”Joyfoot’s Cyber System: A Virtual Landscape Walking Interface Device for Virtual Reality Applications”

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Abstract

Technological limitations on current interfaces have made researches 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. The implementation of a walking interface for a virtual reality system also allows a greater range of biomechanical experimentation and game research. 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. To make this possible, we created a new and 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. The design was called ”Joyfoot’s Cyber System” as shown in Figure 1. This experimentation could prove beneficial in future virtual gaming. Validation of our approach is given by discussion and illustration of some results.

Figure 1. ”Joyfoot’s Cyber System” A new foot motion sensing device

1 Previous work

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 a pressure-sensing insole for golfers to improve their balance during a swing (www.pro-balance. com). Although most interfaces for virtual reality applications concentrate on the hands, fingers, and head, some have been extended to the feet. Examples are NCSA's Boots (Choi and Ricci, 1997), the "Fantastic Phantom Slipper" [13], where a pair of infrared-emitting shoes are tracked over a limited area and haptic feedback applied by driving vibrators in the sole.

Finally "Waraji"[1] in which we used an array of rotary encoder sensors mounted in an overshoe to drive interaction when walking in CAVE (Cave Automatic Virtual Reality Environment), This version of foot input was based on detecting the orientation of the sole, converting it to a directional signal. This implementation had rotary encoder sensors on a sole as show in Figure 2.

Since we require more active and natural participation on behalf of the user as well as to manipulate different degrees of freedom for different postures of the foot. we introduce a new approach to a virtual reality input devices focusing on the basic input foot operations, reducing the response time.

Figure 2. Previous Foot Input Device called "WARAJI II"

For this input device, we used acceleration sensors, as illustrated in Figure 3. The forces of acceleration move the piezoelectric seismic mass, thereby causing strains to it, which generates the voltage. The sensors measure acceleration in three directions x, y and z. As shown in Figure 5, sensing the detectable ankle motions for the foot movement [2]. Although the system allows to consider z like a new value, only we make reference to plane x,y. As part of future work we are considering to include z for further new applications. "Joyfoot" 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[4]. 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[3]. We have set out to make these interface as "natural" as possible.

2 Methodology

"Joyfoot" consists of some acceleration sensors attached to the human leg for detecting motion. The sensors are connected with some rubber bands directly below the knee.

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 3.

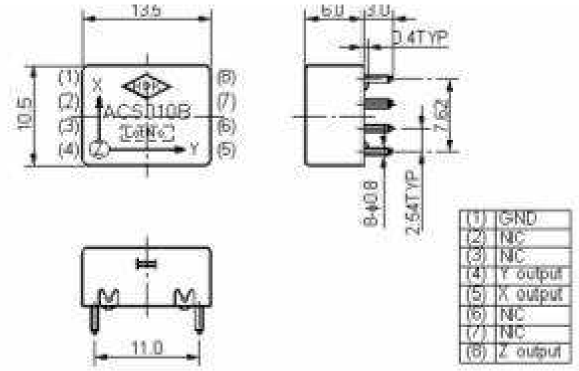


Figure 3. Acceleration Sensor

According to the amount and the direction of the foot, the angle of the ankle is detected and translated to an electrical signal as shown in Figure 4 and 5 [5].

Since the level of voltage of the interface is in an analog form, we need a sampling process to convert it into a digital signal that our PC can manipulate. "Joyfoot" is connected

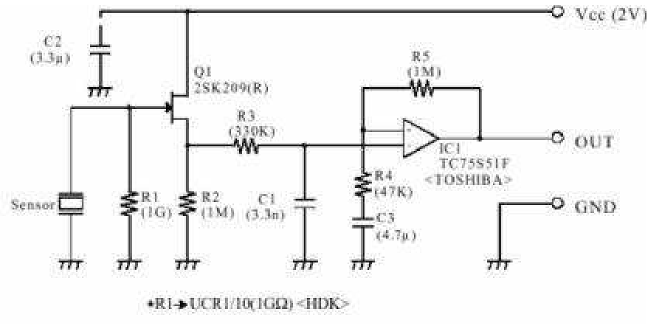


Figure 4. Electronic signal design and interconnection in the sensors

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.

