bike to simulate the user's pace.[Pratt94]

This paper presents a completely new type of locomotion device, called Omni-direction Ball-bearing Disc Platform(OBDP), which provides a natural way for the user to walk inside the virtual environment. Instead of using the 3D tracker, arrays of ball-bearing sensors on a disc are used to detect the pace and an orbiting frame to identify the walking direction. No other sensor, except the head tracker to detect the user's head rotation, is required on the user's body. In addition, the ball-bearing on the sensor slips the user's foot back to the center position of the disc. Compared with other locomotion devices[Darke97, Iwata99], the OBDP is the locomotion interface that is more conform with the kinesiology of the human being. A prototype of the overhead crane training simulator that fully explores the advantage of the OBDP is also designed and introduced in this paper.

In the following sections, an overview of related researches on the locomotion device is given first. The architecture of the ball-bearing disc platform is ten fully discussed. The overhead crane simulator that fully explores the advantage of the locomotion device follows at the end.

2. RELATED RESEARCHES

The locomotion device provides a natural way for the user to explore the virtual environment. Different locomotion devices have been developed over the years, including treadmill, pedaling device and motion capture.[Intil96]

The treadmill, which was originally used for physical fitness, is the simplest way to build a locomotion device for the virtual environment maneuvering. UNC[Brook86] developed the first locomotion device in 1986 to explore the possibility of designing an intuitive user input device. In order to provide the freedom of navigation, they designed a steering bar, which is similar to the bicycle, to enable the user to change the walking direction. Although this treadmill successfully provides a locomotion interface to maneuver the virtual space, it requires the user to use his hand to control the walking direction which is awkward to the human walking method. In addition, in order to simulate human pedestrian activity, a force feedback mechanism has to be provided.

To accurately simulate the human pedestrian behavior, Utah University designed another type of treadmill, Treadport[Chris], to provide the inertia force feedback to the user. One of the major problems on designing the locomotion interface is that, it can not accurately simulate the walking behavior which hinders the user to be fully immersed into the virtual space. For example, when the human walking on an uphill, gravity and inertia will act on body and ankle to counteract his forward motion. This situation is only one of the examples that will divergence the real world walking from the virtual space locomotion.

An important reason that the researcher used the treadmill to design the locomotion device is that the belt on the treadmill can pull back the user while he is walking on it. Hence, the user can travel a long distance in the virtual world without actually moving far in the physical space. However, the acceleration of the treadmill can create another backward inertia force, which will not happen when walking on the ground. The Treadport is the system that is concentrated on simulating inertial force acts on locomotion, and a tether on the Treadport is designed to achieve the goal. A controller was proposed to act on the tether to cancel the backward inertial force that was caused by the acceleration of the treadmill. Nevertheless, Treadport is still a unidirectional locomotion device.

To revoke the restriction on the freedom of navigation that is imposed on previous treadmill systems, the Naval Postgraduate school proposed an omni-directional treadmill(ODT)[Darke97] to allow the locomotion in any direction. The ODT consists of two perpendicular treadmills, one inside of the other, to responsed to the locomotion of the user. In addition, a mechanical tracking arm is attached to the user's waist to detect the locomotion direction. A servo motor drives the displacement and rotation of the top and bottom treadmills based upon the data from the mechanical tracking arm. By this way, the ODT maps an infinite space of the virtual environment to a small physical space and the user can freely navigate the virtual world.

The ODT system had been used for the U.S. Army Dismounted Infantry Training Program. With proper design of the virtual world, the foot solider can hold indoor training for combat on any district or climate.

The Torus treadmill[Iwata99], which is built by the Institute of Engineering Mechanics, University of Tsukuba, is a further enhancement of the omni-directional treadmill. The Torus treadmill employs twelve treadmills moving the walker in X-direction. These twelve treadmills are mounted on two endless rails that are actuated by four chains, which move the walker along the Y-direction. Two six degree-of-freedom motion trackers are set at the knees to detect the moving direction of the user. An infinite walking area is then simulated by a torus that was implemented by these treadmills and chains.

The UniPort[Pratt94] is a variation of the legacy treadmill-based locomotion device. The UniPort is very similar to a unicycle and it is a bipedal locomotion device. The user pedals to simulate walking or running. The moving direction is controlled by the seat of the UniPort. That is, the user uses the waist and thigh to change the direction of locomotion.

