ShoeSoleSense: Proof of Concept for a Wearable Foot Interface for Virtual and Real Environments

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Abstract

ShoeSoleSense is a proof of concept, novel body worn interface - an insole that enables location independent hands-free interaction through the feet. Forgoing hand or finger interaction is especially beneficial when the user is engaged in real world tasks. In virtual environments as moving through safety training applications is often conducted via finger input, which is not very suitable. To enable a more intuitive interaction, alternative control concepts utilize gesture control, which is usually tracked by statically installed cameras in CAVE-like-installations. Since tracking coverage is limited, problems may also occur. The introduced prototype provides a novel control concept for virtual reality as well as real life applications. Demonstrated functions include movement control in a virtual reality installation such as moving straight, turning and jumping. Furthermore the prototype provides additional feedback by heating up the feet and vibrating in dedicated areas on the surface of the insole.

CR Categories: H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces — Input devices and strategies, Interaction styles;

Keywords: Wearable, Shoe, Insole, Foot, Mobile, Physical Interface, Hands-Free, Eyes-Free, Tactile Feedback, Virtual Reality

1 Introduction

Interaction concepts almost exclusively make use of hands, fingers and arms. As humans learned to walk upright, former high dexterity organs like feet degenerated. The developed prototype attempts to give the human back the ability to interact once again through their feet. Much like the hand, the foot is still a sensitive organ and should be used as an additional interface to transmit information to computational devices. When in a virtual reality installation such as CAVE-like-installations [Cruz-Neira et al. 1992] (in this paper denoted as CAVEs) or wearing Head Mounted Displays (HMDs) like the "Oculus Rift" navigation and interaction can be described as a problem as it must be done blindly without visual focus on the input device. A general solution to a hands-free interaction in CAVEs, is gesture and posture control (hands, arms, head movement); very common physical interfaces being joypads and wands. Operating such an interface with hands and fingers to navigate in such a virtual environment is not the most ideal solution.

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"ShoeSoleSense" overcomes this problem by implementing several sensors into the insole of a shoe so that walking and jumping, among other movements, can be easily tracked. Turning is also possible by performing a simple foot gesture. By having all sensors attached to the human body the location dependent tracking problem is circumvented so free movements are possible. "ShoeSoleSense" is not affected by common tracking issues as occlusion and signal noise (e.g. in difficult lightning conditions).

This paper aims to contribute to finding a viable alternative input interface for controlling VR applications, which also matches the requirements of functionality in mobile situations, common in the area of Augmented Reality (AR). After giving an overview of the related work, this paper introduces a fully functional prototype called the "ShoeSoleSense," which overcomes the general problem of location dependent tracking as well as controlling interactions in a hands-free manner. Furthermore the paper gives insight into the development of the said prototype. Finally an outlook onto future work and benefits is provided and discussed.

2 Related Work

As prior work shows a beneficial input interface should not attract the full attention of the user's visual focus nor make use of both hands. [Matthies 2013] When wearing devices like HMD that enable AR the user ideally should still be able to complete real world tasks with their hands. To classify the research prototype it is important to look at existing research, which has been divided here into two categories.

