WARAJI:FOOT-DRIVEN NAVIGATION INTERFACES FOR VIRTUAL REALITY APPLICATIONS ON CAVE

Barrera Salvador, Hiroki Takahashi, Nakajima Masayuki

Graduate School of Information Science and Engineering
Tokyo Institute of Technology
W8-64/70* 2-12-1 Ookayama Meguro-ku 152-8552 Japan
E-mail: [salvador, rocky, nakajima]@img.cs.titech.ac.jp

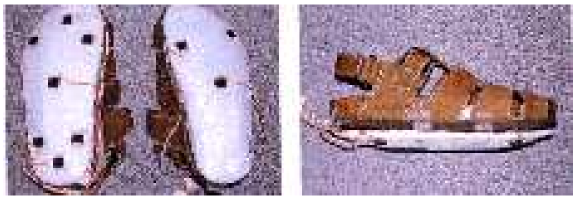

Fig. 1. "WARAJI" First Input Device based on pressure sensors

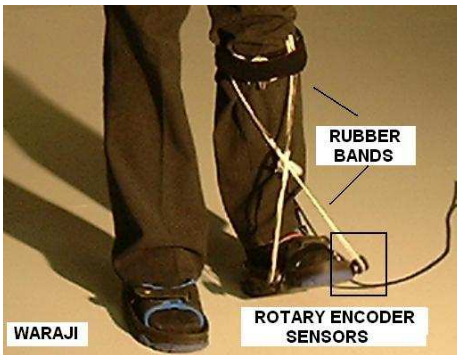

Fig. 2. "WARAJI II" Foot input device based on rotary encoder sensors

ABSTRACT

Presently Technological limitations on current interfaces have made researchers to develop new devices to interact with objects in the virtual environment. The goal of this project is to develop and build a hands-free navigation system to be integrated into virtual environments. One of the most important fields in virtual realty (VR) research, is the development of systems that allow the user to interface with the virtual environment. The most intuitive method for moving through a virtual landscape is by walking. Systems ranging from different platforms have already been implemented to produce virtual walking; however, these systems have been designed primarily for use with head mounted display systems. We believe that hands-free navigation, unlike the majority of navigation techniques based on hand motions, has the greatest potential for maximizing the interactivity of virtual environments, due to more direct motion of the feet.

1. INTRODUCTION

Electronic sensors have been incorporated into footwear for several different applications over the last years. Employing force-sensing resistor arrays or capacitive sensing, insoles with very dense pressure sampling have been developed for research. As sensors and associated processing systems decrease in cost and bulk, they also begin to adorn athletic footwear.

Examples are pressure-sensing insole for golfers to improve their balance during a swing. Although most interfaces for virtual reality applications concentrate on the hands, fingers, and head, some have been extended to the feet. as an example, the "Fantastic Phantom Slipper", where a pair of infrared-emitting shoes are tracked over a limited area and haptic feedback applied by driving vibrators in the sole[6]. Focusing on a different approach for virtual reality input devices, "WARAJI I" was made, WARAJI(Walking, Running and Jumping Interface), had pressure sensors on each foot sole as shown in Figure 1.

Users feet can be used for input basic operations giving freedom to other parts of the body. This version was rather primitive and was based on detecting the pressure orientation of the sole. "WARAJI I" was implemented to cope with the flaws in the design. More specifically the first prototype suffered from lack of sensitivity in backward weight shifts. After many experimental results we designed a new version of the foot input device known as “WARAJI II” as shown in Figure 2. This version of foot input was based on detecting the orientation of the sole, converting it to a directional signal[1]. This implementation had rotary encoder sensors on a sole.

"WARAJI II" was based on rotary encoder sensors[2]. The sensors are mounted on the sides of the sandal and are attached to a Velcro strap located around the knee via rubber bands. This simple device detect ankle movements. These sensors rotate according to the amount and direction of the movement of the foot. The sensor then collects analog information through the user's movements from the legs. The emphasis is in the processing and collection of motion and position data that the sensors accumulate. Rotary encoders serve as measuring sensors for rotary motion, and for linear motion when used in conjunction with mechanical mea-

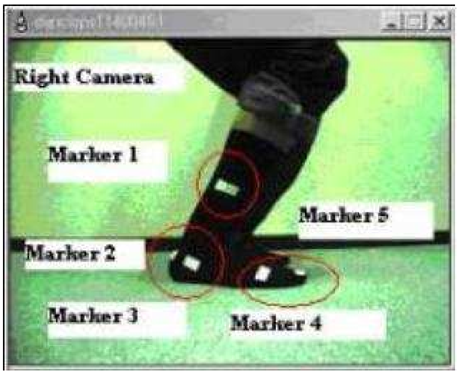

Fig. 3. Markers positions and the segmentation planar model

Fig. 4. "WARAJI IV" Foot motion sensing device based on acceleration sensors

suring standards. These sensors are made on the basis of magneto-induction transducers and are used in the control system where determination of rotation angles, number of revolution, and speed or rotation. The sensors measure the rotary motion of the user's feet and are part of "WARAJI II". Therefore the sensors and the rest of the system work together[3].

