A Multi-Touch enabled Human-Transporter Metaphor for Virtual 3D Traveling

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ABSTRACT

In this tech-note we demonstrate how multi-touch hand gestures in combination with foot gestures can be used to perform navigation tasks in interactive 3D environments. Geographic Information Systems (GIS) are well suited as a complex testbed for evaluation of user interfaces based on multi-modal input. Recent developments in the area of interactive surfaces enable the construction of low-cost multi-touch displays and relatively inexpensive sensor technology to detect foot gestures, which allows to explore these input modalities for virtual reality environments. In this tech-note, we describe an intuitive 3D user interface metaphor and corresponding hardware, which combine multi-touch hand and foot gestures for interaction with spatial data.

Keywords: 3D user interface, 3D navigation, multi-touch interaction

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities; H.5.2 [Information Interfaces and Presentation]: Interfaces—Evaluation/Methodology, Input Devices and Strategies, Interaction Styles;

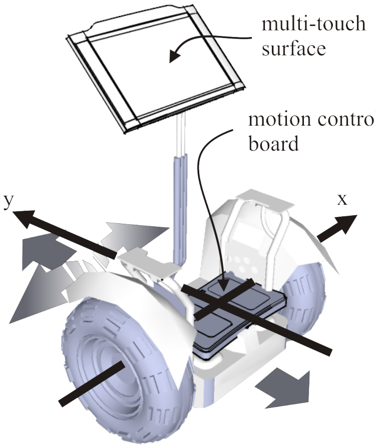

Figure 1: Illustration sketch of the multi-touch enabled human-transporter metaphor. The user can intuitively travel by shifting her weight. The multi-touch enabled transparent surface can be used for additional interaction.

1 INTRODUCTION

Navigation is often referred to as the combination of wayfinding and travel respectively locomotion [3]. Wayfinding denotes the cognitive aspects of navigation in which users have to build a cognitive, mental representation of the environment. Wayfinding is used to determine how to get from one location to another, but does not involve the actual movement, whereas locomotion and travel refer to the physical aspects of navigation. Navigation is one of the most basic and common interaction tasks in virtual environments (VEs). Many applications require intuitive metaphors and techniques to explore the data displayed in a certain domain. For example, 3D geospatial data has grown in popularity and has been used widely in many different application domains in recent years. While generating, processing and visualizing these complex data sets has been addressed through many sophisticated algorithms, current navigation and exploration techniques are often not sufficient for such complex environments [1]. In order to explore data from an egocentric point of view, it has been motivated, that walking is the most intuitive and natural locomotion technique [18]. However, real walking introduces problems in setups with limited walking space, such as CAVEs. Locomotor simulators [10], omnidirectional treadmills [14] and "redirected walking" [11, 15] provide certain solutions in this context, but often require a complex setup and can be exhausting during long term use. Similarly, many 3D input devices for immersive VEs are complex and exhausting to use, may divert the user's focus from her primary task [1], or can result in the user losing orientation due to unnatural motion techniques or unintended input actions.

Instead of using solely 3D hand-based input or physical locomotion systems, we propose to use a combination of hand and foot gestures for 3D traveling. Hand gestures allow precise input regarding point and area information. However, it is difficult to input continuous data with one or two hands for a long period of time. Foot interaction, in contrast, can provide continuous input by just shifting the body weight on the respective foot. Since humans primarily use their feet to travel in real life, such a foot gesture has the potential advantage of being more intuitive in the sense that it approximates a highly innate metaphor. Instead of using a 3D input device to specify, for example, direction or speed of travel, we use multi-touch technology, which gives the user tactile feedback during the interaction and allows to rest the arms. Multi-touch interaction has shown great potential for exploring complex content in an easy and natural manner. The geospatial domain provides a rich and interesting testbed for multi-touch applications because the command and control of geographic space (at different scales) as well as selection, modification and annotation of geospatial data are complicated tasks and have a high potential to benefit from novel interaction paradigms [17].