2.1 Input Interfaces in VR Environments

Even if most established input devices for VR Environments usually require use of the hands, Beckhaus et al. [2007] believe that hands-free navigation is more beneficial since it can maximize the interactivity in VR environments. Therefore a chair-based computer interface was developed that enables the user to move in VR environments hands-free. As Pakkanen and Raisamo [2004] figured out, feet can be used for non-accurate spatial tasks like navigation. This effect is used by LaViola Jr. et al. [2001] to offload the navigation task to more direct motions of the feet and torso. A World In Miniature (WIM) map is being put under the users feet, to enable the user to reach all areas, with the tap of a foot on the map, in a space limited environment. Additionally users are able to scale this map. The same approach of using WIM was pursued from Valkov et al. [2010]. A multi-touch projection is used in front of the user for a non-interactive WIM and a Wii-Balance-Board on the ground for navigation tasks. Both of these techniques interrupt workflow. Nevertheless for an even greater immersive feeling Usoh et al. [1999] evaluated “real walking” against “walking in place” with the support of simple head tracking, which conveyed the position of the user to the avatar in a virtual world. The obvious limitation is the size of walking space, which restricts the user when being in a CAVE. To overcome this problem Darken et al. [1997] already developed the Omni-Directional Treadmill (ODT) – a ground mounted device that allows the user to walk in each direction without leaving the defined area. To track walking in place by foot gestures, Scott et al. [2010] built a system that recognizes and learns foot gestures with the help of the built-in accelerometer via a commodity mobile device. To gain a reliable foot input, Higuchi and Nojima [2010] proposed a tracking device to be mounted to the shoe sole. This solution is claimed to enable the best capability of performing foot gestures. So Nordhal et al. [2012] developed shoes with integrated vibrotactile haptuators and two pressure sensors. The users wearing a HMD are placed onto a virtual snow ground. Audio feedback of squashed snow and haptic feedback at the feet create a much more immersive impression for this setup.

2.2 Body Worn Input Interfaces Beyond VR

Currently camera tracking is still a frequently used method of control in HCI. One of the most relevant and important publications to appear recently is „ShoeSense“ from Bailly et al. [2012], where a camera afixed to the shoe allows the user to perform a series of arm and finger count gestures to control various features including phone call answering, volume, and music. Comparable prototypes such as “Imaginary Interfaces” from Gustafson et al. [2010] and “SixthSense” from Mistry et al. [2009] use cameras mounted on the chest, body, or head to enable control functions. SixthSense additionally combined the use of a projector for augmenting a virtual screen. These input strategies require hand and arm gestures to be performed in front of the body. While these concepts are feasible in virtual environments, gesture recognitions is less reliable in common day-to-day situations such as non-ideal lighting or while engaged in other movements. When examined in contrast to these concepts “WristCam” from Vardy at el. [1999] enables one-handed control with a wrist-worn camera that recognizes seven different finger gestures. Another one-handed control is demonstrated with “Tickle” from Wolf et al. [2013] who utilize a touchless finger interaction with a finger worn gyroscrope to control a video camera. “FreeDigiter” from Metzger et al. [2004] enables rapid entry of digits using finger gestures, which are detected by an infrared proximity sensor attached to a headset that rests over the ear. Touching a particular part of the ear could also be used to control functions as proposed by “EarPut” from Lissermann et al. [2013]. Touch gestures performed on a sensitive watch wristband is introduced by “WatchIt” from Perrault et al. [2013]. A very different wristband introduced by Saponas et al. [2009] enables control of computational devices with simple finger gestures by measuring muscle activity at the arm. The “InEar BioFeedController” from Matthies [2013] is a headset, which also measures muscle activity, but from the face and head gestures using angle accelerators. Salvador et al. [2002] attached angle acceleration sensors to the foot to create a “Foot Motion Sensing Input Device” for VR. In conclusion these projects are more or less practical prototypes, but in theory most of them are operational in mobile context since no tactile or visual contact is required, thus visual attention can remain on real world tasks.

