ISOMETRIC VERSUS ELASTIC SURFBOARD INTERFACES FOR LOCOMOTION IN VIRTUAL REALITY

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ABSTRACT

Inspired by the "Silver Surfer" cartoons and movies, we designed and developed a surfboard travel interface, which works in either tilt or balance mode. The system supports the comparison of isometric and elastic devices for rate-controlled and position-controlled travel in virtual environments. In this paper, we demonstrate the interface as well as the setup of a complete virtual reality system aimed to evaluate its usability in a future study. We also discuss the device-directed feature of this interface and some potential cognitive overload and confusion incurred by user as were observed in a public demonstration.

KEY WORDS

3D user interface, travel, tilt board, balance board, device-directed virtual surfing.

1. Introduction

Travel in virtual environments (VE) has been a difficult problem since the beginnings of virtual reality (VR), basically due to the difficulty of designing an intuitive, effective, and precise interface which can map the user's finite movements in the real world to a potentially infinite virtual world while maintaining as much presence as possible. Because of the intuitiveness of walking, most research in this area focuses on designing interfaces that allow users to "really" walk in VEs. Some of these interfaces are implemented by tracking the user's body location and orientation when they are walking in place or within a very small real space using body-worn sensors, while others rely on specially designed treadmills.

In this paper, we concentrate on 3D travel in which the user's avatar is no longer restricted to underlying terrains, but is allowed to fly in any direction. Based on real world skateboarding, snowboard, and surfing, VR researchers and arcade game platform designers have implemented various board interfaces which enable users to surf a virtual environment intuitively and effectively, such as the PEMRAM motion base [2] and the Hawaii Surf Simulator. Because it is hard for people to yaw (rotate about the "up" vector) a board when standing on it, most board interfaces only support two degrees of freedom (DOF), namely pitch and roll. And they limit the virtual movement to be on a surface (e.g., the ground) due to the 3-DOF requirement of complete 3D travel. This is sometimes not a sufficient solution because for many VR applications, such as virtual cultural heritage modeling, virtual data visualization, and virtual tourism, being able to move in three dimensions is indispensable. Not willing to occupy the user's hands as they were designed to fulfill wayfinding tasks, Valkov [8] programmed a special foot gesture tracked by the Wii Fit balance board to extend his virtual Segway® Patroller to 3-DOF. It allows the user to travel in 3D completely by using her lower body alone, but is not very intuitive or effective, and is prone to undesired inputs. In the system we propose, we choose to add the third DOF (speed control) to the user's arm, which is independent with the lower body movements, and is more intuitive based on the "Silver Surfer" cartoons and movies.

Zhai [11] [13] reported two user studies designed to compare a hand-held elastic device and a hand-held isometric device for 6-DOF manipulations by rate control. Results showed that the former has some superiority over the latter, but that this advantage vanishes after 20 minutes of practice. Yet little research has been done to investigate the same comparison for lower body interfaces, or to fulfill travel tasks. With a tilt board being the elastic device and a balance board being the isometric device, we are able to compare them for 3D space travel tasks, and we can also compare the yaw control under each condition by either rate mapping or position mapping. The purpose of this paper is to introduce the design and implementation of our "Silver Surfer" system designed to facilitate future study, as shown in Figure 1.

Figure 1. The "Silver Surfer" system

2. Related Work

2.1 Travel Interfaces

Many input devices have been proposed and evaluated as travel interfaces. Classic game controllers such as mice, keyboards, joysticks, and game pads were the first to be evaluated. Although the results show low presence and intuitiveness, some of them are fairly effective for certain travel metaphors. To make virtual travel more intuitive, several researchers tried to bring real walking into the limited lab space by developing different types of platforms or mounting orientation and acceleration sensors on the user's body.

Inspired by the prevalence of treadmills in fitness training, some research designed omni-directional treadmills and numerous prototypes were proposed. Among these the Torus Treadmill developed by Iwata [4] proved to be feasible, although it suffered from loud mechanical noise and slow rotations. Several updated versions were developed by other researchers featuring larger surfaces, which significantly reduced the safety threat for the users walking on them.

Templeman [6] designed and implemented the Gaiter system for walking-in-place (WIP) travel. Multiple tilt and pressure sensors were mounted on special locations on the user's body to track gestures of in-place turning, stepping, and strafing. The system included a torso-mounted framework dropping from the ceiling to hold the user in a small area. Backward walking was implemented by an additional gesture because natural forward and backward walking in place are difficult to differentiate using sensor data.

