SkinHaptics: Ultrasound Focused in the Hand Creates Tactile Sensations

Daniel Spelmezan[1] Rafael Morales González[2] Sriram Subramanian[3]

***Abstract*— Recent developments in on-body interfaces have extended the interaction space of physical devices to the skin of our hands. While these interfaces can easily project graphical elements on the bare hand, they cannot give tactile feedback. Here we present a technology that could help to expand the output capability of on-body interfaces to provide tactile feedback without restricting the skin as an interaction surface. SkinHaptics works by focusing ultrasound in the hand using a phased array of ultrasound transmitters and the acoustic time-reversal signal processing technique. We present experimental results that show that this device can steer and focus ultrasound on the skin through the hand, which provides the basis for the envisioned technology. We then present results of a study that show that the focused energy can create sensations that are perceived under the skin and in the hand. We demonstrate the potential of SkinHaptics and discuss how our proof-of-concept device can be scaled beyond the prototype.**

I. Introduction

Our hands and forearms are a natural interaction platform for on-body interfaces that use the skin as an input and output surface. Unlike visual output, which can be displayed with pico- and laser-projectors [1], [2], [3], no practical solution exists to give tactile feedback without placing actuators on the skin, although tactile cues are as important as visual cues for precise pointing (e.g., for eyes-free interaction [4]). Recently, a few technologies have emerged that can give tactile feedback from a distance with air vortices [5], with focused airborne ultrasound [6], or with indirect laser radiation [7]. However, they are not wearable and have a limited haptic design space. Air vortices and airborne ultrasound create low-resolution sensations that resemble a puff of air, whereas laser requires instrumenting the skin with a light-absorbing medium to elicit a sensation similar to a tap.

Here, we propose SkinHaptics, a new type of haptic feedback that is created by focusing ultrasound through the hand using a phased array of ultrasound transmitters (see Fig. 1). The device can be worn on the side of the hand opposite to the interaction surface requested by an on-body interface and does not interfere with interactive elements that the interface could provide (e.g., a menu projected on the skin [1], [2]). In our current implementation the focused acoustic energy can create sensations that seem to be located in the hand. We ultimately envision to be able to create sensations on the skin at the opposite side of the hand.

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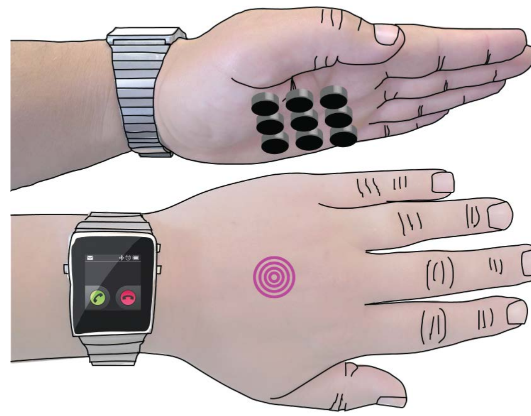

Fig. 1. Ultrasound transmitters emit acoustic energy into the hand. The pressure waves interfere constructively to create tactile feedback in the hand and through the hand (e.g., for smartwatch interactions [3]). Alternatively, the transmitters could be placed at the back of the hand to create tactile feedback at the palm (e.g., for palm-based interfaces [1], [2], [4]).

Our motivation for exploring this technology is grounded in the wide use of ultrasound in medical applications (e.g., for imaging diagnosis and therapy [8], [9]). Moreover, in medical science focused ultrasound has been used as a noninvasive method for diagnosing hearing and neurological disorders, and for creating tactile, temperature and pain sensations in the hand [10]. As a first step to investigate how ultrasound focused in the hand could provide tactile feedback for human-computer interaction, we present a technology that provides the basis for the device we envision and explore the fundamental requirements for creating tactile sensations.

We make the following contributions to demonstrate the feasibility of SkinHaptics: (1) We present the system we developed for focusing ultrasound through the hand using the acoustic time reversal signal processing technique [11], [12]. (2) We conducted two system evaluations using low-intensity, low-frequency ultrasound. In the first informal evaluation we verified that the system can steer and focus ultrasound through the hand. In the second formal evaluation we measured the distribution of acoustic energy at the back of the hand and identified regions with good focusing quality. (3) We conducted a preliminary user study on evoking tactile sensations with focused ultrasound and with unfocused ultrasound. We found that only focused ultrasound created noticeable sensations that were perceived slightly in the hand, which confirmed that SkinHaptics works.

II. SkinHaptics: Background and Principle

Our work is related to haptic feedback devices, focused ultrasound for stimulating neuroreceptor structures for medical diagnosis, and time-reversed acoustics.