3. A STROLL-BASED VIRTUAL REALITY SYSTEM

The locomotion system presented in this paper, called the Omni-directional Ball-bearing Disc Platform(OBDP), has two special features. First, it is not a treadmill-based platform. It is a round-shaped disc with scattered steel balls. The OBDP is designed by Division of Occupational Safety, which belongs to Institute of Occupational Safety and Health, Council of Labor Affairs, Executive Yuan[Tai91], Taiwan. A gait analysis algorithm is designed for the OBDP to allow the user to stroll around the virtual world with the human natural walking posture.

The second feature of the OBDP system is that the simulation system is built on top of distributed personal computers. These distributed computers are communicated and synchronized by a Communication Backbone(CB), which is the kernel of the Multiple User Distributed Simulation(MUDS) system.[Huang97] The MUDS system is a transparent interface among distributed tasks that are run on networked personal computers. In the following subsections, the mechanism and protocol of MUDS will be discussed first. The architecture of the OBDP then follows, and the gait analysis algorithm for the ODBP is at the end.

3.1 The MUDS system

The basic concept of the MUDS system is that each computer of this fully distributive environment works as a standalone machine such that it only needs to convey message to MUDS kernel without knowing the existence of other computers. Hence, under the MUDS structure, each computer can execute at its own pace and the parallelism among distributed tasks is automatically explored. In order to achieve this goal, a transparent interface, called Communication Backbone(CB), is designed to provide seamless communication among distributed tasks. As depicted in Fig. 1, each computer in this distributed environment executes MUDS/CB as its backbone, and tasks of a virtual simulation run on different computers communicate with each other via MUDS/CB. The CB acts like an agent for tasks on each computer to communicate and synchronize data among tasks, no matter they are executed on the same computer or not.

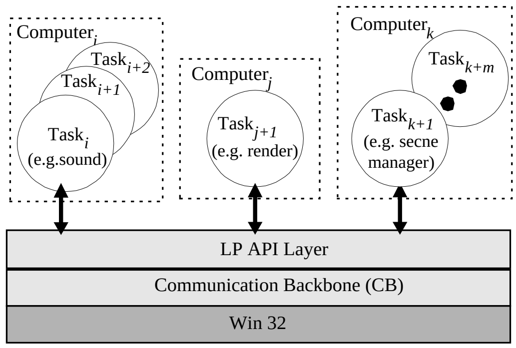

Figure 1. The infrastructure of the MUDS system

For each task, CB plays a role of agency in this distributed virtual environment. That is, each task only needs to register to its resident CB on what type of data it is going to produce. The CB will treat this task as one of the publishers of this distributed environment. Similarly, a task may also need to inform CB on what kind of information it requires and CB will treat it as one of the subscribers in this distributed environment. A task may be both the subscriber and publisher at the same time. Hence, during the initialization phase, CB will be responsible for matching publishers with their corresponding subscribers to seamlessly connect registered tasks to construct this distributed environment. A virtual channel is then constructed between each pair of publisher and subscriber when the initial phase is completed.

During the run-time phase, the publisher will treat CB as a “push” model and pump its data to CB. On the other hand, the subscriber treats CB as the “pull” model that it can dig information out of CB. With this model, a transparent communication among tasks can be easily designed and constructed.

3.2 The OBDP – A Stroll-based locomotion device

Compared with other locomotion devices, the OBDP is unique in terms that no motor is used to provide omni-directional maneuvering. Instead, as shown in Fig. 2, OBDP uses the ball-bearing sensors to detect the user pace and support omni-directional navigation as well.

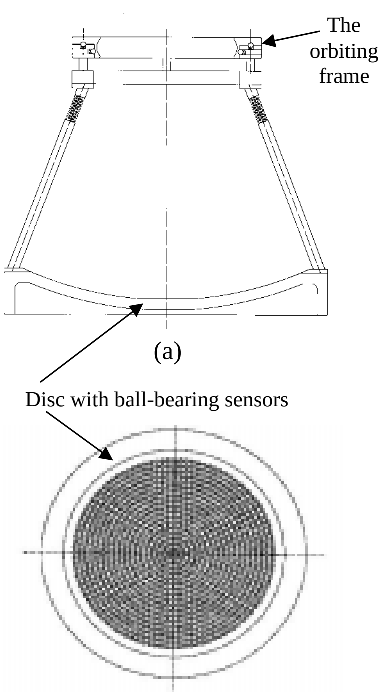

Figure 2. The omni-directional ball-bearing disc locomotion device; (a) Side view; (b) The surface of the OBDP

In order to support the requirement of the omni-directional locomotion, the OBDP has the following distinct features:

(1). It allows the user to perform two-dimensional walking in a limited area --

The surface of the OBDP is laid with a set of balls, as illustrated in Fig. 2(a), to support the two-dimensional walking of the user. The surface of the OBDP was designed based upon the natural gait of the human being. While walking, the human being will either swing his one leg on the air with the other on the ground or have both feet touch the ground. The arc shape design on the disc surface is based upon the swing angle of the human walk, so that the foot can slip back to the center of the disc when the user is walking on the OBDP. By this way, the OBDP allows the user to navigate the virtual world without actually leaving the OBDP. Since the shape of the disc surface is based upon the swing angle of human legs, the user can walk on the OBDP with a natural posture of walking without specific training.

(2). The user does not need to wear any tracker to detect his movement --

The existing locomotion systems[Darke97, Iwata99] require the user to wear a three-dimensional tracker or rolling skate to detect his leg movement for navigating inside the virtual space. To remove the physical encumbrance from the user, the OBDP is embedded with a set of position sensors, as illustrated in Fig. 3, on the surface of the disc to detect the user walking so that the user can comfortably stroll around the virtual space.

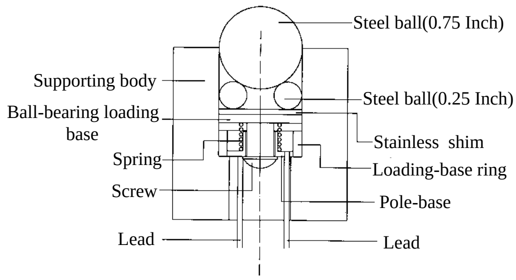

Figure 3. A cross-sectional view of the position sensor

As illustrated in Fig. 3, each position sensor is mainly assembled by steel balls, an isolation axle, a spring and a stainless shim. In order to smoothen the rolling of the steel ball, six small steel balls of 0.25 inch diameter are inserted between the big steel ball of 0.75 inch diameter and the isolation mandrel. The 0.75-inch-diameter steel ball on top of six 0.25-inch-diameter small steel balls provides a slick yet not slippery surface for the user. There are totally 975 sets of position sensors are embedded on the surface of OBDP which can detect the pace between 50 cm and 5 cm.

(3). The OBDP has a safety support to free the user's hand --

The OBDP has an orbiting frame on the user's waist. This orbiting frame can be easily rotated along with the user when he turns around. In addition, this orbiting frame is a half-open support to ease the user to pass in and out. During the operation, this orbiting frame can constrain the user in the center of the OBDP and equilibrate the user when he is walking. Furthermore, the supporting frame can simulate the friction on the foot by counteracting the force feedback produced by the foot slipping on the surface of the OBDP.

(4). The OBDP can interactively respond to the user's stroll --

The OBDP uses a set of A/D and D/A interface cards to translate the signals of the position sensors into the computer to analyze the gait. As shown in Fig. 2(b), the surface of the OBDP is laid with 975 position sensors in 19 concentric circles. In order to increase the scanning rate of these position sensors, they are logically organized into a matrix of 28 rows and 36 columns. By this way, the system can effectively scan the position sensors and analyze the gait within 10 ms to realistically reflect the walking of the user.

3.3 The gait analysis

When the user on the OBDP is navigating the virtual world, the OBDP system scans the position sensors to collect the data of the user motion. The collected data is input to the gait analysis algorithm to compute the walking status and the pace of the user. The virtual scene is then updated based upon the gait analysis to response to the user's motion instantaneously.

Two phases are commonly used to describe the biomechanics of gait: stance and swing. The stance phase begins when the heel of one leg strikes the ground and ends when the toes of the same leg are lifted off. The swing phase represents the period between a toe on one leg is lifted off from the ground and the heel on the same leg contacts the ground. The walking posture is the process of alternation between the stance phase and the swing phase. That is, while walking, one leg is at the stance phase and the other is at the swing phase and vice versa. The locomotion then happens during the swing phase. Within this period, the pelvis moves forward away from the contact point of the leg at the stance phase and the other leg is swung forward.

To simulate this biomechanical phenomenon, the OBDP uses an orbiting frame to constraint the user in the center of the arc-shaped platform. As shown in Fig. 4, the swing phase on the OBDP produces a slipping action on the ball bearing of the position sensors, which is then recognized by the system as a locomotion. In addition, the orbiting frame is around the waist of the user, and it is used to detect the turning motion of the user. By this way, the OBDP system can effectively reflect the locomotion of the user.