In this tech-note we propose a navigation device based on a Nintendo BalanceBoard and a transparent FTIR-based [7] multi-touch

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surface for navigation in 3D geospatial data from an egocentric perspective, as well as a *Worlds In Miniature (WIM)* [16] approach for wayfinding. As a proof-of-concept we simulate a Human-Transport vehicle with a physically inspired steering technique. In addition, multi-touch input is used to manipulate the WIM.

The remainder of this tech-note is structured as follows. Section 2 gives an overview of related work. Section 3 describes the proposed setup. In Section 3.1 we sketch the hardware setup, in Section 3.2 we present the physical background of the Human Transporter's implementation, and in Section 3.3 we describe a multi-touch based WIM implementation as navigation aid. We conclude in Section 4 with a discussion and an outlook on future work.

2 RELATED WORK

Many different approaches for exploring a virtual environment have been introduced in the last decades [2, 12, 19]. Some of them require the user to locomote through the real world while these movements are mapped to motions of the virtual camera [9, 15], other approaches make use of 2D or 3D input devices [6], which are used to specify motion parameters like direction, speed, start and stop [2, 12].

Several metaphors address the challenge of unlimited and efficient navigation in VEs by preventing a displacement of the user in the real world. In [18] some examples are presented and compared which show the benefits of natural navigation techniques in particular for egocentric navigation tasks. The BalanceBoard introduced by Nintendo in the second half of 2007 is shaped like a household body scale and contains multiple pressure sensors that are used to measure the user's center of balance and weight. Nintendo introduced several metaphors to use this board for traveling in games like a surfboard, magic carpet, or 2D transporter. Since the Nintendo BalanceBoard has been introduced, it has already been applied in some research projects. For instance, De Haan et al. [4] have applied the board to define a 3 DOF input device, which they used to implement 3D rotation or basic navigation techniques. Schöning et al. [13] have examined simultaneous usage of hands and feet to manipulate two-dimensional GIS data sets. By separating the tasks which have to be performed by hands or feet, they were able to achieve an improvement of the user's performance due to the parallel input from multiple channels. Hilsendeger et al. [8] proposed a navigation technique similar to a Human-Transporter. In their research different transfer functions for steering control, as well as differences between speed and acceleration control are evaluated. Their choice of the transfer function and control options is based on empirical consideration and lacks physical background.

Multi-touch technology is in the focus of several research projects, and it has been shown that it provides many benefits over traditional desktop systems, in particular, when it comes to natural 2D interactions. Tactile feedback provided by a multi-touch enabled surface is beneficial, especially in tasks where visual feedback is often occluded by the pointing device or graphical representations [5]. Furthermore, the combination of multi-touch input devices with a physics engine is shown to increase the naturalness for a range of interaction tasks [20]. Another advantage of multi-touch surfaces is that the user does not need to wear any instrumentation in order to interact in an intuitive way. However, until now challenges and limitations of multi-touch interaction in the context of 3D navigation have rarely been considered. One important observation of previous studies with multi-touch GIS is that users initially preferred simple gestures, which are familiar from systems with mouse input using the WIMP desktop metaphor [13]. After experiencing the potential of multi-touch, users tended towards more advanced physical gestures to solve spatial tasks, but often these were single-hand gestures or gestures, in which the non-dominant hand just sets a frame of reference that determines the navigation mode, while the dominant hand specifies the amount of movement [20].