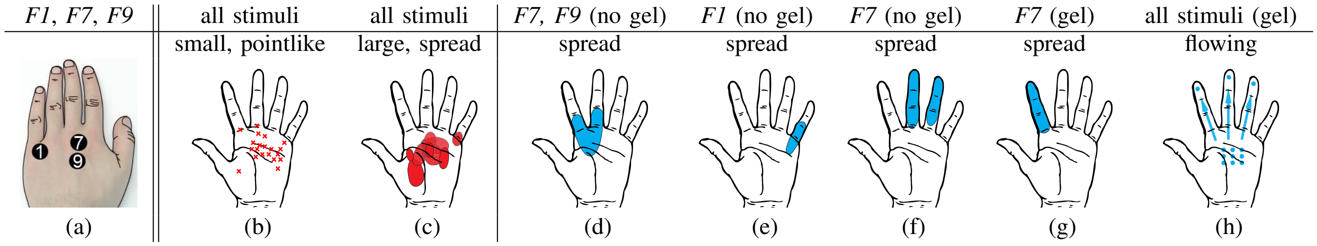

Fig. 10. (a) Focus locations at the back of the hand. (b–h) Characteristics of the sensations and the locations where the focused pulse series was perceived. (b,c) Frequent sensations on the skin, in the skin, or deeper in the hand. (d–h) Infrequent sensations on or under the skin (2–3×).

and that the focused energy can cause sensations that are perceived in the skin and deeper in the hand. However, we tested only one specific pulse series for which we did not vary the ultrasound intensity, nor the duration or the transmitter characteristics (e.g., size, directivity and coupling efficiency). Moreover, the frequency affects the size of the focal region and the optimal geometry of the focusing array [9], [11], [12], as well as the attenuation of energy that can change the intensity needed to create tactile sensations by several orders of magnitude [10]. For future work we intend to explore these parameters to better understand the conditions under which to focus the tactile sensations.

Our technology requires tight contact between the skin and transmitters and calibration to set the focus location. Recalibration is needed when the hand or the array is moved. We surmise that a one-time per-user calibration for different hand postures and array positions could be feasible with a transmit-receive array for sensing the posture from the waves reflected in the hand (similar to ultrasound imaging), and emitting the impulse responses that refocus the waves.

We hope that our work demonstrates the possibilities SkinHaptics offers for human-computer interaction and inspires other researchers to explore this technology.

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Custom-made Tangible Interfaces with TouchTokens

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ABSTRACT

TouchTokens were introduced recently as a means to design low-cost tangible interfaces. The technique consists in recognizing multi-touch patterns associated with specific tokens, and works on any touch-sensitive surface, with passive tokens that can be made out of any material. TouchTokens have so far been limited to a few basic geometrical shapes only, which puts a significant practical limit to how tailored token sets can be. In this article, we introduce *TouchTokenBuilder* and *TouchTokenTracker* that, taken together, aim at facilitating the development of tailor-made tangible interfaces. *TouchTokenBuilder* is an application that assists interface designers in creating token sets using a simple direct-manipulation interface. *TouchTokenTracker* is a library that enables tracking the tokens' full geometry. We report on experiments with those tools, showing the strengths and limitations of tangible interfaces with passive tokens.

CCS CONCEPTS

• **Human-centered computing → Interface design prototyping**; *Gestural input*;

KEYWORDS

Multi-touch surfaces, Tangible Interaction, Customization

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1 INTRODUCTION

Tangible interfaces have been designed for use in various domains such as music composition [14], storytelling [23], games [3, 26], teaching [21], programming [5, 11] and database querying [13, 25]. All of these interfaces feature physical tokens that aim at resembling actual objects from the targeted application area. Variations in the shape, size and material of these tokens all play an important role in providing the right manipulation affordances and conveying the proper semantics [22, 25]. Promoting tangible interfaces thus requires enabling designers to easily build tailor-made tokens that suit their specific needs.

The physicality of tangible interfaces makes them resistant to customization, however [12]. Various approaches to building tangible interfaces exist, such as vision-based frame analysis for diffused illumination tabletops (*e.g.*, [13, 14]), conductive tokens tracked on a capacitive surface (*e.g.*, [16, 27]) or specific sensors (magnetometers, Hall-effect sensors) augmenting the display surface in order to detect magnetic tokens [12, 18]. But whichever the technology considered, building and tracking tangible tokens remains an effortful process in terms of fabrication, software development, or both.

TouchTokens [19] offer an alternative solution, enabling the design of low-cost tangible interfaces. The general principle consists of designing tokens of varying shapes, all featuring notches that constrain how users grasp them. When users touch the surface while holding a given token, the specific multi-touch spatial pattern associated with it is recognized using a pattern-matching algorithm that does not require any training or calibration. TouchTokens are fully passive. They can be fabricated using any non-conductive material, offering designers much flexibility in that respect. However, the proposed approach is currently limited to a set of simple shapes (square, rectangle, circle and triangle). In this article, we introduce two tools that allow interface designers to build and recognize TouchTokens featuring arbitrary shapes.

