MudPad: tactile feedback and haptic texture overlay for touch surfaces
Yvonne Jansen, Thorsten Karrer, Jan Borchers

To cite this version:
Yvonne Jansen, Thorsten Karrer, Jan Borchers. MudPad: tactile feedback and haptic texture overlay for touch surfaces. ACM International Conference on Interactive Tabletops and Surfaces (ITS '10), ACM, Nov 2010, Saarebruck, Germany. pp.11-14, 10.1145/1936652.1936655. hal-01404492
MudPad: Tactile Feedback and Haptic Texture Overlay for Touch Surfaces

Yvonne Jansen, Thorsten Karrer, Jan Borchers
RWTH Aachen University
{yvonne, karrer, borchers}@cs.rwth-aachen.de

ABSTRACT
We introduce MudPad, a system capable of localized active haptic feedback on multitouch screens. We use an array of electromagnets combined with an overlay containing magnetorheological (MR) fluid to actuate a tablet-sized area. As MudPad has a very low reaction time it is able to produce instant multi-point feedback for multitouch input, ranging from static levels of surface softness to a broad set of dynamically changeable textures. Our system does not only convey global confirmative feedback on user input but allows the UI designer to enrich the entire interface with a tactile layer conveying local semantic information. This also allows users to explore the interface haptically.

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

General terms: Human Factors

Keywords: Haptic I/O, tactile feedback, magnetic fluid, texture display

INTRODUCTION
Touch screen interfaces are increasingly common in both mobile and stationary computers because their user interfaces are intuitive to use and their visuals can be easily changed or re-arranged on the fly. Designing user feedback on these devices, however, is limited by a number of factors. While vibration and sound may be available to acknowledge user input these types of feedback are non-local and generally undirected. Especially on touch devices that allow multiple points of input a richer feedback channel is needed.

Temporary graphical overlays which are often used in these situations can give local visual feedback but still have to be moved out of the fingers’ occlusion areas and thus potentially occlude other parts of the interface. Examples of these techniques are the on-screen keyboards of current smart phones. The Samsung i718, e.g., uses global tactile clicks to confirm key presses, the Apple iPhone uses sound and graphical overlays that appear above the pressed keys.

Although these approaches work reasonably well, MudPad combines the advantages of graphical overlays - locality and low latency - with those of tactile feedback - privacy, eyes-free access, and no need for screen real estate. For this, we add a continuous haptic feedback layer to the display that is able to produce a wide range of tactile signals at arbitrary positions. Since every position or area on the surface can be addressed individually, each graphically displayed UI element can be associated with a distinct tactile sensation making MudPad a haptic feedback counterpart for multitouch input.

RELATED WORK
As both the field of haptic feedback and multitouch input is very broad, we will restrict the coverage here to only those systems which lie in the much smaller intersection of these fields.

Until now there has not been a system capable of localized active haptic feedback for touch screens. There are some intersecting projects though. Poupyrev et al. [14] 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 [6] 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 [7] 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 entry.

Marquardt et al. introduced the haptic tabletop puck [12] that allows a one-point access to an additional layer of haptic information on a multitouch table. Even though it is possible to use several of these pucks simultaneously, each one occludes part of the interface.

Recently, Leithinger et al. presented with Relief [11] a low-cost height display using rods combined with top projection. Even though the system provides multi-point sensing and feedback, 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. [9] 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 electrotouch. The device produces a subtle tactile feedback when a user moves his fingertips over the surface.

**USAGE SCENARIOS**

Before diving into the specifics of the proposed design, we introduce some possible scenarios to illustrate the benefits of localized active haptic feedback.

**Virtual Keyboard**

Adding feedback to virtual keyboards (like Figure 2a) is probably one of the most intuitive applications for localized tactile feedback. Virtual keyboards are in general much harder to use than physical ones as either constant visual attention or very accurate muscle memory is necessary to operate them [8, 4]. Being able to distinguish keys from each other and to feel whether intended input was recognized by the system would be an enormous improvement.

**Music Sequencer**

A special purpose application would be touch-based music instruments or sequencer applications. The use of touch input for music creation became popular with the ReacTable [10] where tangibles provide physical controls. In general, musicians benefit from touch input devices (see Figure 2b) for music production purposes as they offer the flexibility of a digital recording environment without the need of special hardware for different kinds of controls. Being able to feel the music in the controls or at the touch surface would further help musicians to stay ‘in touch’ with the music they are producing.

**Secure Touchpad Input**

The idea of a secure touchpad [2] (see Figure 2c) 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.