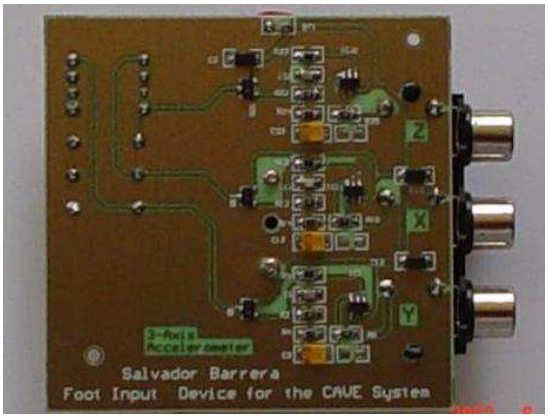


Figure 5. System's hardware

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[6]. Namely the model of a universal standard converter, which is based on a layered functional architecture as shown in Figure 7. 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 "Joyfoot" unit, reconstructs the scene picture and transmits it into the projector[7] as shown in Figure 6.

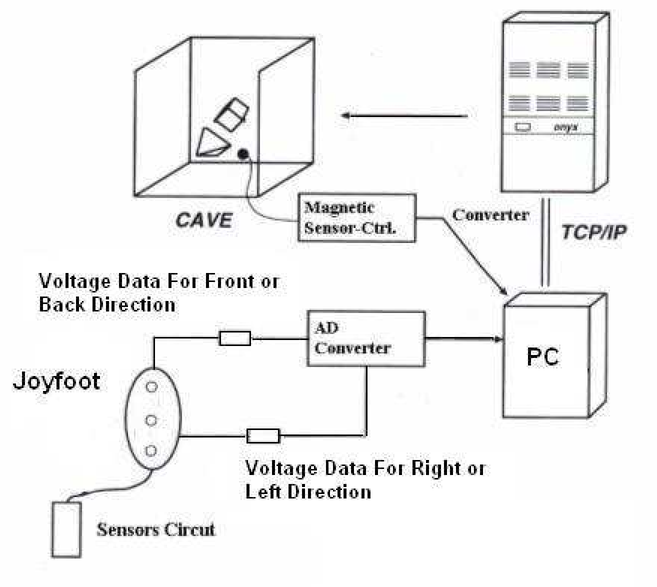


Figure 6. Overview of the System Architecture

4 Data Acquisition Technique

Before using the "Joyfoot" 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 sensor values[8].

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.

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

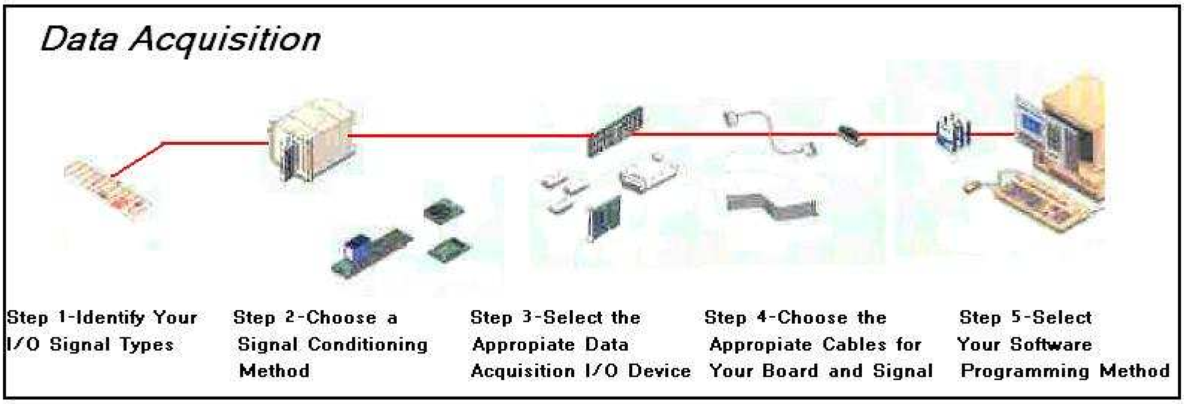


Figure 7. Standard conversions by a signal processing approach

Cave wall projected onto the floor plane. Next we defined d as the distance the user is from the back of the Cave[9]. Using these two variables, we calculate the rotation factor ϕ using a scaled 2D Gaussian function as follow[14]:

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

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 :

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

6 System's sensing plane

In order to map the system's sensing plane to a right-handed coordinate system, we calculate a transformation matrix. The process of this transformation is handled by the algorithm. The transformation matrix is the one that makes the vectors collinear to each axis (Sensor plane/Coordinate Plane) and scales the sensors coordinates in order to normalize the input to one for each quarter (eg. Front-Center-Left) of the sensing plane using the following formulas.

$$T_n = InvCos \frac{\begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} * \begin{pmatrix} \alpha_2 \\ \beta_2 \end{pmatrix}}{\sqrt{\alpha_1^2 + \beta_1^2} * \sqrt{\alpha_2^2 + \beta_2^2}} \tag{1}$$

$$Vector \begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} \tag{2}$$

$$Dot \quad product \begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} * \begin{pmatrix} \alpha_2 \\ \beta_2 \end{pmatrix} \tag{3}$$

$$Length \quad of \quad the \quad vector \sqrt{\alpha_1^2 + \beta_1^2} \tag{4}$$

We need to calculate the angle for each quarter, for every quarter we have two vectors as shown in Figure 5. Where α and β represents (x,y) depending on each quarter and $\sqrt{\alpha_n^2 + \beta_n^2}$ represents the lengths.

This transformation aims in making the Center Right and the Center left vectors collinear to xx axis, as well as the center front and center back vector collinear to the YY axis. The transformation also scales then sensor coordinates in order to normalize the input to one.

On the other hand, the program takes five points, center, right, left, front and back. For every point we start from zero, if it is right or left in their axes in order to know if it is perpendicular or not.

7 Calibration Algorithm

Sometimes the calibration fails and the system can not perform the conversion due to user error. In such a case, the conversion software will warn the user and the calibration will be repeated. Optionally, the user can then choose to use a logarithmic function to increase the stability around the center without diminishing the responsiveness of the interface.

The values returned by the sensors simply refer to angles corresponding to distances between points on the foot and points around the knee. These values are not very useful when used directly. For this reason, we used the device to input a user's positional movement. We made a data transformation algorithm using two sensor values to calculate X and Y directional acceleration values shown in Figure 6. The basic idea of the data transformation algorithm is a space transformation [10]. We used the following method to define the relationship between the sensor values and the XY values.

The algorithm requires 5 points of basic postures (center, front, back, right and left) in sensor space. Those points are related respectively to points (0,0), (0,1), (0,-1), (0,1), (0,-1) in XY space.

The movement, rotation, shear and rescaling have to be calculated for each one of the four parts of the sensor plane and the results are stored in a transformation matrix. The sensor's input value is multiplied every time with the correct part of the transformation matrix and then manipulated in various ways to include a customizable stability around the neutral point, a measure correction to make more efficient the corner positions, and the application of logarithmic functions to improve response time.

8 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[11].

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.

"Joyfoot" provides a powerful application programmer interface, network distribution mechanism and the necessary device interface for the implementation of virtual reality games[12]. Its main strengths are high-level interaction methods, integrated multi-user concept as well as the adaptability to many different hardware set-ups.

Figure 8. Game Playing Scene

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

9 Experimental Results

A number of design choices were presented and centered for the user control. As measurement results with horizontal, vertical and gravity ratings of motions are preserved, even though the system is distributed and depends on how much the person can move his foot at the time they wear the input device.

The output was generated and changed at the very moment when the acceleration was applied as illustrated in Figure 9.

The position and orientation of the foot for the output values were detected as shown in Figure 10, same as measured and the impact of 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