"WARAJI III" used stereoscopic images from the foot of the human body and were used to estimate the foot motion in three-dimensional space. The basic approach is to store a number of 2D views of the human feet in a variety of different configurations. Markers were attached to the surface of the foot based on the known location of the forefoot, variants include the case of camera viewing the same tracking the foot configuration and pose over time from video input as shown in Figure 3.

Finally, "WARAJI IV". A simple device using acceleration sensors to detect ankle movements within the virtual environment. The acceleration sensors are attached to the foot and detect movement based on direction for three different angles as shown in Figure 4. The forces of acceleration move the piezoelectric seismic mass, thereby causing strains to it, which generates the voltage[4]. The sensors measure acceleration in three directions x, y and z. sensing the detectable ankle motions for the foot movement.

"WARAJI IV" permits users freedom for changing motion directions naturally. This allows users to input two or more operations simultaneously. Examples include pointing out an object and changing position at the same time. Users can express where they want to go or what they want to do trough natural movements. This also allows the user to move, jump or walk without making any step or hand movement. Such an interface presents a series of design choices, centered on the user control and number of degrees of freedom to be presented. We have set out to make these interface as "natural" as possible. This experimentation could prove beneficial in future virtual gaming[5]. Validation of our approach is given by discussion and illustration of some results.

2. WARAJI II VS. WARAJI IV

"Waraji II" consists of two rotary encoder sensors attached to a sandal for detecting motion. The sensors are connected to a strap right below the knee with rubber bands. These sensors rotate according to the amount and the direction of the foot. The angle of the ankle is detected and translated to an electrical signal, the PC detects changes in voltage and calculates the direction data and inputs it into graphic system. Since the level of the voltage that the interface outputs is in an analog form, we need a sampling process to convert it into a digital signal that our PC can manipulate. "Waraji II" is connected to an A/D conversion board which takes care of the conversion in a rate that provides the user with high play ability and unnoticeable response times. The PC detects changes in voltage, calculates and sends direction data to the graphic system according to increases or decreases in voltage sending direction data to the graphic system. In this application, because we choose a game which only requires two dimensional input, we use only two sensor values. However for other cases which require three dimensional values, the algorithm could not be extended to incorporate vertical, horizontal and rotationally values. Starting from this view point was necessary to upgrade the version using acceleration sensors. These sensors permit users to sense foot motion in 3 different dimensional values.

2.1. WARAJI IV

"WARAJI IV" consists of some acceleration sensors attached to the human leg for detecting motion as illustrated in Figure 4. The sensors are connected with some rubber bands directly below the knee[1].

The acceleration sensors sense foot motions and translate that action into movement. Specifically, the acceleration sensors measure the acceleration, direction and amount of the foot's motion as shown in Figure 5. According to the amount and the direction of the foot, the angle of the ankle is detected and translated to an electrical signal. Since the level of voltage of the interface is in an analog form, we

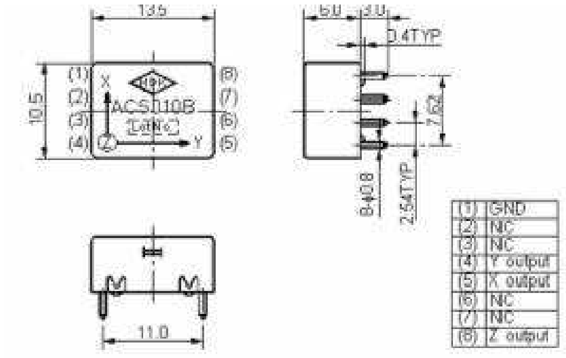

Fig. 5. Acceleration Sensor

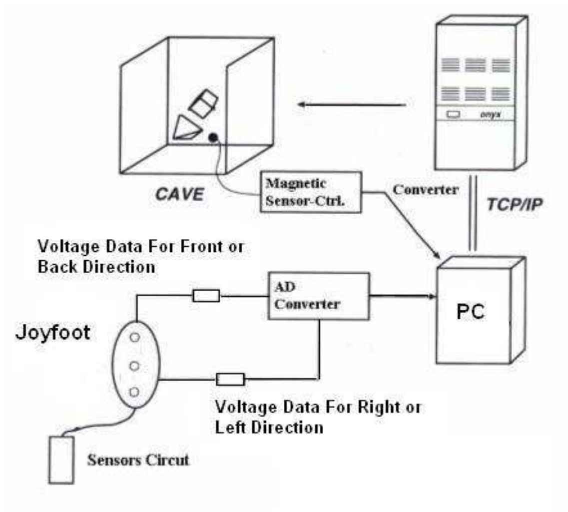

Fig. 6. Overview of the System Architecture

need a sampling process to convert it into a digital signal that our PC can manipulate. "WARAJI IV" is connected to an A/D conversion board which takes care of the conversion in a rate that provides the user with high play ability and unnoticeable response times. Afterwards the PC detects changes in voltage, calculates and sends direction data to the graphic system, according to increases or decreases in voltage.