**SYSTEM DESIGN**

MudPad consists of four layers as shown in Figure 3 with the bottom layer (d) being an array of electromagnets similar to the Actuated Workbench [13]. Each magnet can be addressed individually to build up a localized magnetic field. Directly

Figure 2: Possible usage scenarios for localized multi-point haptic feedback. (a) Virtual keyboard of an iPad. (b) JazzMutant Lemur (www.jazzmutant.com) (c) The secure haptic keypad by Bianchi.
on top is a thin resistive high-resolution touch surface (c) ide-
ally capable of multitouch sensing (e.g., an UnMousePad as
proposed by [15]). The touch surface 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 cover (a) is used as a top-
projection surface.

**Magnetorheologic Fluid**

The liquid inside the pouch (b) is a smart fluid, i.e., its phys-
ical properties can be controlled. For our purposes we use
a magnetic fluid the viscosity of which can be linearly con-
trolled by applying a magnetic field. Viscosity levels range
from fluid like water (Figure 4a) to viscous like peanut but-
ter (Figure 4b). The liquid is a suspension of a carrier fluid

![Figure 4: Magnetorheologic fluid under the influence of a
homogeneous magnetic field. (a) Off state: free flowing par-
ticles within the carrier fluid, i.e., low viscosity. (b) On state:
particles align along the flux lines, i.e., high viscosity.](image)

(we use glycerin as it is chemically compliant with the latex
cover) and free flowing carbonyl iron particles\(^1\) sized \(3\mu\)m in average. When a magnetic field is applied, the particles
align in chains along the flux lines, thereby increasing the
viscosity—the fluid stiffens. Removing the field allows the
fluid to return to its original state.

**Actuation**

Particle alignment and dealignment in the MR fluid happen
very quickly. Typical response times are less than 2 ms. This
allows us to locally actuate the fluid using frequencies up to
600 Hz covering the full range of human tactile perception
(highest sensitivity for vibrations at about 250 Hz, see, e.g.,
[5]). 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. Also, different static levels of stiff-
ness can be achieved by applying a pulse width modulation
(PWM) signal at a much higher frequency. This way, the
fluid’s viscosity can be linearly controlled via the PWM duty
cycle without incurring any perceivable vibration.

**Electronics used to control the magnets**

As we mentioned before a reasonably strong magnetic field
is necessary to actuate the fluid. Accordingly each of the
custom made magnets draws up to 400 mA at 35 V and is
controlled by a motor driver IC (ST L6219).

**Limitations of the approach**

As the fluid contains iron particles it is opaque. Therefore,
we can only use top projection for now. A thin and highly
flexible display could be used instead of the latex cover but
we are not aware of a currently available, suitable product.

**Touch Input Technology**

Most of today's touch screen de-

[15]). The touch surface 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 cover (a) is used as a top-
projection surface.

**Magnetorheologic Fluid**

The liquid inside the pouch (b) is a smart fluid, i.e., its phys-
ical properties can be controlled. For our purposes we use
a magnetic fluid the viscosity of which can be linearly con-
trolled by applying a magnetic field. Viscosity levels range
from fluid like water (Figure 4a) to viscous like peanut but-
ter (Figure 4b). The liquid is a suspension of a carrier fluid

![Figure 4: Magnetorheologic fluid under the influence of a
homogeneous magnetic field. (a) Off state: free flowing par-
ticles within the carrier fluid, i.e., low viscosity. (b) On state:
particles align along the flux lines, i.e., high viscosity.](image)

(we use glycerin as it is chemically compliant with the latex
cover) and free flowing carbonyl iron particles\(^1\) sized \(3\mu\)m in average. When a magnetic field is applied, the particles
align in chains along the flux lines, thereby increasing the
viscosity—the fluid stiffens. Removing the field allows the
fluid to return to its original state.

**Actuation**

Particle alignment and dealignment in the MR fluid happen
very quickly. Typical response times are less than 2 ms. This
allows us to locally actuate the fluid using frequencies up to
600 Hz covering the full range of human tactile perception
(highest sensitivity for vibrations at about 250 Hz, see, e.g.,
[5]). 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. Also, different static levels of stiff-
ness can be achieved by applying a pulse width modulation
(PWM) signal at a much higher frequency. This way, the
fluid’s viscosity can be linearly controlled via the PWM duty
cycle without incurring any perceivable vibration.

**Electronics used to control the magnets**

As we mentioned before a reasonably strong magnetic field
is necessary to actuate the fluid. Accordingly each of the
custom made magnets draws up to 400 mA at 35 V and is
controlled by a motor driver IC (ST L6219).

**Limitations of the approach**

As the fluid contains iron particles it is opaque. Therefore,
we can only use top projection for now. A thin and highly

\(^1\) BASF CEP SQ carbonyl iron powder.

