An Architectural Platform for Audio-Haptic Simulation in Walking

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Abstract

This paper presents work on the EcoTile*, a new interactive platform for the simulation of auditory and haptic experiences of everyday materials in walking. Walking is noteworthy as an enactive activity that is continuously negotiated in direct contact with its surroundings, in a way that is strongly dependent on the mutual morphology and material properties of both. As a situated activity, it is charged with many sources of meaning, and with potential for intervention at responsive and informational levels, although to date comparatively few devices have taken advantage of the unique opportunities it provides. The main design considerations behind the EcoTile are described, followed by the system organization and components, and initial experiences with the prototype.*

1. Introduction and context

Walking is an activity common to most humans, and to an impressive range of activities ranging from the functional to the recreational. It also carries significance for our health and well-being, and the study of walking and its disorders occupy a prominent role in the movement sciences. Walking has been prominently read by cultural theorists and philosophers including Michel de Certeau and Walter Benjamin as intimately tied to both the experience of space and the manner in which it is cognitively constructed through movement [1, 4].

It is surprising that more attention has not been devoted to the engineering of interfaces that explicitly make use of walking as an enactive activity. Recent years have seen a growth in invention in the area of mobile information devices that are adapted to movement by foot. For example, the Nike+ running shoe and music player system provides a sensor interface that lends an added informational dimension to the activities of runners. However, comparatively few devices have sought to take advantage of the unique qualities that accompany such modes of movement, whether at the sensorimotor level or the semantic one.

Our research is directed toward the design of floor-based interfaces whose sensing and actuating capabilities furnish dynamic control over the ecological information that is available in walking, interactively shaping the perceived auditory and haptic material qualities of the ground. A key source of motivation for this research is the possibility of merging new technologies for generating virtual experiences of material with the intrinsically tangible, physical, and spatial experience of walking. An advantage of foot based interaction lies in the possibility to engage intimately and individually with the senses and activities of people in public and semi-public spaces in ways that are difficult with conventional displays. For reasons such as these, we have elected to focus on the development of an architectural interface for enaction in walking, as one that can be utilized for the design of diverse spaces, without the kinds of restriction that would result from requiring users to don special equipment to experience it.

2. Related Work

Informative ground materials for walkers have long played a role in the design of urban environments. Passive haptic indicators are commonly used to mark important locations including stairways, crosswalks or subway platforms, and outdoor paths are designed to be readily distinguished by their material properties. However, the possibility of conveying these kinds of information through active devices embedded in real spaces in which people walk remains basically unknown. Devices that have been developed for interactive simulation in walking have been typically confined to laboratories or other closed environments.

Many researchers have investigated aspects of walking in the context of location-based interaction with a personal mobile information device. A few have addressed the role of computing in sensorimotor level interaction, such as the studies by Crossan et al on interactions between gait phase during walking and simultaneous target selection on a mobile device [3]. Further, there is extensive prior research on medical applications of walking based interfaces, particularly in the diagnosis, care, and rehabilitation of disorders affecting gait (eg. [7]).

Several research groups have developed instrumented floors for the sensing of walking, dancing, or running movements. For an overview, see chapter 2 of the book by Wanderley and Miranda [6]. The PhOLIEMat developed by Cook [2] is somewhat unique as a floor-based device for the control of synthesized walking sounds via the feet (evoking the work of the Foley artist in film). To our knowledge no research has yet addressed the design of a floor for interactive simulation of surface material properties in walking, whether through the auditory or haptic channel.

As noted below, this work draws directly on the work of Fontana and Bresin on the physically based modeling of crumpling sounds [5].

3. Device Design and Characterization

A floor component called the *EcoTile* has been created with the aim of supplying interactive audio-haptic simulations of ecological ground materials in walking, based on a model for the simulation of the physical phenomenon of crumpling. The prototype device was designed with the aim of exploring the capability of an actuated but otherwise rigid interactive platform to interactively simulate the experience of walking on various materials. This aim was partly motivated by the notion that the auditory information alone is capable of conveying considerable information about the properties of surfaces that are walked upon. As a result, an even modestly successful haptic stimulus that is highly correlated with the auditory signal may be sufficient for a convincing percept.

In the prototype, the user walks on or otherwise interacts via the feet with the tile, which interactively delivers a signal designed to mimic the sensation provided by a given surface type. The stimulus consists of a vibration transmitted to the foot and simultaneously an acoustic signal transmitted to the ear, but originating near the platform. For this prototype, a snowy surface was selected as phenomenologically interesting and as a material that might be readily identified by the user through interaction[1]. The device is pictured in the images of Figure 3.

