MudPad
Tactile Feedback for Touch Screens

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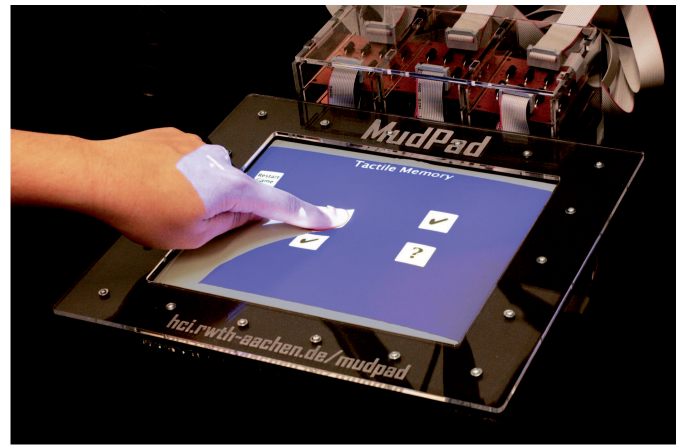

Figure 1: MudPad provides localized active haptic feedback independently at multiple points.

Abstract
MudPad is a system enriching touch surfaces with localized active haptic feedback. A soft and flexible overlay containing magnetorheological fluid is actuated by an array of electromagnets to create a variety of tactile sensations. As each magnet can be controlled individually, we are able to produce feedback in realtime locally at arbitrary points of interaction.

Keywords
Tactile feedback, haptic feedback, tactile textures, touch interface.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User interfaces – Haptic I/O

General Terms
Human Factors

Introduction
Touch screen interfaces are increasingly common input devices. They are intuitive to use and their visual interface can easily be changed or re-arranged. Several studies published in the last years [6, 7, 13] point to performance increases on touch screen devices when tactile feedback is provided. But so far touch screen devices do not offer localized tactile feedback for individual points of interaction. With MudPad we present an overlay for pressure sensitive touch screens that provides localized active haptic feedback at multiple points. We can therefore enrich the entire interface with a haptic layer as each display area can be individually controlled to 'display' a distinct tactile feedback pattern.

Related Work
Poupyrev et al. [12] presented Lumen, a low resolution height display capable of displaying an additional layer of information through different pixel heights. As it is based on shape memory alloy its reaction time is slow and not comparable to MudPad.
Harrison et al. introduced inflatable buttons [4] and thus gave virtual buttons a physical shape. However, the placement of the buttons is fixed once assembled. Additionally, each button requires a dedicated pneumatic pump to be able to operate it independently.
Hoffmann et al. presented a haptic keyboard [5] that prevents the user from accidentally pressing keys by increasing their resistance. While this approach is related to MudPad, it is also a special purpose system limited to keyboard input.
Marquardt et al. introduced the haptic tabletop puck [11] that allows a one-point access to an additional layer of haptic information (height map) on a multitouch table. To get simultaneous access to several points one puck for each point is necessary.
Recently, Leithinger et al. presented with Relief [10] a low-cost height display using rods combined with top projection. The system provides multi-point sensing and feedback, although as a height display it mainly addresses visual perception.
Block et al. introduced touch-display keyboards [3], unmarked keyboards supplemented by top-projection and a camera to detect touch positions. Such a physical keyboard has excellent tactile feedback, but it also restricts interaction to discrete key-based input.
Hook et al. [8] presented a system using ferrofluid for multitouch sensing. While this approach is similar in construction to MudPad, it is an input device without active haptic feedback.
Bau et al. [1] recently presented TeslaTouch, a touchscreen using electrovibration. The device produces a subtle tactile feedback when a user moves his fingertips over the surface.

System Design
MudPad consists of three functional layers (Figure 2). The bottom part is an array of electromagnets (Figure 3) driven by a microcontroller which is controlled by a PC. We

installed a thin pressure-sensitive resistive touch screen directly above the magnets. The uppermost layer consists of a pouch with flexible top and bottom foils filled with magnetorheological fluid. It is covered by a latex sheet that also acts as a top-projection surface.

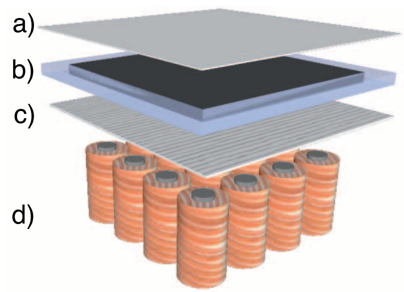

Figure 2: Schematic overview of the system design (projector omitted in this drawing).

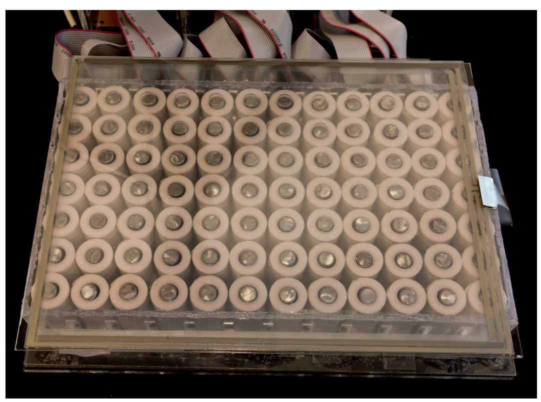

Figure 3: The array of electromagnets used for actuation with a thin resistive touch screen on top.