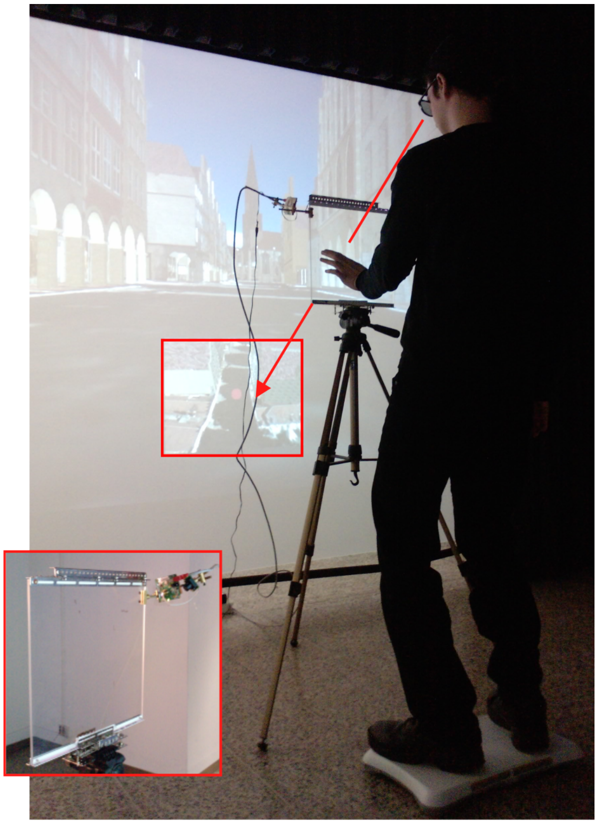

Figure 2: Subject using the multi-touch enabled Human-Transporter metaphor to travel through a virtual 3D city model displayed on a stereoscopic back-projection wall. The setup consists of a transparent FTIR-based multi-touch surface statically mounted on a camera tripod for hand input, and a Nintendo BalanceBoard for foot input.

3 IMPLEMENTATION

In this section we explain how we implemented the multi-touch enabled Human-Transporter metaphor as natural combination of hand and foot gestures for 3D traveling. We use the multi-touch surface for discrete, constrained input gestures and the BalanceBoard for continuous input to navigate.

3.1 Hardware Setup

The hardware setup (shown in Figure 2) consists of a BalanceBoard and a transparent FTIR-based multi-touch surface. The multi-touch surface is an acrylic plate with a set of IR LEDs and a wide-angle (107°) camera mounted on its side. The camera is mounted outside the view frustum defined by the border of the acrylic plate and the user's head. Hence, the camera itself does not occlude objects behind the transparent surface. For finger detection ReacTIVision's[1] TUIO server was used. In order to reduce the fatigue for the user, it is mounted on a common camera tripod.

The BalanceBoard (see Figure 3) features a bluetooth connection and contains multiple pressure sensors that are used to measure the user's center of balance as well as her weight. The center is determined by the intersection between an imaginary line drawn vertically through the center of mass and the surface of the BalanceBoard.

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[1] http://reactivision.sourceforge.net/

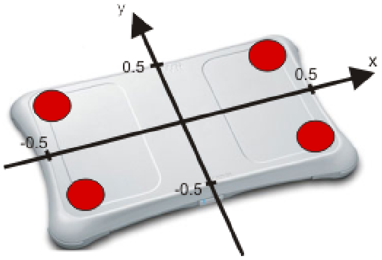

Figure 3: Illustration of the BalanceBoard and its four pressure sensors at its corners

3.2 Simulation of a Human Transporter

As mentioned above, we use the BalanceBoard for navigation in a virtual world. The steering and speed control are inspired by the Human-Transporter vehicle and are based on the simulated setup illustrated in Figure 1. Leaning forward or backward leads to forward/backward motion of the vehicle, while leaning left or right turns it in this direction. In order to implement such a control a 2D projection of the user's center of gravity, i. e., her center of balance *cb*, is used to move a *uniform* mass across the board. This way we minimize the impact of different user weights.

