Mudpad: Fluid Haptics for Multitouch Surfaces

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Abstract
In this paper, we present an active haptic multitouch input device. Its touch surface is a malleable pouch filled with a smart fluid. The viscosity of this fluid can be controlled to provide localized active haptic feedback. Magnetic fields can stiffen the liquid locally, thus creating an invisible ”labyrinth” that can be felt when a user tries to displace the liquid at an activated location. The user feels this labyrinth as a relief when running her fingers over the surface. We believe there are promising applications for this kind of haptic feedback. Hence, we intend to further investigate them in comparison to traditional vibrotactile feedback techniques.

Keywords
fluid haptics, haptic input device, active feedback, multitouch, magnetic fluid, magneto-rheologic effect

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

General Terms
Human Factors

Introduction

Haptic feedback has been around for many years, though only force-feedback devices made it to the consumer market (e.g., in mobile phones or game controllers). Those devices use vibrotactile actuators to get the user's attention or to give feedback about some action. With the ever rising popularity of touchscreen phones, such as the iPhone, constant and immediate visual (and/or auditory) feedback is necessary to confirm a user's actions. Eyes-free operation without any tactile feedback is almost impossible.

With multitouch tabletops the problems are essentially the same, but for multi-user systems they cannot be solved by audio feedback. Visual feedback is possible, but for a multi-user system, it also attracts the attention from users who are not interested in it but cannot help noticing when the visual information is in their peripheral field of vision. The best solution for this problem would be localized tactile feedback considering it uses the same modality for output as for input.

Scalability is an important factor when designing to enhance the interaction with multitouch tabletops. For the system we are presenting, we chose a fluid-based approach where touch is detected by displacement of a fluid. Besides, we already achieve a feeling of continuous (passive) feedback just by the choice of touch surface.

Related Work

The techniques combined in our system have each been studied individually by several groups and in different variations. Multitouch input has become very popular over the last years using a variety of techniques (e.g., SmartSkin [12] uses capacitive sensing, malleable surface touch [14] uses visual distortion, FTIR [2] and diffuse illumination, e.g. [7], use infrared lighting, furthermore fluid displacement [3], and ferromagnetic sensing [4] were proposed). Even though it has not reached the consumer market, there are commercially available solutions at least for institutions (e.g., Reactable[1] or Microsoft Surface[2]).
Multitouch surfaces provide a feeling of rich and direct interaction with content. But their smooth glass surfaces also lack physical feedback about user actions. There have been various efforts to alleviate this shortcoming, e.g., using a piston array [5], tangibles [16], clay [10], or foam [13]).

We take a different approach and add a fluid-based overlay to a horizontal multitouch surface with the ability to change the viscosity of the fluid through a magnetic field. Such ”smart fluids” have received attention for haptic displays for some time now (e.g., [18]). Recently, ferromagnetic fluid has also been used for multitouch input [4]. But to our knowledge, no system has combined techniques for a multitouch input device with active haptic feedback. Systems that make use of tactile feedback mostly use vibration for actuation (e.g., [11]), while a few more recently published systems make use of electroactive polymers such as shape memory alloys (e.g., [1]).

A system based on an array of magnets was introduced with the Actuated Workbench by Pangaro et al. [9]. Weiss et al. [15] built a similar system which is also used for Mudpad.

There are no commercially available solutions apart from roughly localized vibrotactile feedback. The Nokia N97 smartphone, for example, interpolates between several actuators underneath its screen. So far, both Nokia [8] and Apple [17] have filed patents for tactile feedback touchscreens using protuberances to create bumps on the

[1] Reactable. http://www.reactable.com.
[2] Microsoft Surface. http://www.microsoft.com/surface.

screen. But actual implementations of these techniques have yet to appear.

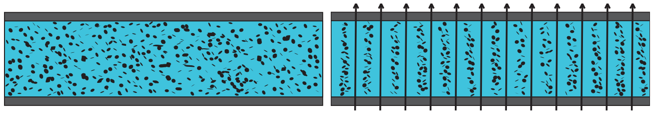
Mudpad's fiber technique to transport the light to the camera was proposed by Jackson et al. [6].

