Enhanced Pressure-Based Multimodal Immersive Experiences

Taeyong Kim
McGill University
Montreal, Quebec
taeyong@cim.mcgill.ca

Jeremy R. Cooperstock
McGill University
Montreal, Quebec
jer@cim.mcgill.ca

ABSTRACT

Haptic feedback to the feet has been explored in the context of ground surface simulation, but existing solutions have generally not taken into account the effects of variable foot pressure during naturalistic stepping movements. We present here our approach to simulating the surface of a frozen pond, including ice cracking under increased foot pressure. This serves as a compelling example of a wearable mobile augmented foot-based surface simulator, whose response varies as a function of applied foot pressure. To enhance the illusion, we render multi-sensory feedback, comprising audio, visual, and haptic effects. We describe the hardware employed, the algorithm used to determine the distribution of foot pressure, and suggest potential possibilities for such a foot-pressure-based augmented reality system.

CCS CONCEPTS

• **Human-centered computing → Usability testing**; **Mixed / augmented reality**; **Haptic devices**; *Graphics input devices*; *Gestural input*;

KEYWORDS

Immersive Environment; Wearable Computing; Augmented Human; Haptic Effect; Foot-based Interface, Surface Textures.

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1 INTRODUCTION

Although virtual reality is largely associated with exclusively visual displays, multimodal feedback offers the potential for improved realism and immersion in computer-simulated experiences. Haptic feedback, the sense of touch, is a significant factor in our perception of the world, and may be used to provide tactile augmentation of physical environments [1] or for extending our methods of communication [11].

Multimodality achieves compelling performances by combining haptic feedback with various aspects of auditory feedback. Most research in this domain has focused on hand-based interfaces. Difanco et al. studied the psychophysical influence of sound feedback on the haptic experience in virtual environments [2]. Ha et al. developed a hand-based augmented Digilog book with audio and vibration feedback [3].

Visell at el. studied immersive virtual environments through a distributed, multimodal floor interface [12]. Each of their floor tiles generated haptic feedback using a vibrotactile actuator, according to the force input measured by four force sensors. Visual feedback was rendered via overhead video projectors. However, this architecture is limited in scale due its significant hardware requirements. Turchet et al. explored shoe-based walking experiences where auditory and haptic feedback were rendered directly in the shoes, simulating different ground surfaces, such as snow or sand [10]. However, the integration of foot-pressure sensing and vibrotactile actuation, directly in the shoes, has not yet been considered.

Here, we investigate the usability and applicability of foot-pressure feedback, produced by our instrumented haptic shoes, in a multimodal walking simulation.

2 SYSTEM ARCHITECTURE

In order to explore foot-based multimodal immersive experiences, our system simulates walking on a frozen pond. The shoes detect the distribution of foot pressure as participants shift their weight and walk on the floor. Based on this data, the system renders vibrotactile, audio, and visual feedback to simulate ice cracking underneath the participants' feet.

2.1 Vibrotactile and Acoustic Feeedback

A vibrotactile "Haptuator" (Tactile Labs Inc., Deux-Montagnes, Canada) is embedded in each of our instrumented haptic shoes (see Figure 1). Because of their wide frequency response, these actuators provide both haptic and auditory feedback simultaneously. The ice cracking signal is generated using Pure Data [9], based on the Sound Design Toolkit (SDT), comprising a set of physical-based sound synthesis models [7]. In order to measure precise foot pressure distribution, four force sensitive resistors (FSR) are embedded in the insole where physiological mechanoreceptors are present to detect foot pressure effectively [4].

Figure 1: Haptic shoes and positions of foot pressure sensors

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2.2 Measuring Foot Pressure

According to the amplitude of foot pressure detected by four FSRs in each shoe, ice cracking feedback is rendered visually where the position of shoes are detected by Vicon motion capture system. The detected pressure values by the four FSRs are adjusted in the process of finding the best position to generate ice cracks when its values exceed a specific threshold.

