MudPad: Localized Tactile Feedback on Touch Surfaces

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ABSTRACT
We present MudPad, a system that is capable of localized active haptic feedback on multitouch surfaces. An array of electromagnets locally actuates a tablet-sized overlay containing magnetorheological (MR) fluid. The reaction time of the fluid is fast enough for realtime feedback ranging from static levels of surface softness to a broad set of dynamically changeable textures. As each area can be addressed individually, the entire visual interface can be enriched with a multitouch haptic layer that conveys semantic information as the appropriate counterpart to multi-touch input.

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

General terms: Human Factors

Keywords: haptic I/O, tactile feedback, multitouch

INTRODUCTION
Touch screens have become common input devices. While they are intuitive to use, they do not provide tactile feedback for user input. Simple vibration and audio signals can be used to alleviate this problem, but these signals are undirected and do not support complex messages beyond simple acknowledgments. Additionally, fingers touching the surface occlude the visual interface. With MudPad [3], we enrich the entire GUI with a continuous haptic layer. Each display area can be individually controlled to 'display' a distinct tactile feedback pattern, i.e., each graphical UI element or part thereof can be associated with a different tactile sensation. By doing so, we cannot only acknowledge user input but also convey additional semantic information, e.g., about system states and background processes, possibly saving valuable screen real estate.

SYSTEM DESIGN
MudPad consists of four layers (Figure 2). The bottom layer *(d)* is an array of electromagnets and associated electronics. Each magnet can be addressed individually to build up a localized magnetic field. A thin resistive high-resolution touch surface *(c)* capable of multitouch sensing (e.g., as proposed by [4]) is placed directly on top. It is covered by a thin (3–5 mm) fluid-filled pouch *(b)* with flexible top and bottom sheets so that pressure from user input can be detected by the touch surface. A white latex sheet *(a)* is used as a top-projection surface. Similar setups using layers *(d)* + *(b)* have been proposed before by White [5] to construct a haptic display, and by Hook et al. [2] as a ferromagnetic input device.

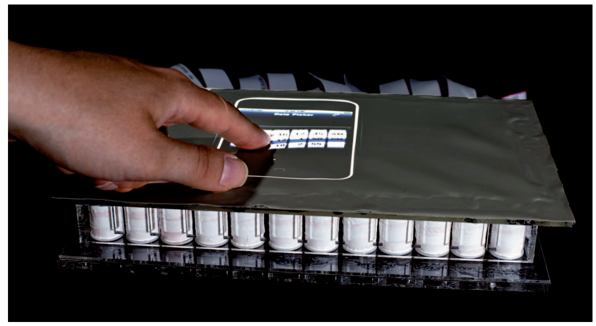


Figure 1: MudPad is a system that provides localized haptic feedback independently at multiple points.

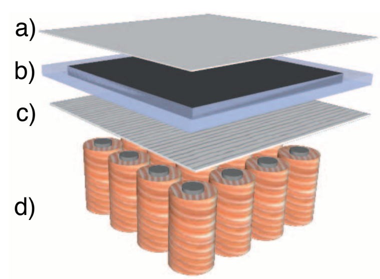
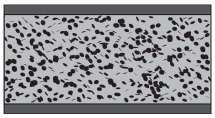


Figure 2: Exploded view of system design: a) latex touch & projection surface, b) MR fluid pouch, c) resistive touch input pad, d) array of electromagnets (projector omitted in this schematic).

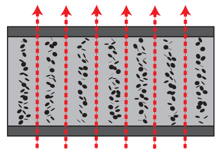
Magnetorheological Fluid
MR fluid is a "smart fluid" whose viscosity can be altered linearly by applying a magnetic field of variable strength. The liquid is a suspension of a carrier fluid (glycerin) and free flowing carbonyl iron particles[1]. When a magnetic field is applied, the particles align in chains along the flux lines, thereby increasing the viscosity. Viscosity levels range from fluid like water (Figure 3(a)) to viscous like peanut butter (Figure 3(b)). Removing the field allows the fluid to return to its original state.