System Design

The design space outlined by these related projects leaves room in the area of localized active haptic feedback. Mudpad combines this feature with multitouch input. Thus, we are able to explore interaction using active haptic feedback in a multi-user context. As the feedback is very unobtrusive by design, only a user physically interacting at a specific location notices it.

Magneto-rheological Effect

We chose magneto-rheological fluid (MR-fluid) because it changes viscosity when exposed to a magnetic field. It contains ferrous particles 1-10 microns in size dissolved in a carrier (Fig. 1(a)).



(a) Off state: free flowing particles within the carrier, i.e. low viscosity. (b) On state: particles arrange along the flux lines, i.e. high viscosity.

Figure 1: How MR-fluid works.

A magnetic field causes these particles to build chains along the flux lines (Fig. 1(b)), increasing the fluid's viscosity as a consequence. The fluid can be switched from off to on and back within 5 ms. It is mainly employed for variable dampers and shock absorbers (e.g., in the suspension of sports cars such as Audi's TT model), or for clutches and brakes.

To activate the fluid, the electromagnets at the desired locations are turned on, instantly causing the fluid above those locations to stiff. The total refresh-rate is only limited by the Arduino boards used to control the magnets.

MR-fluid differs from its cousin ferrofluid by the size of its particles. Ferrofluid contains nanoparticles while those in MR-fluid are 1000 times bigger. Consequently, ferrofluid changes its form when exposed to a magnetic field, while MR-fluid does not. The change in viscosity is invisible and can only be felt. We believe this to be an advantage since a visible change would distort the projected image and attract peripheral attention from co-located users who are not interested in this information.

Mudpad Design

Our system uses an array of electromagnets (similar to the Actuated Workbench [9]) which was built for a different project at our group [15]. The aim with Mudpad is not to move things around but to change the physical properties of the fluid, specifically to cause a local change in viscosity wherever a magnet is turned on.

This first prototype uses an MR-fluid from Lord Corporation[3] which is based on hydrocarbon and therefore reacts with the latex surface if brought into direct contact. Hence, we switched to a better suited fluid made by BASF[4] to simplify the construction process of the pouch.

[3] Lord Corporation. http://www.lord.com.
[4] BASF SE. http://www.inorganics.basf.com.

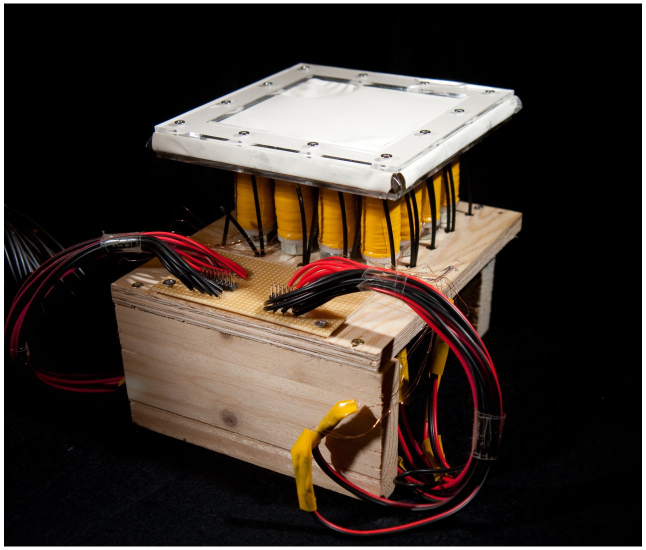


Figure 2: First prototype.

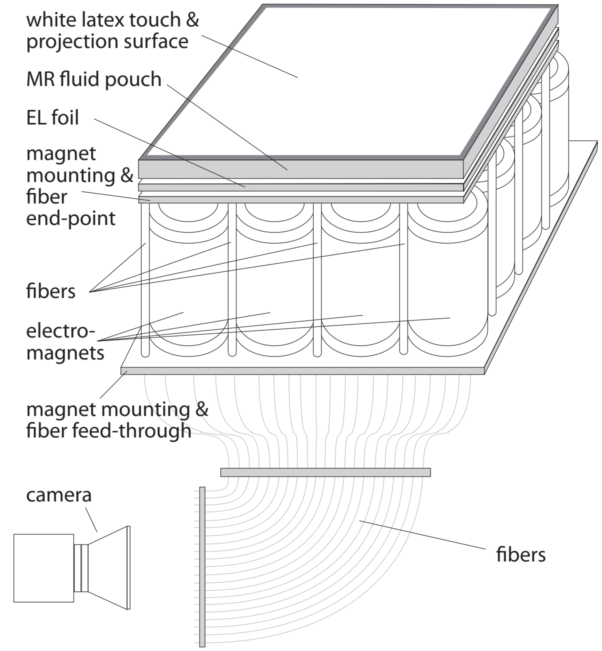


Figure 3: Schematic overview.