\(^2\) www.stantum.com
Table 1: Elementary building blocks from which feedback patterns can be constructed.

| Magnet Signal | Fluid State | UI Mapping (System View)     | UI Mapping (User View) |
|---------------|-------------|------------------------------|------------------------|
|               | stiff       | inactive areas, i.e., no user input possible | prevent interaction |
| press release | quick on/off transition | active UI elements, e.g., buttons | acknowledge user input |
|               | (rapidly changing vibrating) | active areas, demanding user attention | communicate system processes, e.g., progress bar |
|               | fluid       | active areas, allow interaction | neutral |

it harder to press them.

Due to the fast response of the fluid, the lower frequency part of audio signals can be ‘played back’ by the magnets, letting the user feel the rhythm of the music as described in one of the usage scenarios above. Thus, with MudPad, each slider in a music sequencer could play the signal it controls.

As a user’s fingers can rest on the surface we can also use subtle ambient patterns to convey context information. Indicating running background tasks such as downloads or making the current system volume perceptible on media playback controls are just some possible examples.

**FUTURE WORK**

We are currently designing user tests to formally evaluate the system. We are also planning to investigate user preferences for mappings of tactile parameters and learning efforts to distinguish different widgets by touch. For example, we are interested to learn if it is possible to haptically distinguish an OK button from a Cancel button.

**CONCLUSION**

We proposed a haptic overlay for a resistive touch surface that is capable of rich tactile feedback. It uses controlled magnetic fields to effect the local viscosity of a smart fluid, simulating different haptic textures. This way, the system is able to produce localized actuation signals covering the full frequency range of human perception and to vary the softness of the surface. The ability to produce this kind of localized multi-point actuation allows users to explore an interface by touch and opens up new possibilities for feedback design.

**ACKNOWLEDGEMENTS**

This work was funded in part by the German B-IT Foundation and by the German government through its UMIC Excellence Cluster for Ultra-High Speed Mobile Information and Communication at RWTH Aachen University.

**REFERENCES**

1. O. Bau, I. Poupyrev, A. Israr, and C. Harrison. Tesla-touch: electrovibration for touch surfaces. In *Proc. of UIST ’10*, pages 283–292.

2. A. Bianchi, I. Oakley, and D. S. Kwon. The secure haptic keypad: a tactile password system. In *Proc. of the CHI ’10*, pages 1089–1092.

3. F. Block, H. Gellersen, and N. Villar. Touch-display keyboards: transforming keyboards into interactive surfaces. In *Proc. of CHI ’10*, pages 1145–1154.

4. W. Buxton, R. Hill, and P. Rowley. Issues and techniques in touch-sensitive tablet input. *SIGGRAPH ’85*, 19(3):215–224.

5. E. Goldstein. *Sensation and Perception*. Wadsworth New York, 2007.

6. C. Harrison and S. E. Hudson. Providing dynamically changeable physical buttons on a visual display. In *Proc. of CHI ’09*, pages 299–308.

7. A. Hoffmann, D. Spelmezan, and J. Borchers. Typertight: a keyboard with tactile error prevention. In *Proc. of CHI ’09*, pages 2265–2268.

8. E. Hoggan, S. A. Brewster, and J. Johnston. Investigating the effectiveness of tactile feedback for mobile touchscreens. In *Proc. of CHI ’08*, pages 1573–1582.

9. J. Hook, S. Taylor, A. Butler, N. Villar, and S. Izadi. A reconfigurable ferromagnetic input device. In *Proc. of UIST ’09*, pages 51–54.

10. S. Jordà, G. Geiger, M. Alonso, and M. Kaltenbrunner. The reactable: Exploring the synergy between live music performance and tabletop tangible interfaces. In *Proc. of TEI ’07*, pages 139–146.

11. D. Leithinger and H. Ishii. Relief: A scalable actuated shape display. In *Proc. of TEI ’10*, pages 221–222.

12. N. Marquardt, M. A. Nacenta, J. E. Young, S. Carpendale, S. Greenberg, and E. Sharlin. The haptic tabletop puck: Tactile feedback for interactive tabletops. In *Proc. of ITS ’09*, pages 85 – 92.

13. G. Pangaro, D. Maynes-Aminzade, and H. Ishii. The actuated workbench: Computer-controlled actuation in tabletop tangible interfaces. In *Proc. of UIST ’02*, pages 181–190.

14. I. Poupyrev, T. Nashida, S. Maruyama, J. Rekimoto, and Y. Yamaji. Lumen: Interactive visual and shape display for calm computing. In *SIGGRAPH ET ’04*, page 17.

15. I. Rosenberg and K. Perlin. The UnMousePad: an interpolating multi-touch force-sensing input pad. In *Proc. of SIGGRAPH ’09*, pages 1–9.

16. M. Weiss, F. Schwarz, S. Jakubowski, and J. Borchers. Madgets: Actuating widgets on interactive tabletops. In *Proc. of UIST ’10*, pages 293–302.