Navigation in Virtual Reality with the Wii Balance Board

Andre Hilsendeger, Stephan Brandauer, Julia Tolksdorf, Christian Fröhlich

Universität Bielefeld
Universitätsstr. 25
33615 Bielefeld
Tel.: +49 (0)521 / 106 - 2917
Fax: +49 (0)521 / 106 - 2962
E-Mail: {ahilsend, sbrandau, jtolksdo, cfroehli}@techfak.uni-bielefeld.de

Abstract: To make interaction with Virtual Realities easier for users without any experience and more efficient for trained users, intuitive input devices are needed. To increase immersion, the input device should orientate on its purpose. Because we walk on our feet, controlling walking in Virtual Reality could feel more natural when done with the feet than with other modes of input.
Since most input devices are controlled by hand, a bottleneck situation occurs when the need to navigate meets the need to interact in Virtual Environments. In our work, we document the steps taken in our student project to develop a solution for navigation in a Virtual Environment based on Nintendo's Wii Balance Board. A solution, which is as we hope, a small step forward in creating rich virtual worlds to be used by everyone.

Keywords: Virtual Reality, Input Devices, Wii Balance Board

1 Introduction

Navigation in a Virtual Reality should be intuitive and not interfering with other interactions. But many navigation tools, like data gloves or WiiMote controllers, require at least one hand. This means the user is only able to interact single-handed with the environment while navigating through Virtual Reality. To solve this issue, we decided to use the Wii Balance Board as an input device for navigation because the board opens a low-cost and accessible way to gain input via a channel not used before.
In addition, the board's output values may be interpreted in several ways, meaning different navigation metaphors may easily be applied to it. Therefore we realized some of those metaphors and tested them in a comparative user study to determine the best and most intuitive locomotion technique for our environment on the Wii Balance Board.

2 Related Work

While our goal was to implement a solution to one problem - that of navigating through a relative small world with egocentric viewpoints at speeds close to or slightly above walking speed, de Haan et al. [dHGP08] used the Wii Balance Board to implement the control of different views on virtual realities and focused on a broad approach. They realized different interaction metaphors like *3D Rotational Control*, used in exocentric Virtual Reality applications as a rotational device, *Navigation Control*, for Virtual Reality navigation purposes, and *Abstract Control*, in which the different axis of the Board use concrete on/off values to switch the state of the application. Their solution for *3D Rotational Control* features rotations around all three axes by specialized foot-gestures: rotating around the X-axis by leaning forward/backward, around the Y-Axis by leaning left/right and around the Z-axis by standing on the right toes and the left heel or opposite for negative rotation.

Schöning et al. [SDKR09] developed a system for controlling a Geographic Information System (GIS) by using foot- and multitouch hand-gestures and made a clever use of the advantages of foot-control: Panning a map over larger distances for example is easier with foot-control since doing this by hand implies the necessity of a wiping gesture. They found, that using both modalities in general improves the user's experience and makes accomplishing tasks faster. One possible explanation for the increased speed is that it is possible to carry out more than one operation at one time when multitouch gestures and foot-control are used in simultaneously.

There is a variety of other foot input devices for navigation in Virtual Realities. For instance Lichtenstein et al. [LBWP07] developed a feedback-controlled treadmill, which is a common treadmill with a modification to allow a computer and not just the user, to control the treadmill speed. The user was tracked on the treadmill and on reaching a too long distance from the center the current treadmill speed was adapted by the software to move him back. This way the user was kept the whole time in the middle but also letting him easily adjust the intended speed. A study showed that walking on the treadmill with the feedback-control required less exertion than the self-propelled version.

The downside of treadmills is that the user is restricted to being able to walk into one direction only. Therefore Iwata et al. [IYFN04] developed the *CirculaFloor* which consists of several foot pads to gain the possibility of omni-directional walking. The user walks on those pads while they actually move on the floor and after the step, when the pad is behind the user, it moves back to the front awaiting the next step, thus achieving an infinite floor and with an additional up-and-down mechanism also an uneven floor.

Such locomotion interfaces have the disadvantages of being expensive and requiring a great amount of effort. Therefore Beckhaus et al. [BBH05] used and compared two low-cost interfaces for novice users, the *Dance Pad Travel Interface* and the *Chair Based Travel Interface*. The *Dance Pad Travel Interface* has four buttons with directional arrows pointing to the front, back, left and right and two buttons pointing at 45° angles., whereas the *Chair Based Travel Interface* is a seat, which may rotate around 360°. As the informal user study showed

that both interfaces are intuitive and the movement was accomplished easily. Only the *Dance Pad Travel Interface* showed the disadvantage of difficult circular movement, while with the *Chair Based Travel Interface* this task was realized well.
But the chair has still the drawback that the user has to sit on it, whereas we want a navigation interface for a CAVE where the user stands or walks while performing the walk-like navigation, since this correlate with real walking in the world. That is why we chose the Wii Balance Board is a cheap alternative to accomplish navigation in Virtual Reality by a foot input device, which is also easily transportable.

