Gilded Gait: Reshaping the Urban Experience with Augmented Footsteps

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ABSTRACT
In this paper we describe Gilded Gait, a system that changes the perceived physical texture of the ground, as felt through the soles of users' feet. Ground texture, in spite of its potential as an effective channel of peripheral information display, has so far been paid little attention in HCI research. The system is designed as a pair of insoles with embedded actuators, and utilizes vibrotactile feedback to simulate the perceptions of a range of different ground textures. The discreet, low-key nature of the interface makes it particularly suited for outdoor use, and its capacity to alter how people experience the built environment may open new possibilities in urban design.

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General terms: Design, Human Factors

Keywords: Ground texture, augmented reality, haptic interface, vibrotactile feedback, urban navigation.

INTRODUCTION
Studies in human locomotion [8] reveal that bipedal walking is a highly complex motor skill, during which we continually adjust our gait in response to environmental conditions. The physical texture of the ground, as sensed through the soles of our feet, plays a large role in this process. Our foot soles are in fact extremely sensitive to touch due to their high density of nerve endings, but despite the growing excitement around haptic technologies in general, this potential has largely gone unnoticed so far in user interface design or HCI research.

In this paper we describe Gilded Gait (Figure 1), an innovative haptic interface system that alters the perceived physical texture of the ground, by mechanically augmenting footsteps with specific vibrotactile patterns applied to the user's soles. The interaction is *passive* in the sense that the vibrations are only triggered upon explicit user movement (footstep), making the system capable of presenting information in unobtrusive manners at the periphery of user attention. Since Gilded Gait is designed in the form of insoles, it can comfortably fit within most common types of footwear.

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Figure 1: Gilded Gait, placed inside Crocs sandals.

The paper will explain the design details of our working prototype of Gilded Gait, along with our repertoire of vibrational feedback patterns, that are intended to provide rough simulations of distinctive ground types/textures. We will also report the comments and insights obtained through our initial experiences with the system, and discuss the range of applications that can be realized with Gilded Gait.

THE "YELLOW BRICK ROAD"
The discreet and passive quality of Gilded Gait makes it particularly attractive for use in urban, outdoor situations, where more traditional methods for conveying information (namely visual and audio information display) are often rendered ineffective due to factors such as urban noise and unavailability of user attention [4, 6]. Therefore we naturally regard urban navigation, one of the most popular genres of outdoor applications, as the primary target usage of Gilded Gait.

Navigation using Gilded Gait may be described as laying out one's own "Yellow Brick Road"—the road leading to Emerald City in the 1900 novel "The Wonderful Wizard of Oz"—that is to say, it takes the form of assigning specific (virtual)

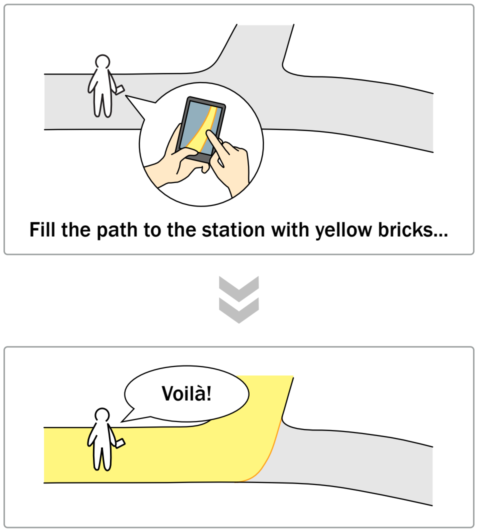

Figure 2: Creating the "Yellow Brick Road", on the spot.

ground textures to regions in the city. For example, a person trying to find his/her way to the nearest train station can give a distinctive, bumpy ground texture to the path leading there from the current location (Figure 2). This way, the user can intuitively understand whether he/she is staying on the right path. As is well known among urban designers/planners, the choice of ground texture (if done correctly) can contribute to making the city more easy to navigate [5], through giving a sense of coherency within districts, emphasizing the central streets, etc. With Gilded Gait, users can lay claim to powers hitherto reserved to urban planners, and transform the urban landscape to fit their own needs and interests.