The HiBall tracker developed by 3rdTech based on an earlier project at the University of North Carolina at Chapel Hill allows a relatively large range for position and orientation tracking. Based on it, a real walking interface was proposed, in which the user wears a HiBall tracker and naturally walks in a larger lab space to travel in a VE. The researchers compared this technique with WIP and joystick flying and reported significantly higher intuitiveness, efficiency, and precision for the real walking technique [7]. To take this further and realize infinite virtual world travel, Razzaque [5] invented a new redirected walking technique. The basic principle it relies on is an observation that humans can hardly walk in a straight line without vision from the real world, although they always believe they do. And most people won't notice small rotations of the whole world she is immersed in. Based on these they imperceptibly rotate the virtual world little by little when the user is walking and by larger amounts when the user's head is rotating, and are able to redirect the user to walk within a limited lab space.

2.2 Board Surfing

Since the release of the inexpensive Nintendo® Wii Fit Balance Board (BB), there has been a trend in the VR community to use it as a travel interface. The BB input device is a sturdy plastic panel that rests on four feet, each containing a pressure sensor that streams pressure values to the computer via Bluetooth ™ [3]. The four pressure values can be synthesized to obtain the gravity center of the user, which consists of X and Y components, as shown in Figure 2. Most of the research based on the BB focuses on using it as a walking interface, by asking the user to face forward on the board and using the gravity center value along the Y-axis to move forward and backward, and that along the X-axis to turn left and right in the virtual environment. The most recent implementation is Valkov's virtual Segway® Patroller [8]. To extend the interface to navigate in 3-DOF, he programmed the interface to identify special foot gesture when the user leans one foot on its toe and the other on its heel. Depending on how much they differ from each other, the avatar's position changes along the Z-axis at different rates. Though feasible, this approach is not so intuitive and effective, and is prone to undesired inputs, because the same foot gesture may be made when the user tries to maintain her balance on the board. In this paper we also use the BB, but because of the 3D surfing metaphor have implemented, we map the data from the X and Y axis to pitch and yaw of a virtual board.

Figure 2. Wii Fit Balance Board coordinate system

2.3 Isometric, Isotonic and Elastic Devices

The terms isometric and isotonic came from exercise physiology. An isometric contraction happens when there is a tension on the muscle but no movement is made causing the length of the muscle to remain the same. On the other hand, in an isotonic contraction, tension remains unchanged and the muscle's length changes. In the context of human computer interaction, according to Zhai [10], an isometric device is a device that senses force but does not perceptibly move, such as the BB, while an isotonic device has zero or negligible resistance, but senses its own movement, such as the mice that are used with most of today's computer systems. Between the isometric and the isotonic, elastic devices refer to those whose resistive forces increase with displacement. For example, most re-centering joysticks are designed to be elastic.

In 1993, Shumin Zhai reported a series of user studies designed to investigate isometric, isotonic, and elastic devices for 6-DOF manipulation by either rate control or position control. In [12], subjects were asked to move a tetrahedron appearing away from the center of the screen as quickly as possible to align it with a target tetrahedron in the center, using a hand-held device that was either isometric or isotonic, under either the condition of position controlled or rate controlled mapping. Results showed that by using isometric rate control and isotonic position control subjects took less time to complete the tasks than using other combinations. Two follow-on studies in [11] and [13] used the same experiment system to compare a hand-held elastic device with an isometric one for manipulating and tracking the tetrahedrons by rate control, and showed that the former has some superiority over the latter. However, all advantages vanished after 20 minutes of practice. In our work, based on the virtual surfing metaphor, we aim to compare the usability of an isometric BB and an elastic tilt board by either rate control or position control as a travel interface.

3. System Design

In this section we will first introduce the methodology that guides the design and development of our system. Specifically, we will give a detailed description of how we map the sensor data to control the travel direction and how we define rate control versus position control in a 3D space flying scenario. Then we will describe our hardware and software implementation.

3.1 Methodology

General 3D space navigation consists of 6-DOF in two categories: pitch, roll, and yaw for orientation control and translations along the X, Y, and Z axes for location control. The fictional “Silver Surfer” can pitch, roll, and yaw his surfboard and use his “super charge” ability to speed up and move forward, giving him control of 4-DOF locomotion by which he can travel to any location in the 3D world. Because in essence three DOF are sufficient to completely travel in 3D, and according to Vidal & Amorim [9], roll (rotation around the forward direction) is against the human natural balance system and may lead to severe sickness and loss of orientation, we disable roll of the virtual board in our design. The left half of Figure 3 illustrates the three DOF we plan to implement.