Speed Control

For speed control we use the y-component cb_y of the user's center of balance. Moving the uniform mass along the y-axis of the board produces a rotational moment, which is proportional to the distance between its center of gravity and the vehicle's wheel axis. Since our coordinate system is aligned with the wheel-axis, the rotation moment is given by:

$$M(cb_y) = -cb_y \cdot F = -m \cdot g \cdot cb_y$$

where m is the weight of the uniform mass, $g \approx 9.81 m/s^2$ is Earth's gravitational acceleration and $F = m \cdot g$ denotes the gravity force of the uniform mass. Applying reverse torque $M_R = -M$ to the wheels in order to compensate the declination of the platform results in forward (or backward for negative cb_y) motion, since the wheels are not statically bound to the ground. In order to keep the calculations simple, we define the torque-to-speed function as $\omega = k \cdot M$ with a transmission coefficient k. Thus the speed for the left and the right wheels ω_R, ω_L is equal and given by:

$$\omega_R\left(cb_y\right) = \omega_L\left(cb_y\right) = k\left(cb_y \cdot F\right) = k \cdot m \cdot g \cdot cb_y \tag{1}$$

Steering Control

By leaning left or right the user moves her center of balance along the vehicle's x-axis. This leads to different weight distribution among the two wheels. A weight applied to the board produces pressure on the wheels and thus increases the rotational friction between the wheels and the ground. Changing the weight distribution among the wheels will result in different friction and thus in different rotational speed of the two wheels, i. e., the wheel to which greater weight is applied will rotate slower than the other and a turn in this direction will be the result. For the calculation of the rotational friction force we use the simplified equation:

$$F_{fr} = \pm\, 0.01 \cdot k_{fr} \cdot F$$

where k_{fr} denotes the friction coefficient between the wheels and the ground. Here F denotes the force applied perpendicularly to the two surfaces in contact. In our case this is the gravity force of the weight applied to the wheel. The multiplication constant 0.01 is the empirically observed relation between rotational and sliding friction forces. Since the friction force takes effect against the motion direction and on the edge of the wheels, the rotational moment resulting from it is given by:

$$M_{fr} = -sign(cb_y) \cdot 0.01 \cdot k_{fr} \cdot r \cdot F$$

where r denotes the radius of the wheel. If the vehicle's platform is a unit square, we can calculate the weight exerted on each wheel. With m as the weight of the uniform mass and cb_x as the x-component of the user's center of balance we have:

$$\begin{aligned} m_R\left(cb_x\right) &= \left(0.5 + cb_x\right) \cdot m \\ m_L\left(cb_x\right) &= \left(0.5 - cb_x\right) \cdot m \end{aligned}$$

Where m_R is the weight exerted on the right wheel, and m_L is the weight exerted on the left wheel.
Finally, the rotational speed loss induced by the friction is:

$$\omega_{fr_R}(cb_x) = -sign(cb_y) \cdot 0.01 \cdot k_{fr} \cdot r \cdot m \cdot g \cdot (0.5 + cb_x) \tag{2}$$

$$\omega_{fr_L}(cb_x) = -sign(cb_y) \cdot 0.01 \cdot k_{fr} \cdot r \cdot m \cdot g \cdot (0.5 - cb_x) \tag{3}$$

The combination of (1) and (2) gives the final result for the wheel speed:

$$\begin{aligned} \omega_R\left(cb\right) &= sign\left(cb_y\right) \cdot m \cdot g \cdot \left(k \cdot \left|cb_y\right| \;-\; 0.01 \cdot k_{fr} \cdot r \cdot \left(0.5 + cb_x\right)\right) \\ &\approx sign\left(cb_y\right) \cdot m \cdot g \cdot \left(k \cdot \left|cb_y\right| + 0.01 \cdot k_{fr} \cdot cb_x\right) \end{aligned}$$

Similarly combining (1) and (3) gives:

$$\omega_L\left(cb\right) \approx sign\left(cb_y\right) \cdot m \cdot g \cdot \left(k \cdot \left|cb_y\right| - 0.01 \cdot k_{fr} \cdot cb_x\right)$$

The last equations show that the rotational speed of each wheel is controlled by the y-component of the user's center of gravity while the x-component adds a negative correction to it, i. e., it acts as braking.