The mechanical component is a physical tile of dimensions 34 cm by 34 cm, together with a linear mechanism that allows it to be driven in a purely vertical direction. This platform is haptically driven with a motion control actuator from D-Box technologies. Sensing of the force applied by the user to the tile is accomplished with four Interlink force sensing resistors (FSRs) connected to a small microcontroller platform. The physically based simulation of the material is run in real time on a personal computer, which synthesizes the sound and haptic signals in response to the force on the tile, in the manner described below. The software environment used for prototyping is Max/MSP by Cycling'74. The sound is reproduced by a powered loudspeaker located at the base of the tile.

[1] Audiovisual documentation can be viewed at http://cim.mcgill.ca/ỹon/HS-Video – naturally, it does not capture the level of haptic interactivity.

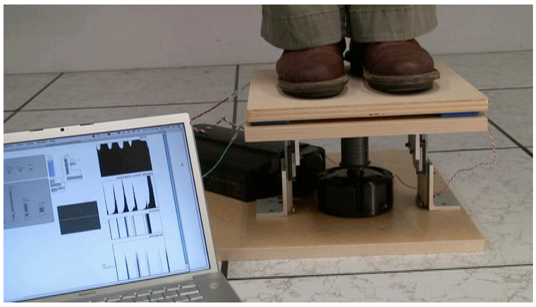

Figure 1: The interactive floor tile with user walking on it, next to the software component running on a laptop computer. The display of the latter shows the force, event density, and a sonogram of the resulting audio/haptic signal.

In the simulation of aggregates like snow, as implemented in the prototype device, the system can be controlled in open loop fashion. The required haptic force feedback through the device is much smaller than the force applied by the user (very roughly the user's weight), so the feedback from actuator to sensors is virtually negligible. Also, effects such as the displacement of the material underfoot (as in the compression of snow), which would likely require a closed loop control strategy, are ignored.

3.1 Physically Based Auditory and Haptic Stimulus Generation

Interactive auditory and haptic stimuli are generated continuously in response to the users footsteps. These are synthesized in real time by means of a physically based signal simulation of the phenomenon of crumpling, in a way that is driven by the force data from the footstep. An overview of the approach is presented in Figure 3.1.

The approach that was adopted utilizes prior work on the sound synthesis of such phenomena by Fontana et al [5], who have described the algorithm in significant detail. The model conceives crumpling pheomena to be composed of microscopic crumpling events, which are modeled as physical impacts between colliding objects, building on an earlier impact model by the same group [8]. Its main features are a stochastic model (Poisson process) governing the rate of production of such events, an energetic model positing the way the available energy is consumed, and a third component that addresses the change in the frequency characteristics of crumple events as crumpling unfolds. Parameters of the synthesis model may be tuned by hand to approximate various common or unusual crumpling artifacts or, as in the case of the current work, common or unusual aggregate ground surfaces.

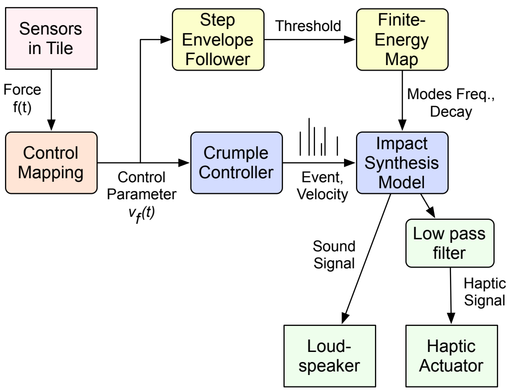

Figure 2: Diagram illustrating the crumple synthesis instrument, with force mapping, simulated crumpling model, and finite energy map.

In the prototype platform, both the auditory and haptic stimuli are derived from the same instance of the crumpling synthesis model. Due to the bandwidth limitation of the haptic actuator, the haptic signal was subjected to a low pass filter removing frequencies above 100Hz.

3.1.1 Force Control of the Crumpling Model

In the present application, a continuous control scheme providing a map from sensed foot pressure to sound synthesis parameters was needed, in order to maintain the highest possible level of interactivity. A parameter v_f used to control the amount of crumpling is obtained from the net force $f(t)$ exerted by the foot on the tile via:

$$v_f = \begin{cases} |df/dt| & \text{if} \quad df/dt < 0 \\ 0 & \text{else} \end{cases} \tag{1}$$

This choice represents a practical simplification in which crumpling occurs during walking only as weight is being transferred from the foot onto the tile, ignoring sensations produced as weight merely shifts from one part of the sole to another. The variation in force on the tile generated by such shifts does nonetheless contribute a qualitatively appropriate crumpling, as illustrated in video clips at the site mentioned above.