To calculate foot distribution within runtime, a simple algorithm was devised according to the location of four FSR sensors by normalizing the foot as a rectangular object, having height of ± 1 unit and width of ± 0.5 units, where the locations of the four FSRs were mapped to **L**eft(-0.5,0), **R**ight(0.5,0), **T**oe(0,1), **H**eel(0,-1) (see Figure 1). Thus, the centroid of the foot position was calculated as the mean of the FSR positions, weighted by their respective readings.

2.3 Frozen Pond Stimuli Rendering

In the frozen pond simulation, cracking is visually rendered on the surface with a sequences of lines. The cracking simulation was implemented based on a simple ice crack pattern algorithm, suggested by Visell [12]. To provide more compelling visual feedback, a secondary type of radial cracking [5] was also designed.

If the pressure values exceed a threshold during a step, a number of ice-cracking-seeds are generated according to pressure, with Gaussian distribution around each foot individually. The first crack is then originated by connecting the seeds with the calculated foot position given in Section 2.2. If another foot pressure input above the threshold is detected near previous seeds, cracks are propagated or radial-shaped cracks are generated.

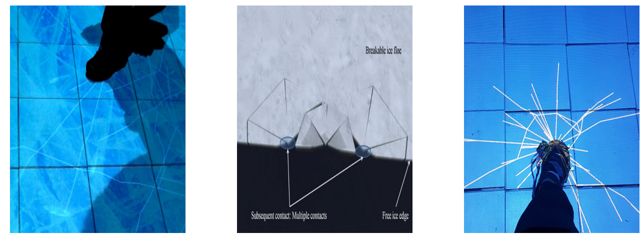
To implement crack propagation at low cost, a modification of Visell's simple crack algorithm was implemented [12]. When foot pressure exceeds the threshold, the nearest previous seed is found, with position (x_1, y_1) and the current foot position is recorded as (x_2, y_2). A "crack" is then generated to position (x_3, y_3):

$$x_3 = x_1 + \mathcal{N}(\mu_x, \sigma_x^2) \text{ and } y_3 = y_1 + \mathcal{N}(\mu_y, \sigma_y^2) \quad (1)$$

where $\mathcal{N}$ is the normalized random function based on Marsaglia polar method [6] and $\mu_x = x_1 - x_2$, $\sigma_x = (x_1 - x_2)/2$ and $\mu_y = y_1 - y_2$, $\sigma_y = (y_1 - y_2)/2$.

This offers benefits over Visell's algorithm by avoiding the need to calculate the crack energy and global growth rate to make a crack, while exhibiting similar performance (See Figure 2).

To simulate ship-ice interaction, Lubbad et al. implemented radial cracks [5] by connecting seeds to each other. Controlling the positions and numbers of seeds, different styles of cracks could be generated. For example, only the last seeds of cracks are connected to each other, it could show big radial ice crack (e.g., shape of thick ice in north pole-see Figure 2b). If all cracks are connected to each other located in near certain area, it could generate smashed-ice cracks, such as glass broken by a hammer. However, this algorithm needed considerable computational processing to detect seeds. To minimize processing cost, such radial cracks were designed to occur only rarely as a special event, such as when a large impulse force was applied to the surface of a frozen pond (see Figure 2c). Since foot-ice interaction is largely confined to the ice surface, we can save considerable computational demands over Lubbad's algorithm by limiting the calculation of contact forces to two dimensions. In addition, we ignore the complex dynamic models of floating ice chunks employed by Lubbad [5].



(a) Propagated cracks by Visell [12] **(b) Radial cracks by Lubbad [5]** **(c) Combined cracks by authors**

Figure 2: Comparison of ice crack visual rendering.

3 FUTURE EXTENSIONS AND CONCLUSION

The mobile augmented foot-based simulator described here takes into account variable foot pressure via our instrumented haptic shoes. To convey compelling experiences beyond visual feedback, haptic and sound feedback are provided through the shoes. We believe that delivery of such feedback through the foot could enhance realism in VR and AR scenarios [10], provide feedback for balance control in a rehabilitation context [8], and enhance the experience of mobile gaming. To achieve mobile visual feedback, various possibilities can be considered, such as body-worn pico-projectors illuminating the ground around the user, OLED shoe coverings, or head-worn VR/AR displays.

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