3. HARDWARE SYSTEM ARCHITECTURE

Since various scanning modes are being investigated we use a stereo viewing system for displaying., which results in a number of systems incompatible to one another. We address the problem of the interconnection of such a device through standard conversions by a signal processing approach,we used stereo viewing system for displaying. Namely the model of a universal standard converter, which is based on a layered functional architecture. The concept of a virtual standard is introduced for stereoscopic signals. When this machine receives direction data, it redraws a picture according to the data. In summary, the system receives direction data from the "WARAJI" unit, reconstructs the scene picture and transmits it into the projector as shown in Figure 6.

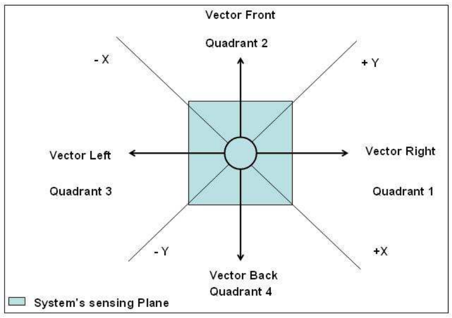

Fig. 7. System's sensing plane

4. DATA ACQUISITION TECHNIQUE

Before using the "WARAJI" calibration is needed, this requires five key-points: Center (C) to serve as the neutral position, Front (F), Left (L), Back (B) and Right (R). The vectors CR, CF, CL and CB divide the sensor plane to four parts, which are mapped to the four quarters of XY. Each of these vectors is moved, rotated, sheared and re-scaled to coincide with the vectors x, y, -x, -y of the target system. The transformation algorithm takes into account the possibility that the key points form a left-handed coordinate system, and manipulates the values. These points form a region of all the possible sensing values for each angle of the user's foot. This is called The user's sensing plane. Vectors from the Center point to the four other points are used to decompose arbitrary directions to a regular coordinate plane as shown in Figure 7.

5. THE VIEWING ANGLE

In order to calculate the correct viewing angle, we first define the user's waist orientation as the angle θ between the waist direction vector and the horizontal vector to the front Cave wall projected onto the floor plane. Next we defined d as the distance the user is from the back of the Cave. Using these two variables, we calculate the rotation factor ϕ using a scaled 2D Gaussian function as follow:

$$\phi = f(\theta, d) = \frac{1}{\sqrt{2\pi}\sigma_1} \cdot e^{-\frac{(|\theta| - \pi(1-d/L))^2}{2\sigma_2^2}}$$

Where $\sigma 1$ is a Gaussian height parameter, $\sigma 2$ is a Gaussian steepness parameter, L is a normalization constant which is used to lessen the effect of d , and the function's μ value is set to π .Using ϕ, we find the new viewing angle by the following formula :

$$\theta_{new} = \theta(1 - \phi)$$

Fig. 8. Game playing Scene

6. APPLICATION GAME

In this application, because we choose a game which only requires two dimensional input, The system can be extended for an extra value. When the users change movement according to motion, the sensors receive information. Since we considered the structure of the human legs, it was possible to detect different movements.

The goal of this game ”space voyage” is originally played in 2D, the player have to use his foot in two dimensions to manipulate the spacecraft and avoid the meteorites that are coming or passing by in the space. We adapted this game for VR by allowing the player to move his lower part of the body directly via a handle tracked with six degrees of freedom. Thereby not only position, but also orientation of the device can control the game through a virtual space game as shown in Figure 8.

The game rules are very simple and easily understood. This game requires the player to use the lower part of their body, increasing the exhilaration of the gaming experience.

”WARAJI” provides a powerful application programmer interface, network distribution mechanism and the necessary device interface for the implementation of virtual reality games. Its main strengths are high-level interaction methods, integrated multi-user concept as well as the adaptability to many different hardware set-ups.

The game implemented is relatively simple, but we expect this to change with the impending open source distribution of new ideas.

6.1. Calibration Dynamic

About the application the results were display as follow; Between times the data was measured and showed that the error is relative and diminishes by the mechanism of auto-calibration showing the result for the three axes horizontal, vertical and gravity axes as shown in Figure 10.

As we can appreciate the mean ratings of motions with horizontal, vertical and gravity errors for unchanged motions are plotted for reference. Each plot is broken out by error direction and error magnitude. Error bars also show standard error of the mean.

