A new Interface for The Virtual World Foot Motion Sensing Input Device WARAJI II

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Abstract Presently, most virtual reality systems use upper body parts to interact with objects in the virtual environment. This situation is caused by technological limitations of current interface devices. Starting from this viewpoint we developed a new interface for detecting ankle motions relative to the knee. 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 since navigation modes are more direct motion of the feet. We Therefore, created a simple device to detect ankle movements with rotary encoder sensors. These sensors rotate according to the amount and direction of the movement of the foot. The sensors are attached to a sandal and can be used for many purposes for example, virtual games. Validation of our approach is given by discussion and ilustration of some experimental results.

Key words: Foot Motion, Input Device, Computer graphics , Rotary Sensors.

1. Introduction

Input devices on virtual environment have had an increasing demand on the research area in virtual reality[1]. The majority of the Virtual Reality input devices are hand-operated such as keyboard, mouse, joystick, pen-tablet, etc. However, today's interactive games require more active and natural participation on behalf of the user. For this reason researchers are going to investigate other new body parts as input devices. This led us freedom to move in virtual environments.

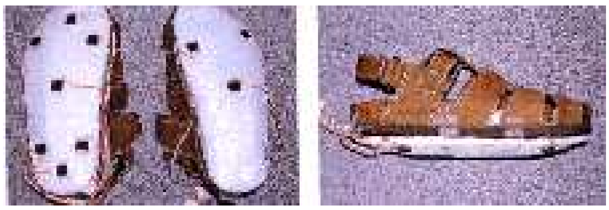

Fig. 1 First foot input device

This paper introduces a new approach to a virtual reality input devices focusing on the foot. We can use our feet for basic input operations giving freedom for other parts of the body.

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This led us to create a simple sensing device for detecting ankle motions [2]. Our first version of foot input device was rather primitive and was based on detecting the pressure orientation of the sole, converting it to a directional signal. This was called "Waraji". This implementation had pressure sensors on each foot sole as shown in Figure 1.

Fig. 2 Foot input device based on foot motion sensing

We implemented "Waraji" interface 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 the "Waraji II" as shown in Figure 2.

"Waraji II" succeeds in providing the user with the versatility and flexibility that all VR application games need, while providing them with relative freedom of movement at the time of playing[3].

"Waraji II" permits users a freedom for changing motion directions naturally between body and feeling. Users can input two operations in one time. For example, 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 allows the user to move or walk without any step or hand movement, freeing other parts of the human body.

2. Methodology

The Warajii II consists of 2 rotary encoder sensors which are used for detecting motion as can be seen in Figure 3.

Fig. 3 Components of Waraji II

The sensors are mounted on the sides of the sandal and are attached to a Velcro strap located around the knee via rubber bands as can be seen in Figure 4.

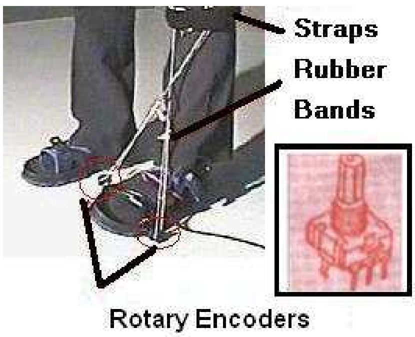

Fig. 4 Rotation according to motions.

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 measuring 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 as shown on Figure 4.

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[5], 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. For that end "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 playability 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.

3. Calibration and Data Transformation

In order to use the Waraji II device, we first need to calibrate it. This is required for two reasons, first as different users wear the device, and the sensors rotate at different amounts resulting in a unique coordinate system for each user. Second, the amount of movement in each direction (i.e. front, back, left and right) is dependent on the physical capabilities of each user. The calibration process is very easy from the user's standpoint; it only requires that the user calibrates five key directions: front (F), back (B), left (L), right (R), and the neutral position (C), similar to (0, 0) in the Cartesian coordinate system. As the user calibrates these five key points through their movements, thereafter, the program transforms the movements into values and begins building the users individual's sensing plane by creating vectors CR- center-right, CL center-left, CF - center front, and CB center-back, as can be seen in Figure 5. The sensing plane created resembles a Cartesian coordinate system, with the exception, that is off center in relation to the plane.