Such style of navigation may lack precision when compared to existing navigation techniques, but has the benefits of requiring no constant attention, and not obscuring visual/audio cues that are crucial to pedestrian safety in urban areas. The system *does* obstruct users from perceiving the true physical texture of the ground, but this should not pose serious threats to safety on the paved, smooth streets of modern cities.

RELATED WORK

Vibrotactile actuation has long been used as a simple way of providing haptic feedback, as can be seen from the long list of commercial game consoles with "rumble" features. More refined implementations can be found in works that focus on touch screens [3, 7], where tailored patterns of vibration are applied, either to the whole device or only the screen, at the moment the user's finger touches the screen. Such techniques are reported to effectively replicate "button-click" sensations on the otherwise unresponsive touch screens, making the interaction feel more *natural* and *direct* to users.

Earlier efforts to place vibrational actuators into shoes [2, 11] have been limited to exploratory attempts aimed at conveying arbitrary signal patterns through foot soles, with no apparent intent to mimic ground texture perceptions. Mechanical simulations of ground textures have been occasionally attempted in Virtual Reality [9, 12], but the systems tend to be large and are not self-contained, and thus can only operate in specially configured environments. We are unaware of any prior work that has resulted in a stand-alone haptic feedback system like Gilded Gait, capable of simulating diverse ground textures in any environment with a smooth ground surface.

Van Erp et al. [10] have created a working haptic system for urban navigation, in which a belt with eight vibration motors on its surface gives turn-by-turn directions using vibrotactile signals. However, such efforts to develop alternative navigation interfaces have so far failed to produce any truly viable competitors to GUI-based navigation. We believe that many of the prior attempts suffer from the same design flaw of using arbitrary signal schemes that are not a natural part of how we humans perceive the surrounding environment, leading to user confusion and increased cognitive load. In Gilded Gait, this flaw is addressed through our focus on the perception of ground texture, a natural channel of information that happens to be underutilized on the paved city streets.

In the context of interactive art/experimental interaction design, Frey [1] has designed shoes whose soles can tilt to automatically guide the wearer to either left or right. While the idea is similar to that of Gilded Gait, the vibrotactile solution adopted in our work provides a far greater level of versatility, as we will illustrate later in this paper where we describe the potential range of applications. Also, Gilded Gait is designed as a pair of slim insoles not specialized shoes, and thus much more feasible as a potential commercial product.

GILDED GAIT

Figure 3 shows our latest prototype of Gilded Gait. Since the prototype is handcrafted, for ease of construction we decided not to pack all the elements into the insole, and hence several electronic components (including the microcontroller and the 9-volt battery) are fixed onto an external circuit board, wired to the insole. The whole system can easily be packed into the insole if made using state-of-the-art fabrication technologies. The system can be connected to custom "app modules" (e.g., GPS receiver module) by linking them to the external boards with cords, to realize a broad range of applications that make use of the unique interface of Gilded Gait (we intend to make the connection wireless in future prototype iterations).

The insole contains six vibration panels that render the feedback patterns, and a push-down switch and an accelerometer to detect users' footsteps. Each vibration panel consists of a vibration motor (Lexin Japan Ltd. LE12A1J) firmly attached to a 1.5mm thick polystyrene panel. The number and layout of the panels were decided through iterative refinement. Two sheets of shock-absorbing gel enclose the whole setup from above and below, securing all the electronic components and creating the final insole shape. Making appropriate choice of gel is crucial; each gel reacts differently to shocks of varying velocities, and gels with unsuitable properties end up dampening the vibrotactile patterns to the extent that users would not feel any sensations. (In fact, in our experiments we found most off-the-shelf shock-absorbing gels sold at D-I-Y stores to be unsuitable.) After trial and error we chose KG Gel from Kitagawa Kogyo Co., Ltd. Using this gel allows users to feel strong vibrations, while securely protecting the internal components from shocks caused by footsteps.

