EdgeMatrix: Remote Tactile Feedback on Interactive Surfaces using a Shape Display

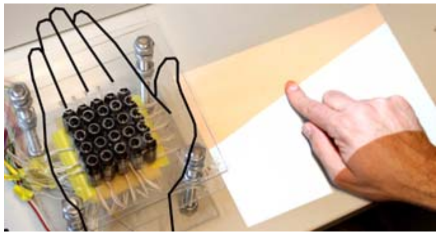

Figure 1 - The EdgeMatrix (left) spatially separates touch-interaction and resulting tactile feedback.

Hendrik Richter
LMU University of Munich
Amalienstrasse 17
80333 Munich, Germany
hendrik.richter@ifi.lmu.de

Alexander Wiethoff
LMU University of Munich
Amalienstrasse 17
80333 Munich, Germany
alexander.wiethoff@ifi.lmu.de

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Abstract
We present the EdgeMatrix, a compact 5x5 pin array to provide remote tactile feedback in conjunction with interactive surfaces. The novel idea of our approach is to communicate cues resulting from a touch interaction on a digital surface to remote parts of the user's body. Thus, the interaction on the screen is spatially separated from the resulting tactile cues about orientation or state of virtual objects. In this paper, we discuss some benefits of our approach, describe the EdgeMatrix system and illustrate our ongoing user study.

Keywords
Tactile Feedback, Pin Array, Tactual Display, Interactive Surfaces, Multi Touch

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces. – *Haptic I/O*

General Terms
Experimentation, Human Factors

Introduction

Tactile feedback during the manipulation and exploration of direct-touch based interfaces has been shown to reduce the errors made, to enhance interaction speed and to minimize visual distraction. This applies especially to situations or environments with increased cognitive or visual load [9]. However, most current multi-touch surfaces do not use haptic feedback as a communication channel.

Research on tactile feedback for direct touch surfaces mostly falls into one of three categories: First, mobile actuator systems like [4] move the mobile device or its screen as a whole using motors or piezoelectric actuators. Thereby only a single touch input can be augmented haptically, which is mostly fine given the size of mobile screens. Second, shape displays, such as Relief [2] segment the interactive surface into individually movable ‘haptic pixels’. Currently, these systems only provide a small number of actuated points due to mechanical constraints. A third way of bringing tactile feedback to interactive surfaces is the use of tangible interfaces on tabletops, which provide the tactile stimulus and can simultaneously be used as input devices [3]. All of these approaches basically assume that tactile feedback for an interaction should be applied directly to the interacting body part, i.e. mostly to the fingertip.

Our work questions this assumption. We assume that the distal communication of tactile feedback can improve the interaction with touch surfaces in terms of error rates, interaction speed and cognitive or visual load. Furthermore, we hypothesize that our approach yields the following benefits:

- The movement of every single finger of multiple hands on the multi touch surface can be augmented haptically. We refer to this feature as true multi-haptics.
- The area of tactile stimulation is not limited to the size of a fingertip. Haptically enlarging the tactile resolution of contacts to the interactive surface becomes possible.
- The design of the actuator system is not constrained by the configuration of the touch interface. Thus, adaptable actuator technologies and signals can be used to convey versatile stimuli.
- Using multiple actuators, every user can feel something else when touching the same objects on a shared interactive display. The communication of tactile information is personal and private.

Tactile Displays

The usage of tactile displays has been realized by several research groups, artists and companies [5]. Probably being the most famous example, Bach-y-Rita has done long-standing work in the fields of tactile vision and sensory substitution [6]. Regarding the positive effects of additional tactile cues during touch based HCI, the transfer of concepts from sensory substitution to touch interaction seems valuable.

EdgeMatrix

Our first step in this direction is the conveyance of geometrical cues like shape and orientation of objects on the screen using the reduced complexity of our actuator system EdgeMatrix (Figure 2).

Figure 2 - EdgeMatrix tactile display prototype

Example of EdgeMatrix Use:
We use the glabrous skin of the contralateral palm as the area of application. Of course, this location prevents the user from interacting using two hands. Nevertheless, we decided to use the contralateral palm so we can base our findings on the well-known characteristics of mechanoreceptive units in the glabrous skin area. Another reason for our decision is the distinct separation of action and resulting stimulus, we are conceptually mirroring the feedback to the other hand.