3.1.1 Speed Control

The first DOF, the control of the travel speed along the forward direction, is implemented by mounting an accelerometer on one of the user’s arms. To eliminate the possible confusion of “moving forward while pointing backwards,” we mount the accelerometer on the user’s forward arm, as indicated in Figure 3. In other words, for a normal surfer (left foot forward) we mount the sensor on her left arm and for a goofy surfer (right foot forward) we mount the sensor on her right arm. The accelerometer senses the tilt of the arm as it is lifted or lowered and feeds data to the system in real time to control the travel speed intuitively. However, when the user leans her body to control her moving directions, she may unintentionally tilt the arm at the same time, which will be detected by the arm sensor to update the speed. To deal with this side effect, we always consult the board sensors to see if the user is leaning or not when we process the arm sensor, and use that to compensate the surfing speed if necessary.

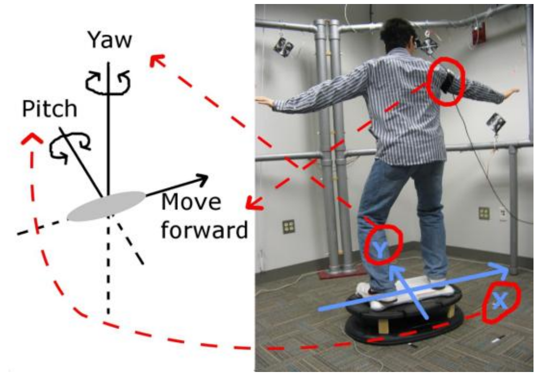

Figure 3. Implementation of 3-DOF travel

3.1.2 Direction Control

The control of the other 2-DOF, namely, the pitch and yaw of the virtual board, is supported by the board interface. The right half of Figure 3 shows an immersed user standing on the board interface. The user stands sidewise on the board, and balances her weight to surf the virtual environment. For a tilt board, we use its pitch and roll angles which are sensed by an accelerometer attached to its surface, and for a balance board, we use the user’s gravity center along the X and Y axes. Because they are both 2-DOF data within specific ranges, we use the same procedure to process them. However, the maximum value and the minimum value are different among users, based on their weight, height, and balance ability. Therefore a calibration procedure is needed for each user. In our system, we ask the user to lean as much as she can in each direction (forward, backward, left, right) and use the data collected to specify the range. When the user is surfing, we get the current data from the board, divide it by the range and clamp the result to [-1.0, 1.0].

Based on Zhai’s research [10], we apply the concept of rate control and position control to the yaw of the virtual board. In rate control, the data from the real board (clamped to [-1.0, 1.0]) are used to control how fast the virtual board yaws, namely, the rate of the yaw. While in position control, it is mapped directly to where exactly the virtual board yaws to, namely, the position of the yaw. Figure 4 illustrates the data processing in these two conditions. The range values used to divide the raw data from the board are obtained from the calibration procedure. The pitch mapping is always by position control because in a rate controlled pitch scenario, the user would pitch the board continuously and reach a pitch value larger than 90 degrees or smaller than -90 degrees. In both cases, her avatar and viewpoint would be upside down while she is still standing normally. According to Vidal & Amorim [9], this can greatly confuse the user.

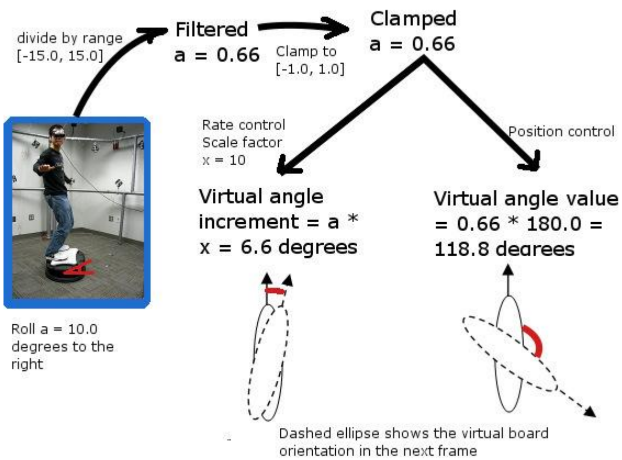

Figure 4. Board data processing

3.1.3 Device-directed Interface

Bowman, Koller, & Hodges [1] categorized travel interfaces into gaze-directed interfaces (moving in the direction the user is looking), pointing-directed interfaces (moving in the direction the user is pointing) and torso-directed interfaces (moving in the direction the user's torso is facing). Our space surfing metaphor belongs to a fourth category, namely device-directed interfaces, because the virtual board, whether pitched or yawed or kept still by the real board, always moves in the direction the front the virtual board is facing, like a vehicle, which is also the front side of the real board from the immersed user's perspective.