3 Setup

The virtual environment we used was the so-called BioSphere which had been developed as an earlier student project. The BioSphere is a greenhouse on a mars-like surface including plants and a waterfall.
It was developed in a VR-CAVE, which consists of three projection walls, front, left and floor, with each one having one projector for each eye, working with polarized light. The position of the user's head is tracked with passive targets on the filter-glasses and ARTTrack[1] tracking-cameras.

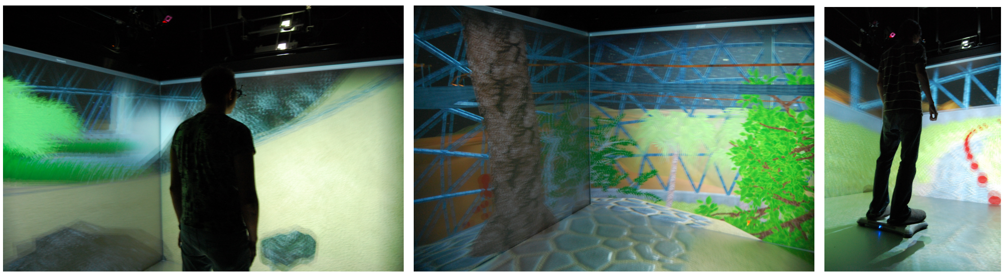

Figure 1: BioSphere in the CAVE.

Originally, the navigation through the BioSphere was accomplished with hand-gestures and was later substituted by a WiiMote controller.
The hand-gestures were recognized by passive markers on the hand tracked by the tracking system. Through pitching the hand forward or backward to move and by rolling to the left or right to steer the navigation was managed. Since imitating walking with such hand-gestures is not very intuitive, it had to be explained to every first-time user.
The navigation with the WiiMote controller on the other hand was simply done by the cursor buttons, its main drawback was that the user had to hold the WiiMote in his hand.

[1]http://www.ar-tracking.de/

4 Using the Wii Balance Board

The Wii Balance Board is a controller for Nintendo's Wii video game console which has one pressure sensor at each corner. The sensor data is transmitted via bluetooth and enables the calculation of the direction the user is leaning to.
To retrieve the data from the Wii Balance Board, we decided to use an extended version of the WiiUse library[2] which supports the Wii Balance Board.
One of the questions that arose was how to use the Wii Balance Board to navigate. Since the Board is a flat surface we decided to develop a two-dimensional navigation. Out of two possible solutions - imitate walking by steps on the Board or steer by leaning to the desired direction - we chose the second one since we did expect better results in accuracy, ease of use, speed of learning and lower cognitive load. Furthermore imitate walking may require some physical effort and thus is not desired for long term usage.

4.1 Interpreting sensor data

For a simple use of the board's data, we chose to convert the four sensor values to a three-dimensional normalized vector, leaning in the same direction as the user: the *user-vector*.
A physical correct calculation of the *user-vector* was not realized since our goal was to deliver values the user wants to communicate with his action, not those he actually acts out.
The main reasons were problems we experienced in earlier development steps:

- it was difficult to stand still in the Virtual Environment: the user had to stand in a close-to-exact position above the center of the board.
- thresholds, as the simplest solution to the first problem, required constant adjustment, and decreased the immersion due to the discontinuous control-mechanism.

The mentioned problems were solved by introducing equations for two angles of the *user-vector* based on all four sensor values:

$$\alpha = \tan\left(\frac{\pi}{4} \cdot \left(\frac{(F_{T,R} + F_{B,R}) - (F_{T,L} + F_{B,L})}{\Sigma F}\right)^3\right), \quad (1)$$

$$\beta = \tan\left(\frac{\pi}{4} \cdot \left(\frac{(F_{B,R} + F_{B,L}) - (F_{T,R} + F_{T,L})}{\Sigma F}\right)^3\right), \quad (2)$$

Where $F_{T,L}, F_{B,L}, F_{T,R}, F_{B,R}$[3] represent the values, the Board delivers for each corner, α represents the rotation around the Z-axis, β the rotation around the X-axis and $\alpha = 0$, $\beta = 0$ yields the vector $(0, 1, 0)^T$ (see figure 2). α is being calculated by dividing the difference of the right sensors compared to the left ones by the sum of all sensors. This results in an value between $[-1, 1]$ and is multiplied with $\frac{\pi}{4}$ to gain only values between $[-1, 1]$ from the tangens function, β is calculated equally with the front and back compared.