Virtual elements such as lines or rectangles with different orientations and sizes are depicted in the virtual scene. The user slides his fingertip over the flat surface of the interactive table. When the user crosses the edge of an inclined object with his fingertip, the EdgeMatrix responds simultaneously. Pins are gently pushing towards the user's other palm resting on the EdgeMatrix, haptically forming the inclined object. The fingertip's permanent exploratory movements on the screen cause a continuous change of the tactile image. Objects elevate distinguishably, their borders under the fingertip feel smooth and rounded.

Technical Details:
According to Kaczmarek et al. [8], *"Sensory Substitution is the use of one human sense to receive information normally received by another sense"*. For the sense of touch, also the relocation of tactile information is called sensory substitution.

According to Visell [1], a sensory substitution system can extend the user's perceptual-motor capabilities into virtual environments. Following his approach, the technical characteristics of the EdgeMatrix system can be described as follows: An interactive surface is created by projecting a graphical user interface on a table. The exploratory movements of the user's finger in the GUI are tracked optically using an infrared camera. The information is translated into a set of signals using the open source multi-touch tracking application CCV[1]. Finger positions are sent via TUIO protocol[2] to the main application that is responsible for controlling interactive elements, visual display, and tactile output. The exploratory movement of the user's finger affects the sensor modality; the interaction loop is closed (see Figure 3).

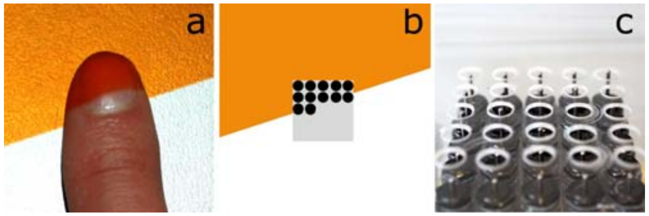

Figure 3 - Closed interaction loop of the EdgeMatrix system. The finger's movement is tracked (a), a virtual sensor matrix computes hit-tests (b), the corresponding individual tactile actuators are triggered (c).

We used 25 off-the-shelf linear tubular solenoid magnets to form the 5x5 pin matrix. A plunger is pushed out of the solenoid's coil body when power is on, switching the power off retracts it. The distance between the pins is 12.7 mm (0.5''); the haptically active display area is 50.8 mm (2'') squared. A transparent membrane can be put atop the haptic area. Thus, the action of distinct pins resembles the sensation of moving shapes.

[1] http://ccv.nuigroup.com/
[2] http://www.tuio.org/

Conclusion and Future Work

With EdgeMatrix, we present a functional interface using the spatial separation of touch based human-computer input from tactile computer-human output. We hypothesize that the remote application of tactile feedback on interactive surfaces enriches interaction and improves usability.

The EdgeMatrix is the first in a series of remote tactile actuators. Encoding additional information about physical or semantic conditions of interactive elements is an integral part of our research. With an ongoing user study comprising orientation and thickness discrimination tasks, we hope to advance our knowledge about the user's perception of distal cues.

We have three objectives of future research. First, the placement of tactile actuators on the human skin by instrumenting the user or the user's direct environment. Second, the actuator technologies that are used including tactile displays, vibrational elements or piezoelectric crystals. Third, the design of haptic signals to enrich and extend the interaction with touch-sensitive surfaces.

With emerging stimulus generating technology (e.g. [7]), it will be possible to develop tactile interfaces that curve around our bodies like a second skin or a haptic clothing. Tactile actuators in our direct environment can adapt to our body surface and to our actions and movements. We believe that our approach of separating action and feedback makes non-planar touch interfaces with true multi-touch feedback possible. Every interactive object can give rich individual tactile feedback to the user.

Considering these assumptions, we want to use the workshop to discuss the future use of adaptive tactile interfaces. We hope to exchange ideas of how to advance touch based HCI using haptic actuators, signals and interactions. Research on our approach has a stake in the development of true Organic User Interfaces.

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