To implement this continuous control mapping, the Poisson process governing the generation of crumpling events was implemented such that the force v_f exerted on the tile at each instant determines, in appropriate units, the probability $P(\tau)$ that the time interval between crumpling events takes the value τ:

$$P(\tau) = v_f \, e^{-v_f \tau} \tag{2}$$

When the interval τ is small, the event probability is approximately v_f. The force f is polled from the device at intervals of $\tau \approx$ 10ms, and the distribution $P(\tau) = v_f$ is sampled to determine whether a crumpling impact is generated in the respective interval.

The energetic decay and frequency evolution of the crumpling model utilize the finite energy model Fontana et al, with the addition of an automated reset mechanism. In our system, the model state is reset at the beginning of each step by a simple footstep onset detector, consisting of a two-state envelope follower with a short attack and with a release time of approximately one second.

4. Qualitative Assessment and Future Work

In the prototype, auditory and haptic stimuli are derived from the same instance of the crumpling model. Due to actuator limitations, the haptic signal lacks frequency components above 100 Hz, whereas the human haptic channel is sensitive to those up to 1000s of Hz. Based on feedback from users, the auditory signal with the limited haptic signal appeared sufficient to convey the impression of snow. Ten users were asked to explore interaction with the device by stepping onto it, in stride or in isolation, with one or both feet. Several expressed surprise at the level of veridicality of the experience of the virtual snow. We felt this could be attributed to the synchronization between feedback channels, to the realism of the sound signal, and to the unexpected nature of interacting with virtual snow in a laboratory.

It was informally observed that the fusion of haptic and auditory modalities into a single percept could be completely disrupted by moving the loudspeaker farther than about 30 cm from the base of the tile, and then completely restored by placing the loudspeaker next to the base of the tile again.

The D-Box motion control actuator used in this prototype, while offering advantages including excellent response at low driving frequencies, has some drawbacks for this application. In particular, the control interface introduces a large latency in response that make it prohibitive to operate in situations that require a fast or closed-loop response, as in the case of hard surfaces.

A 100-tile floor 3m by 3m in size is currently under development. A new, modular tile is being designed to utilize a lower-cost and wider bandwidth, commercially available vibrotactile haptic actuator. The industrial design of the tile will be improved to provide a more solid and integrated platform that is protective of its key components, in order to permit testing with significant numbers of users in diverse settings.

Experiments are in progress with colleagues in psychology, utilizing real ground materials to assess the multisensory factors that contribute to material properties perception in walking. A data collection effort to document the physical signals present in walking on various materials, including applied force, haptic and auditory feedback. The aim is to make it possible to identify physically salient synthesis model parameter settings and control mappings from foot force profile to auditory and haptic response in the EcoTile simulations.

4.1 Future Application Scenarios

Unique applications of the EcoTile are anticipated in the architectural design of public and semi-public spaces, toward enabling the dynamic shaping of the aesthetic experiences of touch and material perception during walking, for functional purposes or with more creative aims in mind. A central question is tied to the possibility of invisibly organizing space and materiality in relation to the experience of walking or otherwise moving on foot within or through it. Functional applications are foreseen, including the reinforcement of sensory qualities for architectural spaces, and the creation of navigational aids or suggestions in the form of active, ecologically-based markers. Likewise, the tile may enable the creation of identity for a space or an organization (for example, the sensation of snow covered ground outside an outdoor store).

Other modes of creative production may be expressed through ground materials that morph in relation to the passage of people – emphasizing or de-emphasizing areas of passage, growing islands in places of congregation, or traces where people have passed. In short, such an interaction method may be thought of as charged with the possibility of lending these surfaces the range of affordances of the material world, but in ways that can be dynamically and interactively shaped. Dedicated structures such as virtual labyrinths might be constructed, as in a medieval church, with invisible paths representing meditation or contemplation, or locations might be linked over a network to other locations, lending one place the presence of those passing through another distant one. Further benefits of the technology being developed could lie with applications that can take advantage of an increased level of perceptual immersion, as in simulation training for rescue or other operations, physical or cognitive therapy, and interactive entertainment for theme parks, interactive science museums, or other play areas.

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