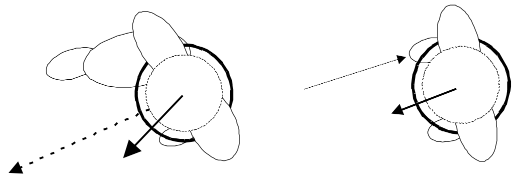

Figure 4. Top view of the locomotive detection; (a). The right leg is lifted-off and swung forward to prepare walking; (b). The right leg is slipped back to produce locomotion.

To detect the locomotion of the user, the gait analysis algorithm for the OBDP system needs to decide if one leg is on the stance phase and the other is on the swing phase. The 19 concentric circles of the position sensors are organized into two areas: the center area and gait sensing area, as shown in Fig. 5. The gait area is further divided into four concentric rings. The sensing data in the center area are used to detect if the user is in the walking posture or simply standing still, and the gait sensing area is to calculate the locomotion.

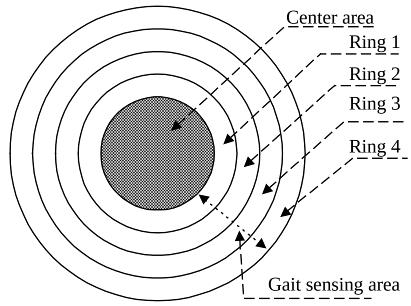

Figure 5. The position sensing areas of the OBDP system

The gait analysis is started with deciding if the user is standing still or performing walking activity. If the user is under locomotion, then the gait sensing area is analyzed to calculate the pace. The rings on the gait sensing area are the units that are used to calculate the pace. Hence, the gait analysis algorithm is illustrated as follows:

```
BEGIN
    Scan the position sensors;
    WHILE both feet are on the center area
    BEGIN
        Clear the swing flag if it is previously set;
    END
    IF the other foot is on the gait sensing area
    BEGIN
        IF the swing flag is set
        BEGIN
            Compare the ring number with the
                previously saved ring number;
```

```
            IF they are different
            BEGIN
                Locomotion is detected, and the
                    pace is calculated;
            END
        END
        ELSE BEGIN
            Set the swing flag;
            Record the ring number that detects
              the foot;
        END
    END
END
```

4. APPLICATION OF THE OBDP SYSTEM – THE OVERHEAD CRANE TRAINING SYSTEM

The overhead crane is a porterage device that is commonly used in the manufacturing industry. Its main structure is an I-steel frame under the roof and an alternator-driven main body is run on that frame. In addition, there is another motor inside that main body, which controls a lift hook under it to porterage cargo. The occupational disaster on the overhead crane often happens due to the insufficient training on handling the hook or controlling the overhand crane. Moreover, the overhead crane training itself is a dangerous process which makes it a perfect case for virtual reality application. In addition, since the overhead crane requires the user to follow the lift hook while controlling it, the OBDP system provides an ideal vehicle to design such a training system.

Based upon the nature of the overhead crane, in addition to the OBDP, the training system uses the 3D tracker and head mount display(HMD) to enable the trainee to observe the virtual scene. Besides, in order to design a realistic training system, the control panel from the actual overhead crane is adapted and refitted as an input device for the simulator. The overhead crane training simulator is composed of the following six functional modules:

- The overhead crane control module --

This module is to receive commands from the control panel to change the states of the simulated overhead crane, such as moving the crane left or raising the lift hook. There are six buttons on the control panel, and it is refitted from an actual overhead crane system. These six buttons control the east, west, north and south movement of the crane, and up and down the lift hook. In order to increase the flexibility of our system, we simulate these buttons as two joystick input. The game port on the conventional personal computer can support two X-axes and two Y-axes along with four buttons. Since we need to simulate six buttons, an X-axis and Y-axis are used to simulate the fifth and sixth buttons respectively.

- The OBDP module --

This module receives signal from the position sensors on the OBDP and executes the gait analysis algorithm discussed in Section 3.3. This module interactively computes the maneuvering direction and distance according to the signal received from the OBDP.

- The 3D scene management module --

The main function of the 3D scene management module is to efficiently manipulate the objects inside a virtual scene. The 3D scene management module is an important factor to increase the performance of a virtual reality system, especially when complex interactions among objects are simulated, such as collision detection among objects and inertia oscillation of the lift hook.