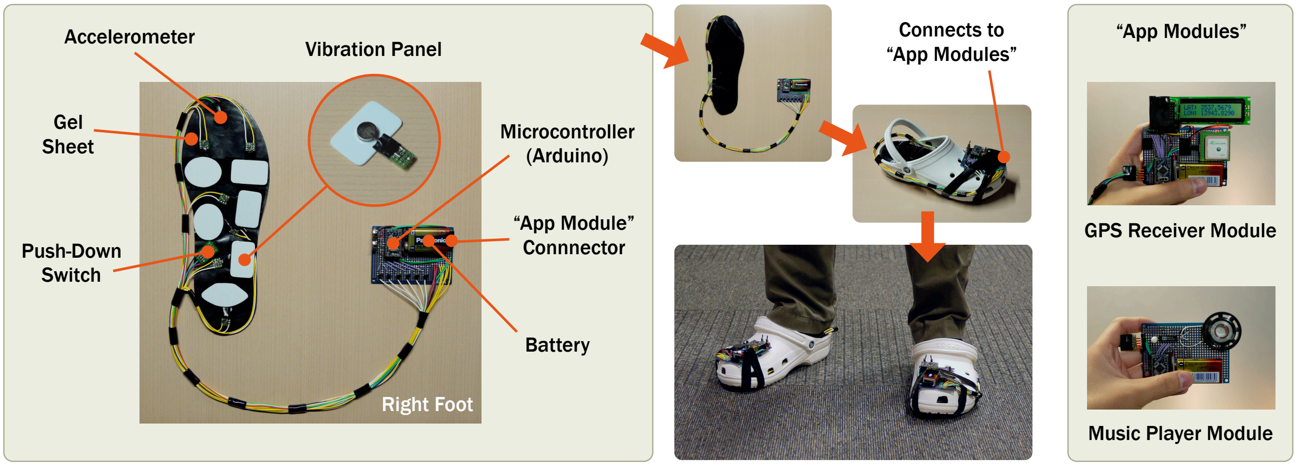

Figure 3: Gilded Gait prototype. We expect all components to fit within the insole in future iterations.

We inserted the insoles into a pair of Crocs sandals, with the external board fastened to the exterior shell with vinyl tapes. When a user wearing these shoes makes a step and the sole touches the ground, the push-down switch is pressed and the accelerometer marks an abrupt surge in upward (i.e., $+z$) acceleration. These two factors are combined to detect the precise timing of the user's footsteps with no noticeable latency. Once a step is detected, the microcontroller immediately orders the vibration panels to vibrate in the designated pattern (one of the patterns described in the next paragraph), giving the illusion of a virtual ground texture to the user.

We have designed three different patterns of vibrational feedback, as depicted in Figure 4. The design of these patterns is based on our informal observation that, following a footstep with vibration in an area within the sole produces a strengthened sense of contact with the ground in that area. Applying this effect, we can control to some extent the perceived way in which the sole touches the ground when taking a step, and thus can offer (rudimentary) simulations of different ground types/textures. For example, following a footstep with a relatively long (0.3s) vibrotactile feedback throughout the sole results in the sensation that the foot is still "sinking into" the ground even after the initial moment of contact, resembling the feeling one gets when walking on soft ground. Also, applying feedback in a zigzag pattern can create a rough sensation of walking on bumpy ground, and a fun (though perhaps over-the-top) "Godzilla" effect, where users feel as if they are causing small earthquakes every time they take a step, can be produced by vibrating the panels in repetitive short bursts.

Applying haptic feedback to only one foot, or applying a separate feedback to each foot can result in some special effects, which may be put to effective use in applications. For example, in the "Yellow Brick Road" urban navigation app, giving feedback to a single foot can produce a "curving road" effect (Figure 5), discreetly signaling the user to make a turn in the direction of the feedback-administered foot. This enables the app to offer simple turn-by-turn navigation (without breaking the "ground texture" metaphor), eliminating the need to refer to maps for all but the most complex intersections.

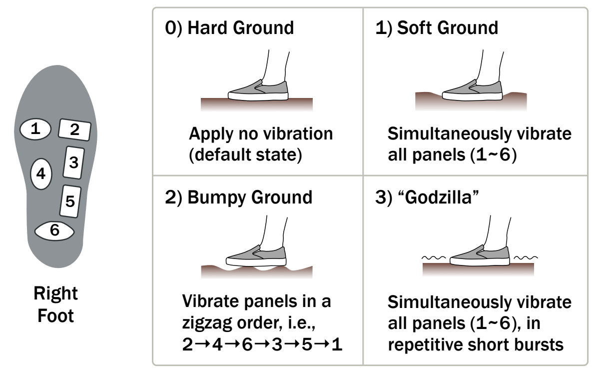

Figure 4: Vibrotactile feedback patterns.