Particle alignment and dealignment in the MR fluid happen very quickly. Typical response times are less than 2 ms. Hence, we can locally actuate the fluid using frequencies of up to 600 Hz, thus covering the full range of human tactile perception. Since arbitrary waveforms can be used, we are able to create a rich set of dynamic haptic textures at any location on MudPad in real-time.

[1]BASF CEP SQ carbonyl iron powder.



(a) Off state: particles flow freely in the carrier fluid, low viscosity.



(b) On state: particles arrange along the flux lines, high viscosity.

Figure 3: MR fluid in a homogeneous magnetic field.

Performance

The output resolution of MudPad is primarily determined by the size and number of the magnets used to activate the MR fluid. The magnets have to be strong enough to line up the particles, hence we use relatively large magnets (⌀ 2 cm) for our prototype. This limits the number of magnets for a 10″ tablet to an array of 12 by 7. Although this means that the sources of the magnetic field are sparsely distributed, creating haptic feedback at arbitrary positions is still possible by superimposing fields of multiple magnets. We call a group of magnets that are responsible for a given location the *actuation domain* of that location.

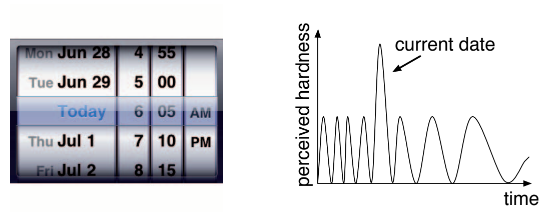
Note that for a single finger per actuation domain the output resolution is still only bounded by the input resolution since the haptic feedback signal in the domain's area will vary according to the exact position of the finger. If, for example, several UI elements with different feedback patterns are placed within a single actuation domain the feedback of the domain changes when the user moves her finger from one element to another.

We cannot yet, however, isolate the effect to areas as small as a single fingertip, although this would be desirable for fine-grained multitouch input and feedback. Two fingers placed right next to each other at the same time would thus receive a mix of their respective haptic feedback signals.

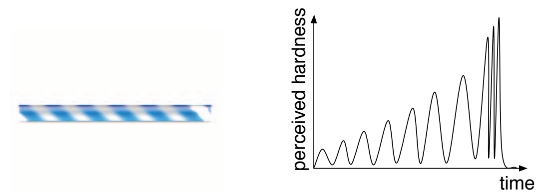
EXAMPLE MAPPINGS

All feedback patterns are constructed from simple elementary signals. The parameters for these signals are intensity, softness, vibration frequencies, and waveforms. Varying these parameters dynamically allows to simulate the haptic impression of interacting with tangible UI elements. This way, pressing the touch surface can give different impressions, for example, that of pressing a mechanical button. Also, other signals like the varying amplitudes of audio files can be used to manipulate the viscosity.

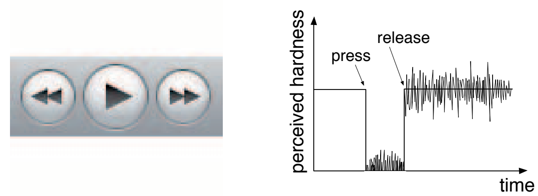
Figure 4 shows some of the widgets for which we designed a tactile mapping (cf. [1]). By quickly varying the hardness each date *(a)* rolling by produces a 'tick' with a more distinct bump for the current date. A progress bar *(b)* changes from softly pulsing to faster intervals when approaching completion which can be useful to monitor the state when the progress bar belongs to a background window. The *Play, Rewind,* and *Forward* buttons *(c)* let a user feel the current, last, or next track respectively. Depicted in the graph is the feedback for *Play*: the button has a certain stiffness to make it tangible; when pressed it becomes fluid and the user's finger sinks in; at the same time the music starts and a tactile interpretation of, e.g., its amplitude can be felt on the button.



(a) Date picker widget



(b) Progress bar widget



(c) Playback control buttons for a music player application

Figure 4: A selection of widgets together with their respective tactile representations.

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