# Creating Malleable Interactive Surfaces using Liquid Displacement Sensing

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## Abstract

*We present a new approach for rapidly prototyping multi-touch and object sensing surfaces. It works by liquid displacement inside a malleable projection surface. The system provides both touch and pressure information and a distinct organic quality when touched. The system is easy to build and produces a clean signal revealing multiple fingers, whole hands and other object outlines that can be processed using computer vision techniques. This approach provides an easy mechanism to build interactive surfaces, requiring no infrared edge lighting or soldering. In this paper we provide an overview of the approach, some of its unique capabilities, and uncover some of the tradeoffs between viscosity of liquid, air pressure, surface malleability and the volume of liquid used. Our aim is to allow practitioners – from DIY enthusiasts to researchers – to build and experiment with such systems more readily*.

## 1. Introduction

Interactive tabletops afford more direct ways to interact with the digital, incorporating multi-touch input and even tangible elements into the interface. Such systems have captured the interest of both researchers and DIY enthusiasts alike, leading to many experimenting with their own tabletop systems. Sensing on these surfaces is non-trivial and many different approaches have been suggested over the years (a more detailed overview is provided later in our related work).

In this paper we describe a new technique for rapidly prototyping multi-touch and object sensing surfaces, which carries some unique properties when compared to existing approaches. It works by liquid displacement inside a malleable projection surface. A latex pouch is filled with a mixture of water and black ink. The pouch serves both as projection screen and transducer for user input. The black liquid hides the white latex surface from the camera when nothing touches the surface. Touching objects displace the liquid and press the latex onto an acrylic or glass plate placed underneath the surface. This reveals the shape of the touching object in bright white to a camera mounted behind the surface. This provides both touch and pressure information and a distinct organic quality when touched.

The system is easy to build and produces an extremely clean signal revealing multiple fingers, whole hands and objects that can be processed using computer vision techniques. This approach provides an even easier mechanism to build interactive surfaces than techniques such as frustrated total internal reflection (FTIR) [3], requiring no Infrared (IR) lighting, no mounting of LEDs, and no soldering to build. In this paper we provide an overview of the technique, some of its unique capabilities, and uncover some of the tradeoffs between viscosity of liquid, surface malleability, air pressure and the volume of liquid used. Our aim is to allow practitioners to build and experiment with such systems more readily.

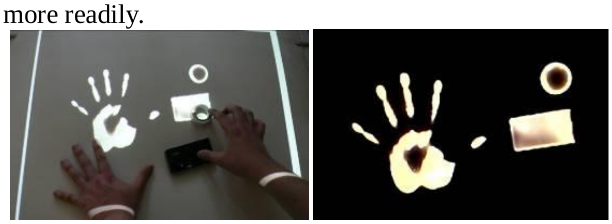

**Figure 1: The capabilities of a liquid displacement table. Left: the user pressing a hand, cellphone and tape roll onto the surface to interact. Here the objects cause the black liquid to be displaced as the white latex is pressed onto a sheet of acrylic. This produces a bright white imprint of the objects, which is captured by a camera placed underneath the surface. Right: the raw unprocessed images as captured by the camera. These are also projected onto the surface from above. Note that the approach requires near zero force to interact, and that objects can be sensed at speed in full motion.**

## 2. Related Work

Sensing fingers and other objects on an interactive surface is a fairly non-trivial task. This has led researchers to experiment with various techniques. Common approaches to sensing can be loosely grouped into two categories: 1) camera-based sensing and 2) sensor electronics integrated into the surface. In the latter, many techniques have been proposed including ones based on capacitive [1, 2, 9, 17], resistive [5], or IR sensing [4, 13]. In the former, numerous systems have been built using the camera as the sensor, coupled with some form of illumination scheme, be it FTIR [3] or other diffuse lighting [8, 10, 18].

Camera-based approaches potentially give higher resolution sensing and can scale to detecting objects beyond fingertips, even supporting unique identification of objects using visual markers [6, 18]. What is perhaps most compelling about these systems, which has led to a great deal of adoption in the community, is that the sensing electronics (the camera) is readily procurable, allowing people to prototype such systems with little electronics expertise.