- The 3D rendering module --

The 3D rendering module is implemented by Microsoft Direct 3D library. The Direct 3D library automatically builds a tree of objects in the scene when a scene file is imported. However, this scene tree is an exclusive data structure and it is difficult to control an individual object in the scene tree. In order to integrate with the 3D scene management module, an object table is designed as the interface between the 3D scene management module and the Direct 3D scene tree. Hence, this module displays the virtual scene according to the user head movement, the gait data from the OBDP and the control panel.

- The 3D tracker module --

The main purpose of this module is to allow the user to change view by turning his head. A crucial factor to build an effective virtual training system is to allow the user to easily observe the virtual scene. The overhead crane training system uses the Polhemus tracker mounted on the HMD to detect the user's head movement. The Polhemus tracker uses the electromagnetic wave to detect the six-degree of motion of the receiver which allows the trainee to have a great flexibility to browse the virtual scene.

- The sound module --

The sound module is responsible for producing, inside the virtual scene, the static sound, such as the background noise, as well as the dynamic sound effect, such as collision sound or motor working noise. The overhead crane training system uses the Microsoft DirectSound library to implement the sound module. With this sound module, a realistic training scenario can be designed for the trainee.

- The overhead crane training system --

The overhead crane training system is run on three networked personal computers which construct a distributed virtual environment. As illustrated in Fig. 6, the crane control module and the OBDP module is run on one computer, the 3D rendering module and 3D scene management module on the second computer, and the 3D tracker module and the sound module on the last computer.

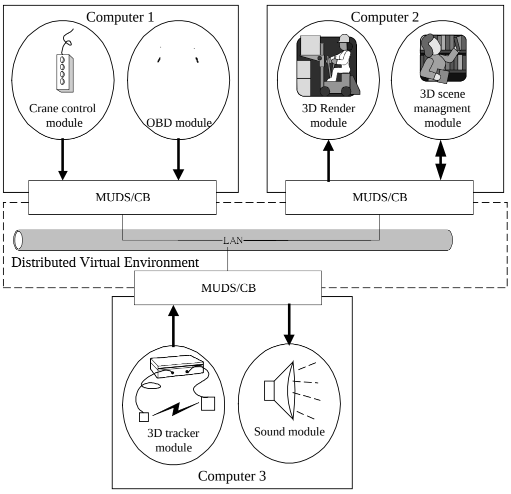

Figure 6. The architecture of the overhead crane training system

Fig. 7 is the snapshot of the scene of the currently investigated virtual environment. Figure 8 demonstrates a researcher trained by the OBDP system. In Figure 8, the player perceives the virtual scene through his HMD while the observer can see the same image from the monitor next to the OBDP system.

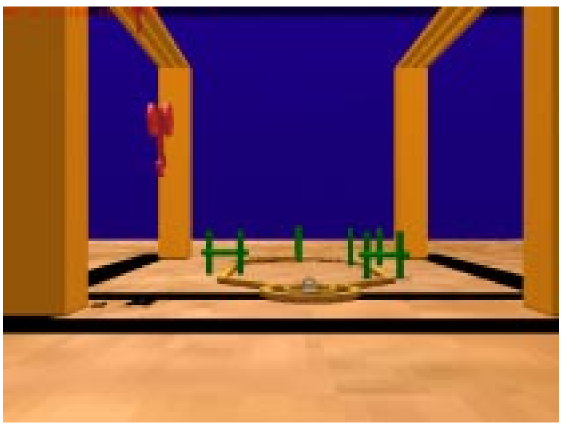

Figure 7. The snapshot of the virtual scene

Figure 8. A trainee is immersed in the overhead crane training system

In this training scenario, the user handles the control panel to control the hook of the overhead crane, shown as the red object in Fig. 7, to clasp a heavy object. He then requires to move the hook and heavy object along the yellow rail to cross the green barriers on the rail. During this training process, the trainee needs to stroll along with the overhead crane to precisely control it. The OBDP detects the walking posture of the user and produces locomotion inside the virtual scene.

5. CONCLUSION AND FUTURE WORKS

Locomotion is the most natural way for the user to navigate the virtual environment. Different types of locomotion device have been developed for the user over these couple years. The OBDP is the first type of locomotion interface that does not require any motor to enable the user to roam around the virtual environment. The OBDP is designed based upon the walking posture of the human being and it allows the user to walk on it in a natural way. The OBDP uses a set of position sensors to detect the user's gait and the ball-bearing on the sensor maintains the user in the center of the disc. This mechanism makes the OBDP become an effective yet smallest locomotion interface ever been designed.