As the liquid is opaque, an approach different from commonly known vision-based multitouch surfaces (e.g., as described by Han [2]) is necessary. First, we need to top-project onto the touch surface which is made of latex or natural rubber. Secondly, the system is closed in terms of light: the EL-foil emits light which will only be transported by the fibers if it is reflected by the latex being pressed down onto the clear bottom. The light has to have a certain angle of incident to be transported by the fibers and this will happen only with reflected light. Consequently, the resulting camera image shows a very high contrast for the blobs even in the range of visible light. Figure 3 shows a schematic overview of the system's design.

Resolution & Accuracy

Output accuracy for the haptic display depends on magnet size. As the magnets require a certain power to affect the fluid, their size cannot be reduced arbitrarily. The current prototype uses magnets about 1" (2.5cm) in diameter, which determines its resolution. The fluid causes a continuous feel for the user by smoothing the on/off-transitions between magnets. This rather low resolution would not be suitable for a small mobile device. But for a tabletop it is sufficient to investigate the resulting interaction paradigms for this kind of feedback. Furthermore, resolution could be improved by using electro-rheological (ER) fluid instead of MR-fluid. The reaction time of the fluid is very low (about 5 ms), so the refresh rate for the complete display only depends on the switching time for the magnets. The current prototype is composed of only 16 magnets so they can be triggered by two Arduino Mega boards without the need of multiplexing.

The input resolution solely depends on the number, i.e., the spacing, of the fibers that transport light to the camera. Should the number of fibers exceed the camera resolution, more cameras could be added.

Interaction paradigms

The presented system combines multitouch input and active with passive haptic feedback. The fluid as such already provides passive feedback as was demonstrated by Hilliges et al. [3]. Previously presented systems mostly use some form of vibration, a ubiquitous form of feedback used, e.g., in most cellphones. Its main disadvantage is that it is usually applied globally to the whole device or screen (e.g., [11]). Accordingly, the device can only communicate that *some* action was performed, but the user cannot tell by vibrotactile feedback alone if it was the *intended* one (e.g., which button was pushed). With localized feedback it is possible to actuate only the region where user input was registered.

Another advantage of our fluid-based system is its continuity — in contrast to existing vibrotactile feedback which gives pulsing feedback in a specific frequency, Mudpad can maintain areas of different viscosity as long as the corresponding magnets stay turned on. A user can easily distinguish those areas whereas vibrotactile actuators have to use a certain frequency range to be noticed. So it is possible to haptically display window outlines etc. within the liquid which are not visible (so they don't alter a top-projected image), but can only be *felt* by a user. Using this property eyes-free touchscreen operation becomes possible.

Conclusion and Future Work

We presented a multitouch system with active tactile feedback and bring a scalable solution for localized haptics to horizontal multitouch surfaces. Until now vibrotactile feedback is the most common technique for tactile feedback. Fluid-based feedback has not received much attention yet. We focus our research on suitable usage scenarios and user acceptance. We will also run simple performance tests to get some quantitative data about the device's performance.

The system we described is a proof-of-concept prototype. Next, we will build a system the size of a 24" display covered by around 300 electromagnets. With this bigger system we will run user tests to compare performance and accuracy for different tasks with and without different kinds of haptic feedback. Another interesting point is how users perceive their performance in relation to feedback modalities.

To increase the output resolution electro-rheological fluid could be used. It behaves essentially the same as MR-fluid but it is activated by current instead of magnetic flux. The necessary electrodes could be designed much smaller than magnets. Also, we are looking into transparent ER-fluid which would allow to use an LCD instead of top-projection.

Acknowledgements

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