3.3 Transparent Multi-touch Surface

As mentioned above, we make use of a multi-touch surface, which consists of an acrylic plate with a set of IR LEDs and a wide-angle (107°) camera mounted on its side. Since we can track both the user's head as well as the multi-touch surface in our setup, the transparency of the surface allows to display objects on a projection screen behind the surface in such a way that they appear either behind, attached to or in front of the multi-touch surface. In order to reduce the fatigue for the user, the surface is mounted on a common camera tripod.

WIM Interface

In order to support the user's orientation in the virtual environment we provide a WIM view, which the user can control using multi-touch gestures. The WIM view is displayed as inset in the viewport that is used to render the egocentric view of the VE, which the user perceives on the projection wall. The position of this viewport is calculated separately for the left and the right eye according to the frustum defined by the user's head and the multi-touch surface in such a way, that the WIM appears attached to the multi-touch surface (illustrated in Figure 2). The WIM view itself is created by rendering the VE from the viewpoint of an additional (slave) camera, placed with an offset relative to the egocentric camera and directed to it. The scale of the WIM and the position of the slave camera can be manipulated using multi-touch gestures, such as pan, pinch, rotation, etc.

Viewpoint Control

Using the interactive surface the user can steer the virtual slave camera and modify the scale of the WIM view via single- and double-touch gestures. These multi-touch gestures affect only the slave camera used to render the WIM, whereas the view on the projection wall is not altered. On the other hand, when using the BalanceBoard to move the egocentric viewpoint through the VE, the focus point for the WIM changes accordingly. This allows users to get additional information about the environment via the WIM, while traveling using the BalanceBoard. Therefore, we map single-finger pan gestures to azimuth and elevation of a virtual trackball control centered around the user's current position as used to render the egocentric view on the projection wall. If two touch points are detected on the surface, we can define a line between them. Changing the position of one or both touch points defines a new line with different length and/or orientation. The difference of the length of these two lines and the angle between them is used for pinch and rotate gestures. The rotate gesture is used to rotate the slave camera around the Human-Transporter's up axis. The pinch gesture is mapped to scalings of the WIM, providing users with the ability to get a detailed view of the current surroundings in an arbitrary direction or a broader overview of the environment. The transmission coefficient of the Human-Transporter, thus its speed sensitivity, is adjusted with the scaling factor of the WIM to provide an adequate motion speed according to the WIM view.

We also implemented long distance travel via the WIM. Therefore, a user has to double-tap on the desired position on the WIM view, which places the main camera used for the projection wall (and thus the Human-Transporter) at the corresponding position in the VE and aligns the WIM accordingly.

4 CONCLUSION AND FUTURE WORK

In this tech-note we introduced a novel navigation metaphor based on a device combination of a Nintendo BalanceBoard and a transparent FTIR-based multi-touch surface. We have presented the hardware setup and the metaphor to six subjects in a typical virtual reality environment. At the beginning of the experiment the subjects were given no instructions about the simulated vehicle or the manipulation of the WIM viewpoint, besides the notion, that they had to use the device in order to navigate through a virtual 3D city model. Afterwards, they were asked for any comments they had about the device.

Overall, the feedback of the subjects was very positive. All six subjects remarked that after a short adaptation they were able to navigate easily through the virtual world, and found the steering very natural. Furthermore, all six subjects were amused during the experiment, and have tried out different options without being required to do so. Nevertheless, all subjects had particular problems to make a turn in place or in short distances. Furthermore, some of the subjects remarked that it was difficult to maintain direction for a long time.

The results of the preliminary usability test motivated us to further develop the proposed metaphor. In the future we want to further improve the setup used to implement the described metaphor. Moreover, we want to incorporate further interaction metaphors, which make use of the multi-touch capability of the transparent surface and further investigate the combination of a WIM metaphor and multi-touch input.

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