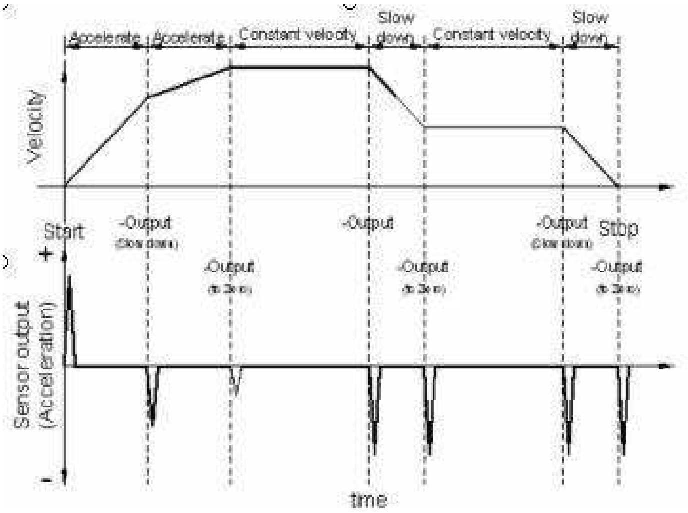
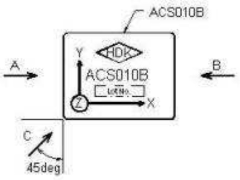


Figure 9. Output generated when acceleration was applied



Acceleration Direction	Output		
	X Axis	Y axis	Z Axis
A	100 mV	0 mV	0 mV
B	-100 mV	0 mV	0 mV
C *	70.7 mV	70.7 mV	0 mV

Figure 10. As a result, the output voltage is proportional to the acceleration from the corresponding axis output terminal

when they faced the front wall of Cave by first turning to the body either the right or left. We have observed that user's need time to adjust to this distorted spatial mapping, but can at least navigate in any direction after only a few minutes. However, we have not yet attempted to quantify the effect of this auto rotation technique on a user's sense of spatial relations as shown in Figure 11.

9.1 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 12.

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.

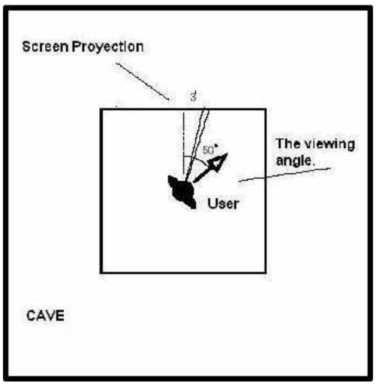


Figure 11. An illustration of the auto rotation technique. As the user rotates to the right, the world auto rotates in the opposite direction based on the scaled 2D Gaussian function (see equation 1).

10 Conclusions and Future Work

We have presented a a new Virtual Reality Input device of hands-free controls for multi-scale navigation through a broad class of virtual environments.

Since all our controls are hands-free, virtual environment designers have greater flexibility when mapping additional functionality since the user's hands are completely offloaded. Specifically, our controls allow users to move small and medium distances, users can simply lean in the direction they want to move independent of their head orientation.

The design of this interface opens the way to a new foot interface based on foot position and motion measurement. "Joyfoot", compared with the traditional input devices, opens a new wearable user interface technology with motion detected from the foot. We believe that our current set of controls are adequate for navigating through a broad range of virtual environments, although additional free controls would be helpful for navigating around specific objects and or navigating through spaces that do not have a floor-plane constraint. These techniques are shown to be simple and sufficiently accurate. As well, this link technology does not disturb the visual interaction and keep enough freedom for the user.

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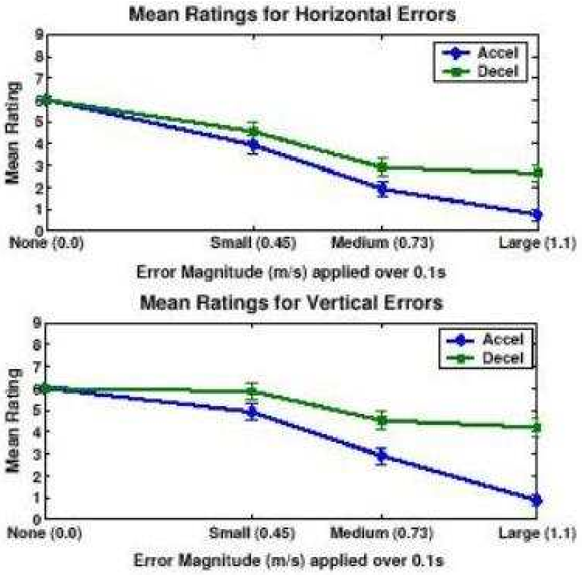

Figure 12. Ratings of motions with horizontal, vertical and gravity errors

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