[2] $http://www.wiiuse.net$
[3] T: top, B: bottom, L: left, R: right

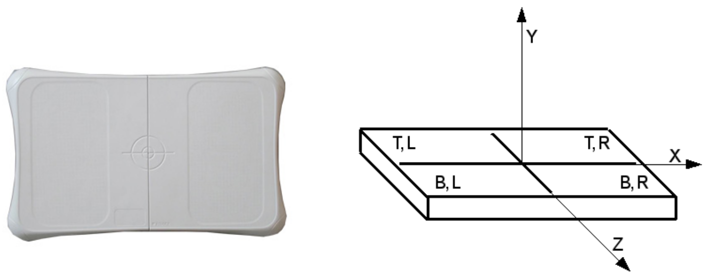

Figure 2: Sketch of the board's local coordinate system.

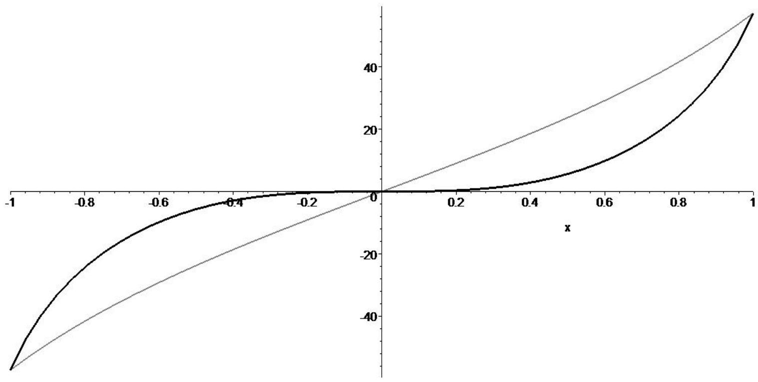

Figure 3: Comparison of different tangens functions (thick line: $tan(x^3)$, thin line: $tan(x)$).

This approach simplifies generating a *user-vector* that leads to a stop, because the chosen exponent pulls vectors close to $(0,1,0)^T$ towards the Y-axis (see figure 3). The exponent has to be an uneven number, because every even exponent would drop the sign of the angle. However, this way is still not sufficient - the shallow slope of the function makes it difficult to reach top speed and forces the user to put too much effort into moving forward.
The third attempt was using two concatenated sigmoid functions (see equation 3, figure 4).

$$\sigma(x) = \begin{cases} \frac{1}{1+e^{-c(t-d)}} - \frac{1}{1+e^{c\cdot d)}}, & \text{if } x \geq 0, \\ -\frac{1}{1+e^{-c(-t-d)}} + \frac{1}{1+e^{c\cdot d}}, & \text{else} \end{cases} \tag{3}$$

(with $x = \frac{((F_{T,R}+F_{B,R})-(F_{T,L}+F_{B,L}))}{\Sigma F}$ for α and $x = \frac{((F_{B,R}+F_{B,L})-(F_{T,R}+F_{T,L}))}{\Sigma F}$ for β.)
This way it was easily possible to use different parameters for steering (α) and accelerating (β).

5 Navigation with the user-vector

The calculated *user-vector* can be used in different ways to move within a Virtual Reality. For example by moving the viewport around an object or scenario, or by moving through the Virtual Environment, as if walking. As we intended to walk around in the BioSphere, the goal was to steer as simple and intuitive as possible.

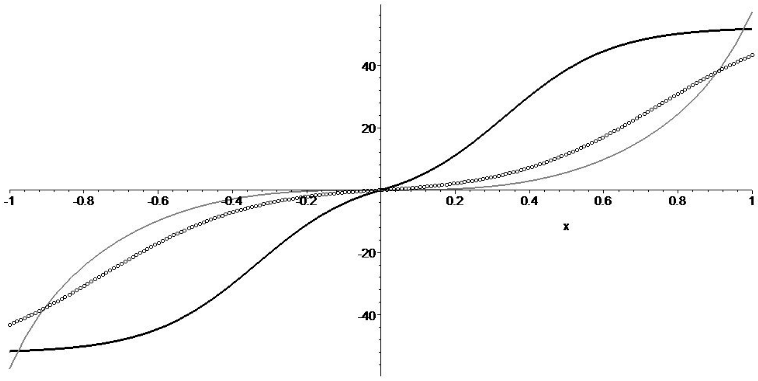

Figure 4: Comparison of tangens and sigmoid functions (thin line: $tan(x^3)$, thick line (α) : $\sigma(x)$ with $c = 7$ and $d = \frac{1}{3}$, circled line (β.): $\sigma(x)$ with $c = 5$ and $d = \frac{3}{4}$).