Figure 5: "Curving road" effect.

To quickly assess the effectiveness of the vibrotactile texture simulations, we asked eight subjects (lab colleagues and students) to try out the interface in an informal setting. Although users commented that the simulations were still far from being indistinguishable from actual ground textures (which was expected, since even the most elaborate VR equipments cannot offer such high levels of fidelity), when we presented the list of possible choices, all users were able to (given enough time) correctly link each of the vibrotactile patterns with the ground texture it is intended to replicate. This means that the simulations offered by the current prototype are already realistic enough that users can easily form mental links between the vibration patterns and actual ground textures. Thus in our view, the current level of fidelity adequately fulfills the basic premise of Gilded Gait, i.e., to provide “natural” haptic cues that do not feel like arbitrary signals to users. This translates to a significant benefit over past haptic navigation systems.

Several aspects of the hardware may be upgraded to improve simulation fidelity. For example, we currently use coil-based motors for the vibration panels, which have fixed waveforms that cannot be altered programmatically. Designing a custom vibration actuator from piezoelectric materials (with variable vibration waveforms) should allow us to do more fine-tuning of the the feedbacks, increasing fidelity. This may also allow us to inject more variety in the array of vibrotactile patterns, for instance designing multiple versions of the *bumpy ground* pattern, with several different degrees of bumpiness.

Our decision to use vibrotactile actuation, out of the numerous available haptic technologies, merits further explanation. A major advantage of using vibration is that the whole package can be made much smaller compared to using alternative technologies, such as shape memory alloy, pneumatic actuation, etc. This is a pivotal asset, since we believe that whether we can fit Gilded Gait into a thin insole shape is a key factor that determines if our work ends up as a mere gimmick or as a practical system with a potentially wide audience.

APPLICATIONS

To implement the “Yellow Brick Road” urban navigation app we constructed a GPS receiver “app module”, capable of periodically detecting the user’s geographic location. The module is equipped with its own microcontroller, which contains the mapping data between geographic locations and feedback patterns. The mappings can be changed by loading new data to the microcontroller from a PC. Our initial experiences with the app have been positive; the simulated textures were easily noticeable without being unduly obtrusive, offering a sensation comparable to that of walking on the bumpy tiles placed on sidewalks in Japan. Considering that these tiles, originally intended to assist the visually impaired, have been appropriated as guides by young people texting on their phones while walking, we could possibly expect interesting new behaviors to be instigated by Gilded Gait. In addition, we found the gel sheets to do an admirably good job of not only protecting the internal electronics but also of improving ergonomics, dampening the “mechanical” feel of the insole.

Although not yet implemented, we can potentially extend the app by making Gilded Gait resolve the location-texture mappings dynamically, using data downloaded from the Internet. For example, we could link textures with area-mapped crime rate, and warn users (e.g., tourists, children) through changes in ground texture when stepping into dangerous regions.

We also created a music player “app module”, to explore the possibilities of using Gilded Gait for data input. We mapped the basic operations of portable music players to *tapping motions* of the user’s feet. For example, quickly tapping on the same foot twice in a row starts music playback, and tapping three times in a row fast forwards the music to the next song. When a command is entered successfully, a bumpy texture is applied for a short time to notify the user. The operation has the virtue of being entirely hands-free, and as we have found out from our initial experiences with the application, the rate of input errors (false positives) was surprisingly low.

The two applications we described constitute only a tiny fraction of the potential uses of Gilded Gait. The “natural” information display highly robust to urban noise, and the capacity for intuitive, hands-free input, should make the system applicable to a wide variety of purposes.

CONCLUSION

In this paper we described the design of Gilded Gait, a haptic interface system for users’ feet. The idea may initially appear like a novelty, but considering the success of shoe-embedded sensors such as the Nike+iPod accelerometer device, we confidently believe that the system is practical. Our future plans include constructions of further, technically improved prototypes, and more thorough explorations of the system’s application space.

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