Each one of these vectors is then mapped, moved, rotated, sheared and rescaled to coincide with vectors x, y, -x, -y of the target system. The key point in this unique coordinate system is that the sensing plane created specifically for the user, indicates the maximum range of motion in each direction. So if the user's movements are exaggerated and overstrained, the range of the sensing plane will be larger, and require more energy on behalf of the user to generate the same amount of virtual movement, than when compared to a user who is more cautious in their calibration. This will be shown later in the results section when comparing four test subjects.

These points form a region of all the possible sensing values for each angle of the user's foot. We call this region 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 shown in Figure 5.

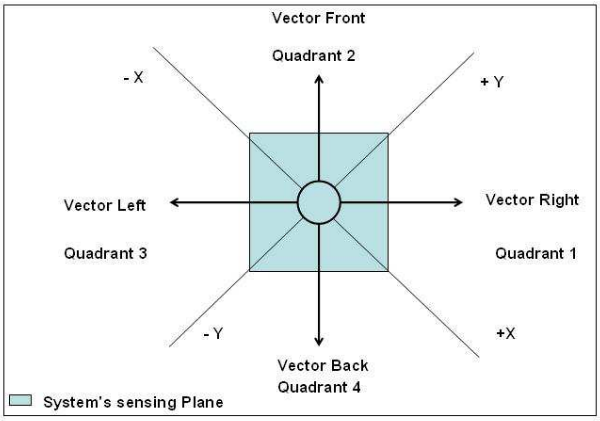

Fig. 5 System's sensing plane

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.

$$Vector \begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} \tag{1}$$

$$Dot \quad product \begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} * \begin{pmatrix} \alpha_2 \\ \beta_2 \end{pmatrix} \tag{2}$$

$$Length \quad of \quad the \quad vector \sqrt{\alpha_1^2 + \beta_1^2} \tag{3}$$

$$T_n = InvCos \frac{\begin{pmatrix} \alpha_1 \\ \beta_1 \end{pmatrix} * \begin{pmatrix} \alpha_2 \\ \beta_2 \end{pmatrix}}{\sqrt{\alpha_1^2+\beta_1^2} * \sqrt{\alpha_2^2+\beta_2^2}} \tag{4}$$

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 length.

The algorithm process of 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 the sensor coordinates in order to normalize the input to one.

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

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

The values returned by the sensors simply refer to rotary 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. We use the following method to define the relationship between the sensor values and the XY values.

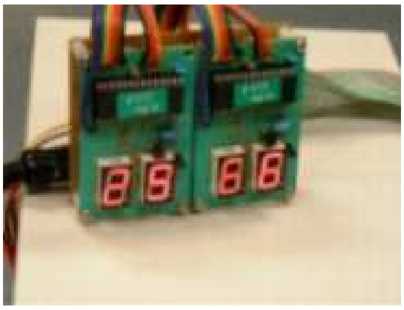

Fig. 6 Calibration Sensors

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 has 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.

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 can be extended to incorporate vertical, horizontal and rotationary values.

4. System Architecture

When the users change the movement according to the motion, the sensors receive the information and directionality. Since we consider the structure of the human legs was possible to detect different movements.

We use stereo viewing system for displaying; correspondingly various scanning modes are being investigated, with results in number of systems incompatible to one another.

We address the problem of the interconnection of such device through standard conversions by a signal processing approach; namely the model of a universal standard converter is proposed, which is based on a layered functional architecture. The concept of a virtual standard is introduced for stereoscopic signals. In the system when this machine receives direction data, it redraws a picture according to the data such as Figure 7. For a more detailed explanation refer to Figure 4 on page 2. In summary, the system receives direction data from "Waraji II" unit, reconstructs the scene picture and transmits it into the projector.