We thought of different interpretations of the *user-vector* to navigate in Virtual Reality. The first one was to rotate around the y-axis by leaning to the left or right of the board, accelerate by leaning forward, brake by leaning backward and keep the velocity while standing still. This had the benefit that the users did not always have to lean forward to move.

Another approach we thought of was to replace the *acceleration mode* with *direct control of the speed*, since the users might expect to control the speed and not the acceleration by leaning forward or backward. Therefore, leaning forward sets the speed proportional to the effort, leaning backward sets the speed to negative values, and standing still on the board translates to standing still in the Virtual Environment. This way of navigation would be less convenient when moving a long time forward, but easier to use in relative small environments, where inspecting non-moving points of interest is the first goal before travelling around.

Another alteration might affect the steering: the angular velocity must not just depend on how much the user leans to the side but also on the current speed. This way it could even be possible to take a sharp turn at a higher speed.

6 Explorative pre-study

To decide which interpretation of the *user-vector* would be best suited for the BioSphere, we decided to evaluate the two navigation modes *direct control of the speed* and the *acceleration mode*. In the first one, the user controls the speed and in the second one, he controls the acceleration by leaning forward or backward. Both accomplish rotation by leaning to the sides whereas the angle of steering also depends on the current speed.

In the early August we had thirteen test subjects, eight of them male and five female, at the average age of 22 years who were mostly students and never used the Wii Balance Board before. Each of them got five minutes of testing with each mode to get used to the environment and both modes. Afterwards, they had to follow a path of red spheres as a concrete and uniform task including steering and speed change in turns. This task was also done once for each of the two modes.

To assure equal terms for both navigation modes, one half of the test subjects started with the *acceleration mode* and the other with *direct control of the speed.* Afterwards they filled out a short questionnaire with six questions, rating from *"I do not agree at all"* to *"I fully agree"* in seven steps, to indicate which mode was the preferred one and how the handling appealed to them.

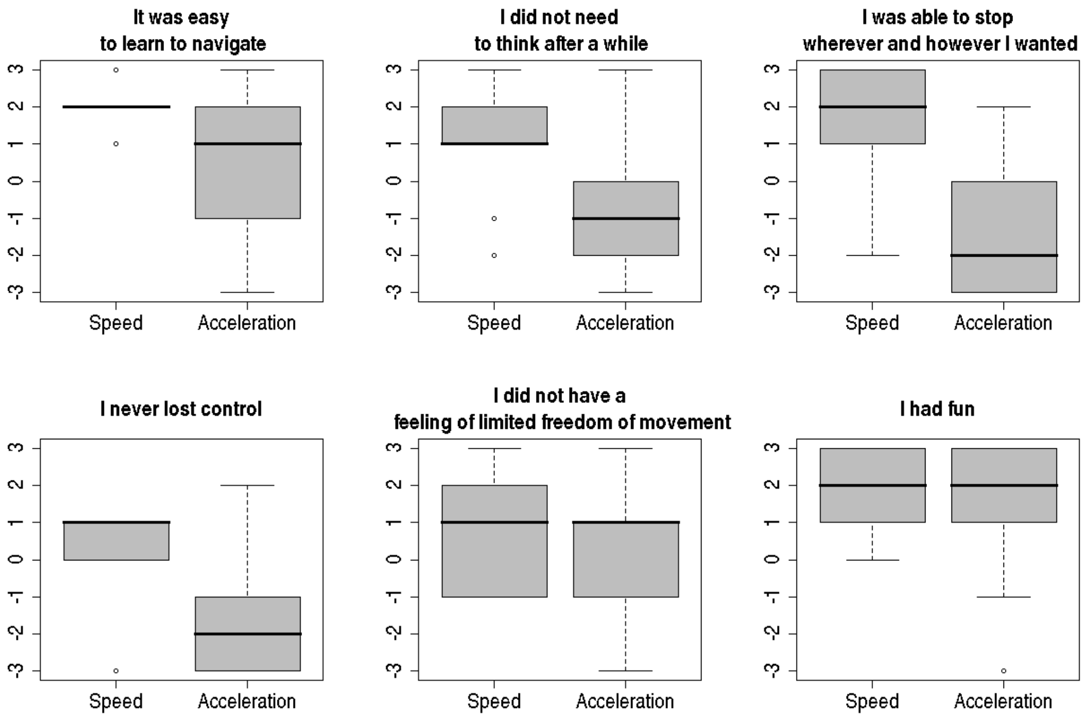

Figure 5: Results of the questionnaire.