In addition, none of the current researches answer the question of what kind of virtual reality application that the locomotion interface fits best? The overhead crane training system is the virtual reality system that fully explores the advantage of the locomotion device in the virtual reality research. The overhead crane is the most frequently used but dangerous porterage machinery in the manufacturing industry. To work with an overhead crane, the user has to walk with it which makes the overhead crane training become a perfect case to build a locomotion-based virtual environment. Although the overhead crane training system presented in this paper is a prototype system, it shows a promising impact on the locomotion interface in virtual reality application. Further study is continuing to improve this training system, so that the trainee can be fully immersed in the training environment.

Further studies on the application of the OBDP system are currently under investigation. As pointed out in [Darke97], the locomotion mechanism best fit to the simulation where the user's hands are busy manipulating the instruments. Hence, applying the OBDP system to the foot soldier training, and nuclear power plant as well as airplane maintenance training is the future investigation direction.

Significantly, the OBDP training system is a modular system on a distributed computing environment. The MUDS is a transparent communication layer for the interactive visual simulation application. With the MUDS architecture, an efficient interactive simulation system can be easily constructed on networked personal computers. Due to the distributive nature imposed by the MUDS, new functional module can be easily added to the overhead crane training system, such as a sophisticate inertia computation for the cable.

Hence, further researches on the OBDP as well as the overhead crane training system will be conducted on the following directions. First, the orbiting frame on the user's waist will put some constraint on the user's motion. For example, the user can not jog on the OBDP. In addition, the elevation of the orbiting frame does not fit well to all users of different types of height. In addition, the ball-bearing position sensor currently used on the OBDP is a custom-made sensor that is difficult to be maintained and installed. A new type of position sensor is under design to increase the sensitivity and ease of maintenance.

Moreover, the gait analysis algorithm presented in this paper can not detect the sidestepping at this moment. Further improvement of the gait analysis algorithm is currently under investigation so that the OBDP can detect the walking direction as well as sidestep. Finally, although the overhead crane training simulator provides a safe and realistic environment for the trainee, the training scenario requires further studies. To further immerse the trainee into the simulate environment, a see-through HMD may be used to fuse the simulated overhead crane with an actual factory which is also under investigation.

6. ACKNOWLEDGEMENTS

This research is founded by Institute of Occupational Safety and Health, Council of Labor Affairs, Executive Yuan, under the contract number: IOSH88-S132. The purpose of this overhead crane simulating project is to design a training system that can actually use it for training courses and permit examinations in the near future.

REFERENCES

[Brook86] Brooks Jr., F.P. : A dynamic graphics system for simulating virtual building, *Proceedings of the 1986 Workshop on Interactive 3D Graphics*, pp. 9-21, October 1986.

[Chris] Christensen, R.R. et al. : Inertial Force Feedback for a Locomotion Interface, available at http://www.cs.utah.edu/~jmh

[Darke97] Darken, R. P. et al : The omni-directional treadmill : a locomotion device for virtual worlds, *Proceedings of the 10th annual ACM symposium on user interface software and technology*, pp. 213-221, 1997.

[DIS] DIS of Combat, available at ftp://otabbs.ota.gov/pub/pdf/dis.combat/

[Huang97] Huang, J.Y. et al. : A Model and Design of a Fully Distributed Computing Environment for Virtual Reality, *IEEE Real-Time Computing Systems and Applications (RTCSA)*, pp.160-168, October 1997.

[Intil96] Intille, S.S., Davis, J.W., Bobick, A.F. : Real-Time Closed-World Tracking, *IEEE Conference on Computer Vision and Pattern Recognition*, pp.607-703, November 1996.

[Iwata99] Iwata, H. : Walking About Virtual Environments on an Infinite Floor, *Proceedings IEEE Virtual Reality*, pp. 286-293, March 1999.

[Pratt94] Pratt, D.R. et al. : Insertion of an Articulated Human into a Networked Virtual Environment, *Proceedings of the 1994 AI, Simulation, and Planning in High Autonomy Systems Conference, University of Florida, Gainesville*, December, 1994. Available at http://www.npsnet.org/~npsnet/publications.html

[Stytz96] Stytz, M.R. : Distributed Virtual Environments, *IEEE Computer Graphics and Applications*, Vol.16, No. 3, pp19-31, May 1996.

[Tai91] Tai, C.F., et al. : Locomotion Platform, apply for new invention patent in US with application number 991.

[Tucke98] Tucker, W.V., Stuckey Jr., L.D. : The Roles of Modeling and Simulation at Boeing, *Transactions of The Society for Computer Simulation International*, Vol. 15, No. 1, pp. 3-9, 1998.