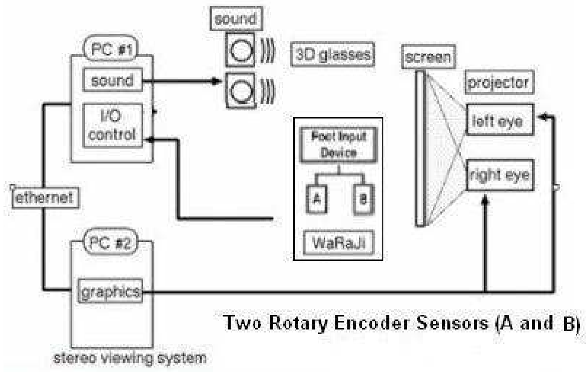

Fig. 7 Overview of the System Architecture

5. Application Game

In this section, we will show how the proposed approach can be applied to a VR game application. A game player first puts on the device and stands in front of a 100 inch projected screen. Then, by using "Waraji II" the player runs through a virtual UKIYOE(Traditional Japanese field) styled field which has many traditional Japanese objects (trees, a creek, a gate. Mr. Fuji, etc.), as shown in Figure 8. In the field there are also many active bombs. The game player must shoot water balls at (and hit) all of bombs before they explode. For shooting game player shakes both hands in a throwing motion (which activates some inertial sensors.

Fig. 8 Game screen design

The game rules are very simple and easily understood.

This game requires that the player use both his/her feet and hands at the same time as shown in Figure 9. Some excited game players might use their whole body for input, increasing the exhilaration of the gaming experience.

Fig. 9 Game playing scence

Playing the game, players can see that "Waraji II" is a very intuitive device and will understand the usefulness and fun of using both their hands and feet in a VR gaming environment.

6. Impact Application Area

For desktop computing. "Waraji II" could be used instead of a mouse as a pointing device, or as second pointing device. When used as the main pointing device, a user can move a pointer on the screen while typing a keyboard. In 3D modeling for example, a user often wants third hand. While the right hand is occupied moving a point, the left hand is also ocupied typing a shortcut key to change operation mode. The modeler may also want to simultaneously change the viewpoint, which he could do using "Waraji II".

In Virtual Reality systems, "Waraji II" is very powerful. Concurrent operations using both hands and feet are natural in the real world. When you move objects from one point to another point. The process would be a repeated action of grabbing, walking and dropping. In this case, assigning walking operations to foot-controlled input is a better solution than using hand actions for walking.

In another example assume that we want to complete a more complex task in a VR environment. When a chief engineer checks a design for complex pipe distribution in a plant, using a VR system such as a CAVE, and finds a point requiring inspection, he may want to take a memo with his/her palm PC (which is connected to the VR host computer). His writing is related to the point coordinate and/or the bad object inmediately. The point is that, his/her hand should be ready for writing when he notices something. Therefore assigning movement operations to foot action in the VR environment is very important.

There is much demand to have hard-to-reach information accessible at awkward times: a craftsman may want to read a blueprint while working, a brain surgeon may want to watch a visualized CT data while operating, a engineer may want to read manuals while doing maintenance, and so on. "Waraji II" will be a useful device as these ideas become a reality.

7. Experimental Results

At a time of wearing "Waraji II", sample data was taken from each of the four users point values for each direction The data taken was for each direction, front (F), back (B), left (L), right (R), and the neutral position (C). Each sensor is considered a cell that holds a 2-digits value from 00-99. The left sensor is considered alpha, and the right sensor was given the value of beta, then the values were taken and analyzed according to the system, these values are expressed in the following table.