Because the virtual locomotion is device-directed, when the user's head is tracked, it is possible for her to travel in one direction while looking in another. However, the user's viewport direction should not be independent of the board interface, because in the virtual world, the user's body is attached to the virtual board and pitching or yawing the latter should naturally influence the former as well. Nonetheless, it is not a good idea to allow position controlled board rotation to affect the viewport, because frequently and drastically changing the camera view may severely confuse the completely immersed user. In our system, the viewport is only dependent on the board when it yaws by rate control.

3.2 Implementation

In this section we describe the implementation of the system, specifically, the hardware and the software.

3.2.1 Hardware

We use two B-Pack Compact Wireless Accelerometers (Model WAA-001) produced by Wireless Technology Inc. The accelerometer is Bluetooth™ enabled and streams 3-axis acceleration data at a maximum frequency of 50Hz to the computer. These data can be synthesized to get the pitch and roll value of the sensor. We mount one of them underneath our elastic tilt board, a Reebok® Core Board, to measure the tilt angle of its top surface. The Reebok® Core Board is a fitness board which tilts in four directions. The rubber springs in it resist tilt to keep the top surface parallel to the ground, which is exactly what we expect to have for an elastic tilt board interface. The other B-Pack is mounted by a neoprene wrap on the triceps of the user to control speed, similar to what people do to balance when surfing. As mentioned before, we use the Wii Fit as the isometric balance board interface.

Because the height and surface size of the two boards are very different, we combined the two into a single board interface which works in either tilt mode or balance mode to ensure an unbiased comparison. Figure 5 illustrates our solution. We fixed the balance board on top of the tilt board using industrial-strength Velcro® hook and loop fastener, and put a piece of wood on each of the corners below the tilt board to remove tilt. When we want the combined board interface to work in tilt mode, we take off the wood pieces so that leaning on the balance board will tilt the tilt board, and we use the B-Pack sensor data below the latter to control the virtual board. On the other hand, when we want it to work in balance mode, we put in the wood pieces so that the surface the balance board rests on is supported and fixed, and we use the data from the pressure sensors to control the virtual board. In this way, we can focus our comparison exclusively to be between the tilt and the balance features of the board interface.

Figure 5. Combined board interface

For the system's output, we use an eMagin z800 HMD to give the user visual and audio feedback. It consists of two OLED screens with a resolution of 800x600, and a gyroscope sensor which tracks the orientation of the user's head. We provide monoscopic vision by rendering the two screens with the same picture. In addition, we use our TactaCage system to simulate wind. This system was designed for an immersed user to stand in the middle, and have her body tracked, as well as allow fans mounted around the perimeter to provide wind feedback under computer control, as shown in Figure 6. Seven muffin fans mounted in front of the user are used in the current system. The speeds of the fans are directly mapped to the speed of movement, which is controlled by the arm-mounted accelerometer.

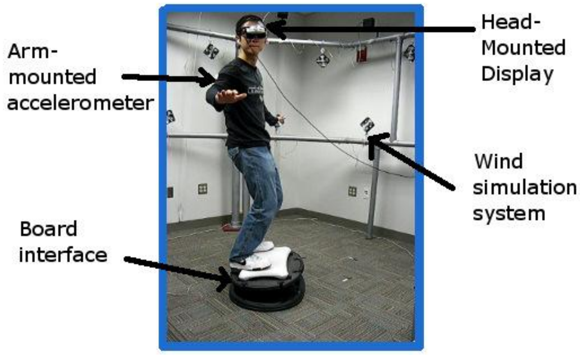

Figure 6. System input and output

3.2.2 Software

Figure 7 shows the virtual environment we developed by the Unity3D game engine. It consists of nine terrain tiles that repeat in eight geographical directions based on the current location of the "Silver Surfer" avatar, forming an infinite virtual world. The avatar stands on a silver board whose direction is controlled by the board interface, either in tilt mode or balance mode. The goal is to find and collect targets floating in the sky by flying through them. To increase immersion, clouds and trees were added to the virtual environment, both of which the avatar can fly through naturally without collision.