Our first contribution, *TouchTokenBuilder*, is a software application that assists interface designers in placing notches on arbitrarily-shaped vector contours for creating *conflict-free* token sets. The application features a simple direct-manipulation interface and outputs two files: a vector-graphics description of all tokens in the set, ready to be fabricated using, *e.g.*, a laser cutter; and a numerical description of the geometry of each token.

Our second contribution, *TouchTokenTracker*, is a software library that takes as input the numerical description produced by *TouchTokenBuilder*. While TouchTokens' original algorithm [19] only provided developers with the ID of the recognized token and the user's finger coordinates, the new *TouchTokenTracker* also enables tracking the tokens' full geometry (location, orientation and shape) throughout their manipulation on the multi-touch surface. In addition, tracking remains robust even when users lift a finger while manipulating tokens (leaving a minimum of two fingers in contact with the surface), as illustrated in Figure 1.

After reviewing related work, we describe *TouchTokenBuilder* and *TouchTokenTracker*. We then present some proof-of-concept token sets designed with *TouchTokenBuilder*, and report on experiments conducted to evaluate *TouchTokenTracker*'s recognition accuracy for these token sets. Finally, we discuss the limitations of our approach and directions for future work.

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Levi-loop: A Mid-Air Gesture Controlled Levitating Particle Game

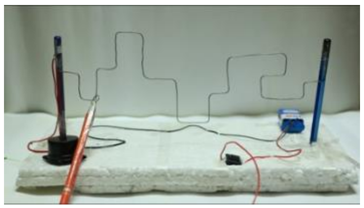

Figure 1: Traditional, do-it-yourself, wire-loop game setup composed of a wire, a loop, a battery and a buzzer.

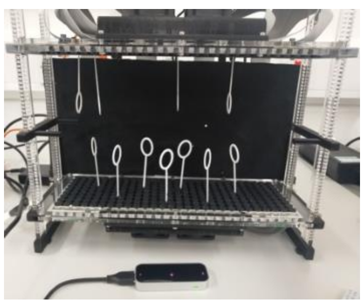

Figure 2: Levi-loop game setup composed of a phased ultrasound array (two sided), a collection of 3D printed hoops, a levitating particle, and a Leap Motion controller.

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Abstract

Acoustic levitation offers a novel alternative to traditional volumetric displays. With state-of-the-art hand-tracking technology, direct interaction and manipulation of levitating objects in 3D is now possible. Further, adding game-elements like completing simple tasks can encourage participant exploration of new technologies. We have therefore developed a gesture controlled levitating particle game, akin to the classic wire-loop game, that combines all these elements (levitation, hand-tracking, and gameplay) together with physical obstacles. Further, we have designed a gesture input set that constrains false triggering gestures and dropping of the levitating particle.

Author Keywords

Acoustic levitation; game; ultrasound; gesture input.

CSS Concepts

• **Human-centered computing~Human computer interaction (HCI)**; *Gestural Input*

Introduction

A wire-loop game, also known as "Buzz wire", is a classic childhood game that involves guiding a metal loop along a serpentine length of wire, without touching the loop to the wire (see Figure 1). The loop and wire are connected to a power source such that, if they touch, they form a closed electric circuit. A light or a

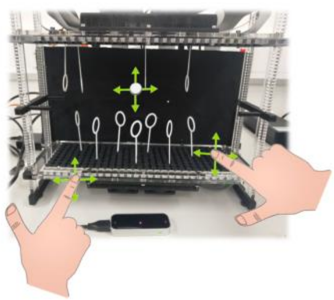

Figure 6: Illustration showing the Levi-loop demo interaction. The player initiates interaction by pointing with her thumb open (as if holding an imaginary gun) to *point-and-select* the levitating particle. The hand is being tracked by the Leap Motion controller. The coordinates of the player's index finger are mapped to levitating particle so that motion is coupled, and the user can *point-and-move* the levitating particle. The player can pause interaction by closing their thumb. The player can re-initiate or continue the interaction from a different location by opening her thumb, as long as her hand is within the field of view of the Leap Motion controller.

as pinch-to-move are also possible and quite stable. Finally, players can reposition themselves and their controlling hand-gesture in mid-play by closing their thumb in order get a better viewing-angle perspective of the maze challenge.

Conclusion

We have described Levi-loop, a novel interactive experience that uses gameplay to reflect on the challenges of precisely controlling mid-air levitating objects in the presence of physical constraints and obstacles. Levi-loop is also an engaging 'hands-on' experience that introduces CHI attendees to acoustic levitation interfaces, an emerging display type seen in the HCI literature and popular press.

Using the Levi-loop platform, we plan to investigate the accuracy-speed tradeoff described by Fitts's law, multiplayer extensions, and how recent projection mapping techniques coupled with rapid levitation movements [6] can be used together with acoustically transparent obstacles to, for instance, replicate the plethora of maze-like arcade games from the 70s and 80s like Pac-Man.

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