	User 1	User 2	User 3	User 4
Center	(22, 89)	(41, 57)	(18, 82)	(24, 66)
Front	(9, 95)	(59, 41)	(9, 76)	(35, 59)
Right	(25, 97)	(31, 64)	(24, 76)	(20, 63)
Left	(14, 82)	(45, 65)	(20, 89)	(31, 68)
Back	(35, 77)	(37, 49)	(27, 89)	(17, 69)

However before these values can be of use, the center position's values prior to offset were used for every key point. The absolute values are expressed in the following table.

	User 1	User 2	User 3	User 4
Center	(0, 0)	(0, 0)	(0, 0)	(0, 0)
Front	(-13, 6)	(18, -16)	(-9, -6)	(11, -7)
Back	(13, -12)	(-10, 7)	(9, 7)	(-7, 3)
Right	(3, 8)	(-4, -8)	(6, 6)	(-4, -3)
Left	(-8, -7)	(4, 8)	(2, 7)	(7, 2)

The values from this table are expressed into the sensing plane for each user, as an example of user 1 and user 3 shown in Figure 10 and Figure 11.

The movement rank was obtained at the time of calibrating the system for each one of the users.

This was determined at the time when the user moves their feet in perspective from anyone of the key points as the displacement of the feet would be different when we compare the data from a different key point.

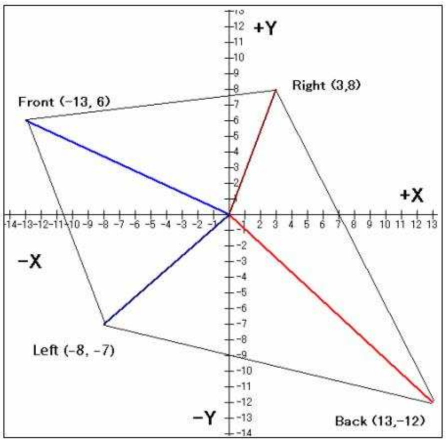

Fig. 10 Calibration Standard for User one

As we can see in Figure 10 and Figure 11, the calibration standards for User 1 with respect to User 3's is different.

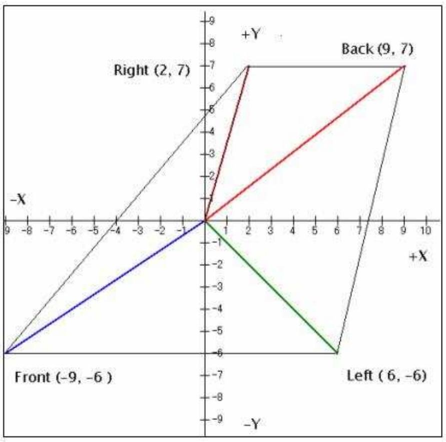

Fig. 11 Calibration Standard for User three

In this case User one has a bigger magnitude, than user three, due to a greater direction of the vector from the movements of the feet, this would be different for each one of the four points. We can conclude that as displacement increases the bigger the direction rank would be.

$$\text{Sensitivity} = \frac{\text{Area of a Quarter}}{\text{Area of all four Quarters}}$$

As measurement results the order of Front (F), Left (L), Back (B), Right (R) is preserved even though is distributed and depends on how much the person can move his foot at the time they wear"Waraji II".

The direction sensitivity of measurement can be defined by the area of a quarter divided by the area of all quarters.

$$\text{FR sensitivity is given by} = \frac{SFR}{SFR + SFL + SLB + SBR}$$

As an example of Front, Right

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.

Since the system is consistent and relative sensitive to any direction. As an experimental results we showed that the sensitivity range between 10 and 50 percent of the movement at the time user ware the device, this gave us an acceptable levels of control as shown in Figure 12.