Surprisingly, even though the questionnaire obviously showed that most users have had less problems in steering with the *direct control of the speed*, about the half of the test subjects still preferred the *acceleration mode* (see figure 5). They accepted the drawback of needing more time to learn the steering to avoid the tedious forward leaning to move. This shows that there might not be an optimal solution and therefore it is appropriate to offer the user different ways of navigation and let him choose his own.

7 Conclusions

In this work we demonstrated the Wii Balance Board as a low-cost and simple input device for Virtual Realities. It provides the advantage of having both hands free and therefore being able to fully interact with the Virtual Environment while navigating.
We described how we interpreted the sensor data to gain an universal adaptable vector and how we solved problems we encountered. Using the *user-vector*, we explained the advantages

and drawbacks of two navigation metaphors and also compared them in a user study whereas the test subjects did not have a clear favorite. This indicates that even for the same task each user has different expectations of the navigation handling and thus providing the user with the option to choose between different modes, which is easily done with the Wii Balance Board, would cover the requirements of more people.

8 Future Work

To demonstrate the use of the Wii Balance Board in Virtual Reality as a navigation tool we are currently developing a simulation. This simulation is based on a Tron [4] scene in which two bikes, so-called light cycles, drive on a plane grid creating walls behind them (see figure 6) with the purpose of getting the other driver to crash into the wall.

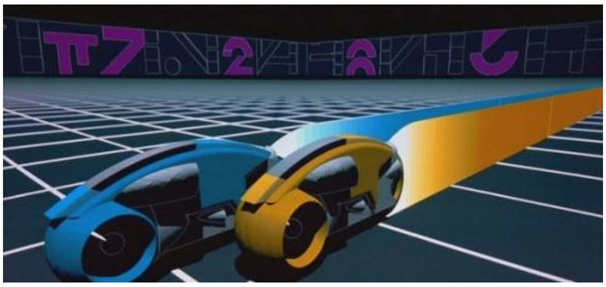

Figure 6: Tron movie scene

To benefit from the three dimensional Virtual Reality inside the CAVE our simulation will take place in a sphere instead of a plane (see figure 7).

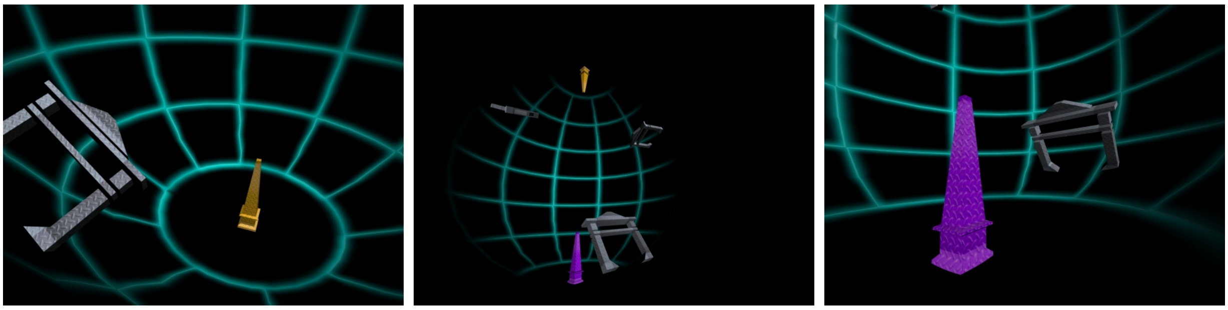

Figure 7: Screenshots of the coming Tron-like simulation

As - amongst others - Riecke et al. [RFR08] and [RVSP09] showed, sounds and vibrations could aid the self-motion-illusion, if well chosen. A solution to create such from movement would be the main goal, as well as comparing different strategies to each other. Finding a final movement-metaphor and generating sounds and vibrations could give users valuable information about their current state in the Virtual Environment.

[4] A science fiction movie from 1982

Additional empirical studies, concerning some constants, thresholds and behaviors of our system, could improve the navigation. For example to decide how fast the view should rotate and specify the most pleasant maximum speed.
To compare the Wii Balance Board navigation with other input devices, like the WiiMote or hand gestures, an evaluation could be realized by relying on Accot et al. [AZ99] and Zhai et al. [ZAW04] and their *Steering Law*, on the basis of Fitts' law, to determine the most suitable input device.

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