Feedback patterns are sent via a serial connection to an Arduino board driving the magnets. Our design is described in detail in [9]. As the actuation fluid has a very fast response time of 1–2ms, low-frequency waveforms, i.e., wave tables can also be used as a source for feedback patterns.

Applications

Many existing touch screen applications could profit from this kind of tactile feedback. The very common task of entering text can be improved by MudPad by manipulating the surface stiffness to give keys from a virtual keyboard a tactile component to create the illusion of actually pressing a physical button.

There is a variety of other usage cases apart from text entry. In Table 1 we summarize the following three dimensions to classify some example applications and point out the different uses.

- Additional vs. substituted information: tactile feedback can be used to adding another layer of information or to substitute visually presented information as would be necessary to help visually impaired users to operate touch screens.
- Multi-modal (increase the total amount of information that can be presented) vs. cross-modal (support the information presented visually or auditory).
- Secondary control vs. integrated device: MudPad as a secondary control device allows for eyes-free interaction by utilizing the tactile feedback to help, e.g., with orientation and navigation, vs. applications which employ MudPad as an integrated device that combines touch input with localized feedback and a visual interface thereby enhancing touch screen interaction with a tactile component.

	control		integrated	
	substitute	additional	substitute	additional
cross-modal	-	graph	keyboard	keyboard
multi-modal	secure keypad	graph, background	sequencer, secure keypad	background, error prevention

Table 1: Categorization of example applications depending on whether MudPad is used as a secondary control or as an integrated device, substituting or adding information, and whether the feedback is designed cross- or multimodal.

Graph exploration. The localized tactile feedback from MudPad can be used to communicate properties of visualizations like cluster density in graph visualizations. The touch surface allows a user to explore a larger visualization shown on a bigger screen. MudPad is here a control device where the tactile feedback allows eyes-free interaction while the visual attention is directed to the larger screen. The density of information at certain locations could be represented by localized pulses with varying rates and rhythms. The fluid thereby allows to create short pulses like a heart beat which is more flexible than commonly used vibrotactile feedback where small motors are turned on for short time intervals to create short buzzing feedback patterns.

Background Information. The unobtrusive tactile feedback possible with MudPad can also be used to communicate background information. This is possible for MudPad as an integrated or as an additional control device. With an integrated device information about a finished background process could be presented as soon as user contact is detected. As tactile feedback relies on a very private sensory channel that requires touch to be perceived, information might go unnoticed when no interaction takes place while the event occurs. If the information is presented with a delay upon the next interaction it might already be outdated. Hence, this application is not sufficient as a sole feedback channel for important background processes.

Music Sequencer. Music composition applications as the one shown in Figure 4 can be augmented, so that each track (featuring one instrument of the composition) can be felt when a finger is placed on the displayed waveform regardless whether it is currently audible or muted. A similar setup would also be useful to DJs when matching the playback speeds of two songs. This would be most useful for an integrated device usage.

Figure 4: Screenshot of Apple's GarageBand application.

Error Prevention for Virtual Keyboards. Another application could be an error-prevention aid for typing on touch screens (Figure 5). As the surface softness is controllable, keys that do not fit an entry in a dictionary can be hardened and thereby made less likely to be pressed accidentally [5].

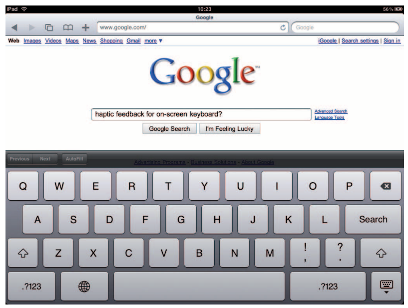

Figure 5: Screenshot of an Apple iPad virtual keyboard.

Secure Touch Input for Public Screens. The idea of a secure touch keypad (see [2] and Figure 6) is to allow users to enter sensitive information on a touch input device while being protected against shoulder surfing. The haptic sense is a private channel where physical contact is necessary to receive information. A secure touchpad therefore gives tactile feedback to tell a user that, e.g., the next entered character will be ignored and should be chosen at random.

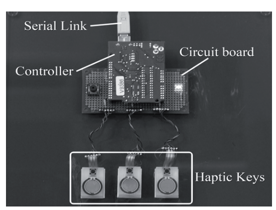

Figure 6: Secure haptic keypad as proposed by Bianchi [2].

Gaming. The tactile patterns can be used to create a tactile version of the 'Memory' game (see Figure 1). A set of buttons is displayed with each one providing a distinct feedback pattern. A player feels the buttons and matches all pairs displaying the same tactile sensation.

Conclusion

We present a haptic overlay for touch screens to provide rich tactile feedback. Due to each location being addressable individually, the whole screen can be associated with an appropriate feedback pattern. The ability to produce this kind of localized multi-point actuation allows the tactile exploration of an interface and opens new possibilities for feedback design.

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