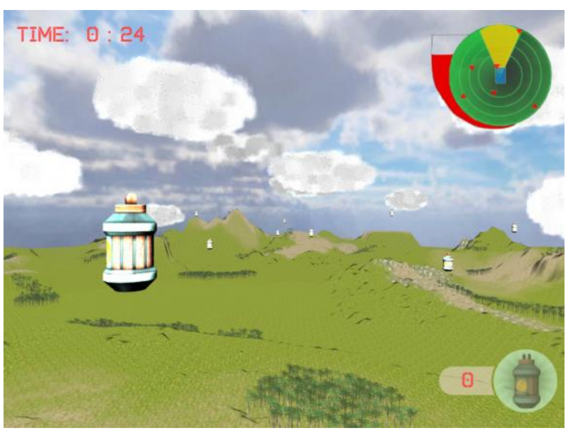

Figure 7. The virtual environment

In the snapshot, the timer in the left top corner shows how long the user has been immersed in the system, and the number next to the canister icon in the right bottom corner shows how many targets the user has collected. To decrease the demands of wayfinding and focus the comparison mainly on travel, we overlay a north-up radar in the top right corner of the user's view, which is zoomed in and shown in Figure 8.

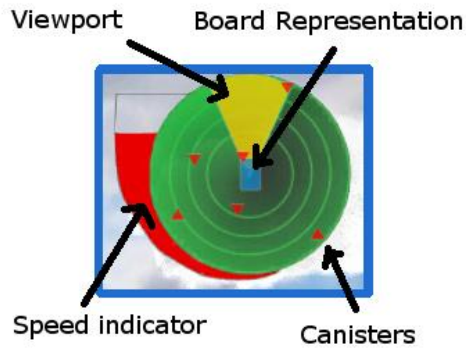

Figure 8. The radar

The red triangles indicate the targets' locations relative to the virtual board, with the point of a triangle used to indicate height (above/below the board). The virtual board is represented as a blue rectangle in the middle, and always faces north on the radar. The yellow sector corresponds to the user's viewport. As mentioned before, it updates based on the data from both the board interface and the HMD gyroscope, because yawing the virtual board also yaws the body of the avatar, which in turn yaws the viewport. The red bar to the left of the radar indicates the current speed, based on the data from the arm-mounted accelerometer.

4. Public Demonstration

In a public demonstration, over 50 people tried the interface. Participants were free to choose between the balance board and the tilt board (not combined at that time), and some of them experienced both. Given the limited amount of time, more people chose to experience the tilt board, mostly because they have tried Wii Fit before in their research projects or video games.

The overall feedback we received from this demonstration was very positive. Participants enjoyed navigating the virtual world using the board interface, particularly with the tactile feedback from the wind simulation system. Most users commented that the interaction was very natural and intuitive. Of all the feedback we received, most people described the surfboard interface to be "very intuitive and cool," while only a few people considered it to be effective, and none of them thought the interface was precise. Comparing the tilt board and the balance board based on our observation and the participants' comments, we discovered that the balance board was easier to use, more effective and precise while the tilt board was more enjoyable and intuitive, and lead to a higher possibility of after effects, such as the loss of balance. We cannot assure this as a result of the isometric and isotonic feature of the board interfaces because the data processing of the tilt board sensor was defective at the time of the demonstration. We are currently further investigating this in a formal user study.

During the demonstration, we observed much confusion about what direction users thought they were moving when first using the system, especially for people who were used to pointing-directed or gaze-directed interfaces, such as First Person Shooter (FPS) game players and VR researchers. In other words, they were confused at the beginning by the device-directed feature of this travel interface. One reason is that as mentioned before, we also track the user's head movement for their viewpoint direction which is partly dependent on the board. Another reason is that some users keep their tracked arms high to maintain a good surfing speed, but they get confused when they expect the avatar to move towards where their arm is pointing. In addition, we also observed several users turning around in the relatively big surface of the tilt board, which adds another possible misperception of the board as a torso-directed interface. However, people with surfing experiences reported much less confusion during the demonstration. Because of this, we are particularly interested in studying subjects with or without surfing experience, and those who have or have not been adapted to other interface metaphors to discover the learning curve of this system and the underlying causes of confusion.

5. Conclusions and Future Work

In this paper, we introduced the "Silver Surfer" 3D space surfing metaphor and a system we developed based on it. We explained our methodology, specifically isometric versus elastic board interface, and rate-controlled yaw versus position-controlled yaw. The system implementation was demonstrated in detail regarding the hardware design and the virtual environment development. And feedbacks from a public demonstration of this system were discussed.

Regarding future work, we plan to run a pilot study first to identify the ideal values of some mapping parameters, for example, the scaling factor from real board pitch and roll to virtual board pitch and yaw. When this is done, a formal user study will be conducted to compare tilt and balance modes of the board interface, for position controlled and rate controlled yaw.

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