3 Prototype

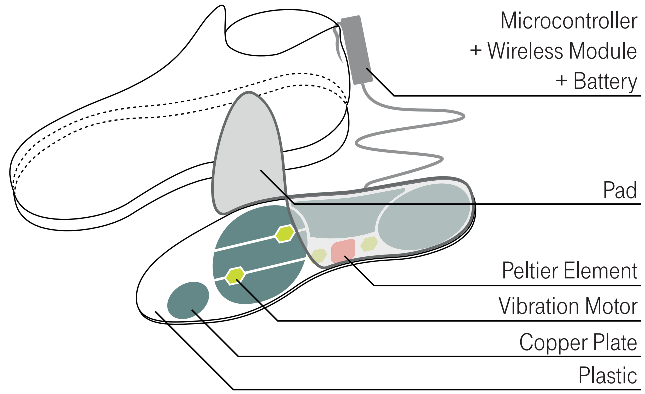

Figure 1: *Conceptual design of the prototype.*

The prototype introduced here is an insole, which can be put into an ordinary shoe. The first example prototype is size 42 (European size) and consists of a laser-cut Plexiglas base. Copper plates are affixed to the surface, which read pressure with capacitive sensing from the foot at specific areas. A layer of foam and an elastic black plastic skin covers the prototype. Inside the Plexiglas base recesses are made where micro vibration motors are located, of the same type used by mobile phones. Also a small power saving Peltier element (TEC1-1703) is attached with modeling clay to the surface of the Plexiglas base. These parts are connected with a short cable to a black box that can be clipped onto the shoe. The black box consists of a micro controller (an Arduino Nano), a wireless module (from a cordless keyboard), a PCB circuit board and a 9V battery to power the prototype - so that the prototype doesn’t need an extra wired power supply from a socket that would limit movement. The prototype communicates wirelessly with the computer like a HID USB keyboard. The vibration motors and the Peltier element are controlled by switching on and off the status LEDs of the former keyboard. Thus the installation of additional software is not required. This guarantees fully compatibility with almost all systems that offer a USB port and the installation of plug’n play keyboards. Additionally a sticky silicon insole is attached underneath the prototype to avoid sliding of the insole at the inside of a shoe. Still the height of the insole is less than 7mm.

Figure 2: *First prototype: each insole works independently.*

3.1 Sensor Placement

To find out which areas of the foot sole are best for measuring pressure; a user study with 18 participants (12 males and 6 females) was conducted. An individual footprint was taken of the right foot from each of the subjects. Obvious findings are that female feet are smaller and narrower at the upper sole. Female footprints were also more flat then the ones from males. Since we had no professional equipment for measuring pressure, the simplest way was to paint the users feet and have them step on white paper. After some graphics processing all footprints were scaled to a uniform size, rotated and compiled together with a transparency of 10%. The peaks are highlighted in shades of red, purple and blue, with blue areas being the highest pressure. There are essentially 4-6 different zones, which create the basis for the layout design of the pressure measurement sections.

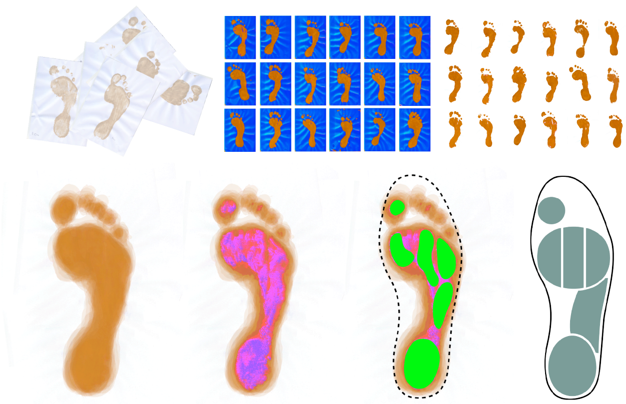

Figure 3. *Creating the layout for the sensor arrangement.*

3.2 Foot Interaction

The prototype enables direct input by performing foot gestures and indirect input by making the computational device aware of one's movement. Additionally, the prototype enables two different kinds of feedback: tactile feedback as vibration under the foot and temperature feedback in order to display ambient states.

3.2.1 Pressure Input

In this design, six different areas are tracked. This first prototype uses capacitive sensing to measuring pressure. There are different ways of accomplishing input with pressure, for example by consciously pressing down the big toe as an input action instead of pushing a button on a handheld input device.

Being in a virtual environment such as a CAVE-like-installation; this prototype enables movement through a scene by simply walking in place. Turning can be managed by shifting pressure to the left or right side of the foot. Jumping can also be recognized. An additional input action can be accomplished by pressing the big toe instead of pushing a button at a handheld input device. Tapping on the ground with one's heel or other special gestures are conceivable, but have not yet been implemented.