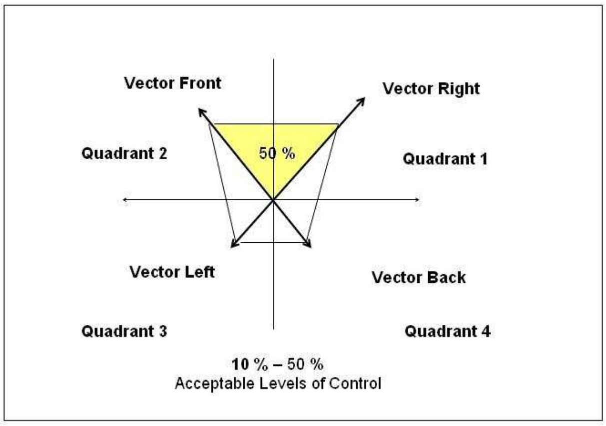

Fig. 12 Measurement Results

8. Comments

The project presents a multi-modal interface that provides a natural space, where the user can interact with a virtual environment via the 3D graphics, audition and natural movement.

1. Replacing input with a keyboard or mouse, foot input devices systems are intuitive for current operations using hands and feet naturally in the real world.
2. The design of this interface opens the way to a new foot interface based on foot position and motion measurement. 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.

9. Conclusions

In this paper we have presented a new VR input device that can be objectively used in many VR applications. Compared with the traditional input devices such as keyboard and mouse, "Waraji II" opens a new wearable user interface technology with motion detected from the foot.

As an advantage of this device we can conclude that giving freedom to other parts of the body, users can interact easily in the virtual world, making hands free from motion operation. Users can input two operations in one time. Foot operation is very useful for moving naturally around the virtual world. Working on a new foot input device has demonstrated the powerful of body sensing giving freedom to our hands and making games interactive to users.

The streamlined configuration requires only a few sensors. The design of this interface also eliminates mechanical parts that could wear out. "Waraji II" opens the way to a new foot interface based on foot position and motion measurement.

〔References〕

1) H. Iwata, and Fujii,T. Virtual Perambulator: A Novel Interface Device for Locomotion in Virtual Environment: Proc of IEEE 1996 Virtual Reality Annual International Symposium.
2) Y. Shinogawa, Kunii T.L., Nomura Y., Okuno T., Young Y. (1990) Automating View Function Generation for Walkthrough Animation Using a Reeb Graph, Proceedings Computer Animation 90 Springer, Tokyo: 227-238.
3) Myers. B.A, "User Interface Software Tools", ACM Transaccions on Computer Human Interaction, 1995 2(1): pp 64-103
4) Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R., and Hart, J.C. The CAVE, Audio-Visual Experience Automatic Virtual Environment. Communications of the ACM, June 1992, pp 67-72
5) Kennedy, R.S., et al. Profile Analysis of Simulator Sickness Symptoms: Application to Virtual Environment Systems. Presence, Volume 1, number 3, Summer 1992, pp 296
6) Davis RB, Oumpw S, Deluca PA (1997)"Gait Data Reporting, Archiving and Sharing", in Allard P, Coppozzo A, Lundberg A, Vaughan CL "Three Dimensional Analysis of Human Locomotion", John Willey and Sons Ltd. Chapter 19, pp. 173-189.
7) Myers, B.A., "User Interface Software Tools." ACM Transactions on Computer Human Interaction, 1995. 2(1): pp. 64-103.
8) Barfield W. Zeltzer, D., Sheridan, T., Slater, M. (1995). Presence and performance within virtual environments. Virtual environments and advanced interface design (pp. 473-541). New York: Oxford University Press.
9) Card, S.K., "Pioneers and Settlers: Methods Used in Successful User Interface Design," in Human-Computer Interface Design: Success Stories, Emerging Methods, and Real-World Context. Rudisill, et al., Editors. 1996, Morgan Kaufmann Publishers: San Francisco. pp. 122-169.
10) Figueiredo, M., Bohm., Teixeira,J. Advanced Interaction Techniques in Virtual Environments. Computers and Graphics, Volume 17, number 6, 1993, pp 655-661

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