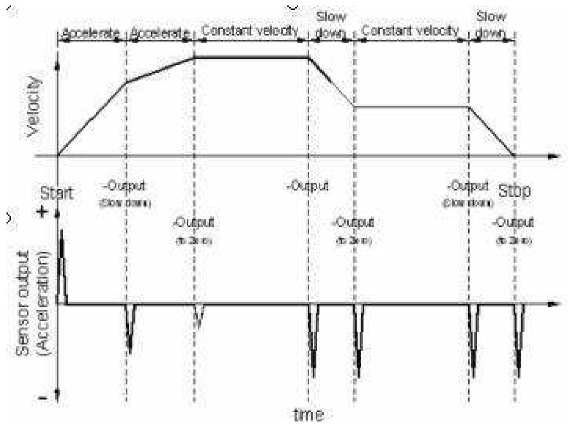

Fig. 9. Output generated when acceleration was applied

7. EXPERIMENTAL RESULTS AND CONCLUSIONS

A number of design choices were presented and centered for the user control that can be objectively used in many Virtual Reality applications. Compared with the traditional input devices such as keyboard and mouse, ”WARAJI” opens a new wearable user interface technology with motion detected from the foot. Giving freedom to other parts of the body, users can interact easily in the virtual world, making hands free from motion operation. Foot operations are very useful for moving naturally around the virtual world. As it is shown in Figure 8, ”WARAJI I” presented some problems such as Balance, Critical Mass and Sensitivity since the pressure sensors were concentrated in the center of WARAJI. This version could not succeed since data were received from the device when there was no movement. Focus on that view point ”WARAJI II” was made demonstrating the power of body sensing by giving freedom to our hands and making games interactive to users, we use only two sensor values. However for other cases which require three dimensional values, the algorithm could not be extended to incorporate vertical, horizontal and rotationally values, same as more freedom.

”WARAJI III” was developed using a stereoscopic camera. We took stereoscopic images from the foot, located the key points and used these to estimate the foot configuration and pose in three-dimensional space. Users were able to walk in the virtual environment without any electronic equipment attached but not in real time. Since part of this version work only for still images we could not succeed. The algorithm and the camera calibration need to be improved. Since new technological advantages we proceed to create ”WARAJI IV” This version gives the user more freedom, as well as, measurement results with horizontal, vertical and gravity ratings of motions. The system is distributed and depends on how much the person can move his/her foot at the time they wear the device. The output is generated and changed at the very moment when the acceleration is applied as shown in Figure 9.

The position and orientation of the foot for the output values were detected, same as measured and the impact of

WARAJI	Version I	Version II	Version III	Version IV
Good for real time	O	O	X	O
No weight limitation	X	O	O	O
Freedom of movement	O	X	O	O
3 Degees of freedom	X	X	X	O

Table 1. WARAJI:Merit and Demerit

the user's velocity, acceleration and direction was applied into a computer game. The actor responded to changes in the environment and the actions of the user.

According to the relative sensitivity to directions, we conclude that from Forward to Backward there is a big movement and equal to the sensors range, not as right and left movement.As an experimental results we showed that a sensitivity range between 5 and 67 percent gave us an acceptable levels of control The direction sensitivity of measurement can be defined by the area of a quarter, divided by the area of all quarters. Since the system is consistent and relatively sensitive to any direction.

In combination with the previous section, users can also travel in directions that were originally directly behind them when they faced the front wall of Cave by first turning to the body either the right or left, also is not weight dependent. We have observed that user's need time to adjust to this distorted spatial mapping, but can at least navigate in any direction. However, we have not yet attempted to quantify the effect of this auto rotation technique on a user's sense of spatial relations.

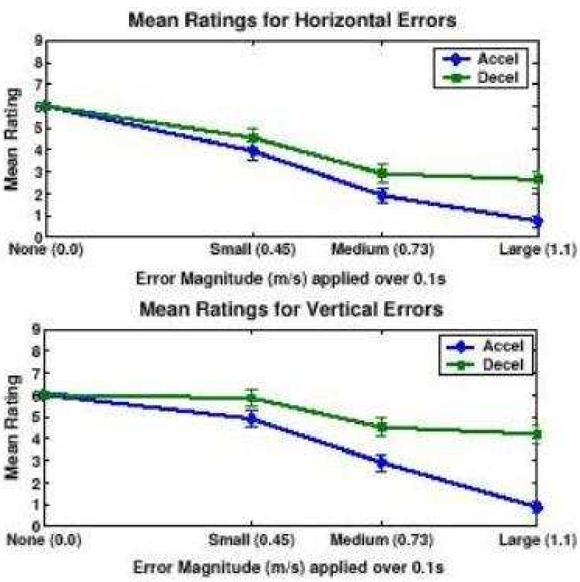

Fig. 10. Ratings of motions with horizontal, vertical and gravity errors

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