Measuring the footprint while walking enables unique authentication, since every human has an individual foot shape, weight and style of walking. The individual footprint could give the computational device information about who the user is. This could be used for authentication purposes. This technology is able to find out if one is walking, running, standing still or sitting. It is also conceivable that software could adjust the interface depending on this information, for example changing font sizes and behavior of the menus while on the go. Of course an approximate walking speed can also be calculated. The same is conceivable in real environments for example with smartphones or AR devices (e.g. google glasses). Conscious gestures like pressing the big toe could be used to react on incoming phone calls as well as controlling the music player.

3.2.2 Tactile Feedback

Instant feedback is delivered by tactile vibrations on the surface of the insole at different areas. This provides additional information in VR environments as feedback from a collision with an object in a scene. It could also be used to provide ambient information on the ground surface to enhance immersion as also introduced by Nordhal et al. [2013].

In real environments: this kind of feedback is silent, so it does not disturb others when engaged with real world tasks. Incoming phone calls might be supported with this kind of feedback, especially when the user is in noisy areas or in inappropriate situations such as in a business meeting.

3.2.3 Temperature Feedback

This shoe insole provides secondary, latent information, which is perceptible as a rising temperature on a dedicated area of the foot, which is ideally free from calluses. This feature could be used to enhance immersion in VR, for example, to make the user unconsciously uncomfortable. As of now it provides information on the state of the user's avatar. In training applications this could mean for example it is wounded or even bleeding by rapidly increasing in heat. Also it could provide information about ground temperature (e.g. desert) for a greater immersion.

In real environments: it could give a vague information on how many phone calls are missed and how many messages are pending in the inbox.

The "central adaption phenomenon" ensures that the human is not able to recognize slight changes in temperature. Even if it becomes too warm under the foot, the human body manages to acclimate to this kind of discomfort, until the nerves become numb. Thus the Peltier element integrated within the system has to be alternated heating and cooling.

4 Conclusion and Future Work

This paper has introduced a novel VR interface, which allows real-time hands-free interaction with a scene, but also provides the possibility for navigation through a VE. The technical implementation of the prototype has been presented and interaction possibilities have been suggested, which still have to be explored and evaluated in a user study. It seems natural to the authors to use this device not to replace common scene manipulation but rather to supplement it. Navigation by using a variety of walking metaphors can be easily and naturally implemented, while keeping the focus of the traditional manipulation tasks with the hand input. While this paper has illustrated the setup and suggested the use in VEs, such a device could be easily usable in the whole mixed reality context especially augmented reality applications. In these contexts relieving hands and arms is intuitive since AR devices often offer mobility and thus the ability to take part in real world simultaneously. Being involved in real world tasks, means often being in a hands-busy situation, in which the prototype could be highly valuable. In the future a control would be possible in the following problematic use cases, which were summed up by Matthies [2013]: when being outside, while carrying bags, hanging on in a bus or train, wearing gloves, holding a child's hand, pushing a pram, having full attention devoted to critical working tasks, having unclean hands, doing anything else with one's hands, or if the computational device is in an inaccessible location such as a jacket pocket.

When involved in traffic as pedestrian, such interface could avoid dangerous situations on the road, as it does not distract visual focus or require use of the hands. “ShoeSoleSense” also enhances social acceptability by recognizing discreet foot gestures as well as information about the users movement (walking, jumping, running, sitting, lying) without the need for additional cumbersome devices mounted on the body such as optic tracking devices on a hat or shoe. The prototype is secure from getting dirty or damaged by external influences, since it is protected in the shoe. As also stated in the related project “ShoeSense” from Bailly et al. [2012], shoes are always available, so there is no need for artificial wardrobe additions such as a pendant or cap. It is also determined that the risk of accidental occlusion of sensing is no longer an issue. Another benefit the shoe potentially offers is space for storing sensors, actuators and the accompanying electronics. New interfaces could take this fact into consideration. Beyond power harvesting through a shoe [Krupenkin et al. 2011], the input and the feedback possibilities of feet still provide a large operating volume for possible applications.

Ensuing goals, in addition to conducting user studies in a VR environment in order to measure accuracy, usability and immersion, will be to connect this prototype to a mobile computational device, such as a smartphone and determine the feasibility in use cases.

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