In these systems, many different arrangements of camera, projector and surface have been experimented with, including projection and sensing from above [16], from the bottom or rear [3, 8, 10, 19], or off axis [18]. To avoid occlusions many systems position the camera behind the projection surface. Usually an IR light source and a camera equipped with an IR pass filter are utilized to sense contours of IR reflective objects placed on top or in front of the surface [6, 10, 19]. This approach does not only track multiple fingers by several users but also allows sensing of objects. Objects can also be equipped with reflective markers or bar codes in order to identify individual objects.

Han [3] presents a different approach to multi-touch sensing based on FTIR. It works by mounting IR LEDs around the edge of a sheet of acrylic (or other material with similar optical properties). These LEDs shine light into the surface. The light is totally internally reflected inside the surface, and touching fingers causes some of this light to scatter downwards where it can be imaged by a camera. This is perhaps one of the most established techniques for sensing multiple touching fingers, partly because the illumination scheme greatly increases the signal-to-noise ratio making the processing of the raw sensor data much more straightforward than with diffuse illumination. This increased signal does come at a cost however. The scheme requires soldering and accurate mounting of IR LEDs, a compliant projection surface and the signal only captures fingers in contact with the surface – not other objects.

Some of these issues around FTIR have led researchers to experiment with different extensions of the technique. Perhaps the work most related to ours is by Smith et al. [12]. Smith proposes a malleable FTIR touch and object sensing surface using silicon rubber for the compliant projection surface. This allows users to press their hands and other objects into the surface with theoretically little force required. It allows the FTIR technique to scale to other objects beyond fingers. Although powerful FTIR and its various extensions still require a fair degree of engineering and expertise to create sensing surfaces – for example soldering and mounting of LEDs.

Other techniques for malleable surfaces have also been proposed [7, 14, 15]. These look for deformations of the surface using embedded patterns in the surface material. Although interesting these systems require a fair degree of deformation of the surface to support robust sensing.

We present a new technique for multi-touch and object sensing that compliments this existing range of approaches. Our approach allows recognition of shapes and outlines of many different objects touching the surface with very high precision. The approach is near zero force, and works without additional IR illumination. This frees practitioners from the need of cumbersome soldering or mounting of IR sources. Like FTIR we generate a high signal-to-noise ratio, producing distinctly sharp images from the camera, and easing the processing phase. As shown later the signal is fairly unique, enabling advanced techniques such as pressure sensing or even some 3D shape reconstruction to be captured from imprints of hands and other objects.

## 3. Liquid Displacement Sensing

Figure 2 gives an overview of our setup. A camera and visible light source(s) are placed underneath a sheet of acrylic or glass. In our prototype we used an 800x600mm, 5mm thick sheet of acrylic, other transparent materials such as common glass would work as well. Black liquid is poured onto this surface, and white latex rubber (approx. 0.4 mm thick), silicone sealant and an alloy frame are used to form a pouch to contain the liquid and stop it from leaking. In our experiments we used common black printer ink as the liquid.

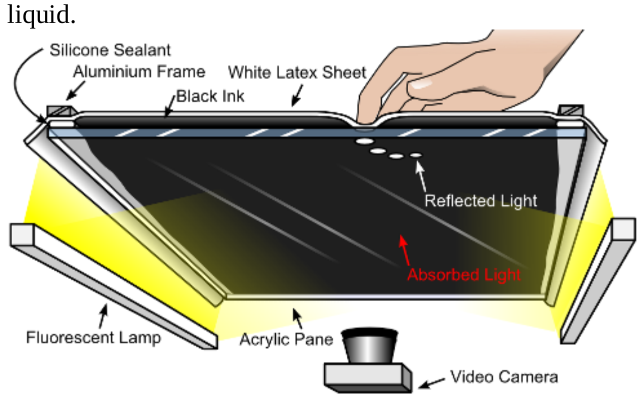


**Figure 2: Sensing overview. Black liquid absorbs light and hides the white latex surface from the camera when nothing touches the surface. Touching objects (e.g., fingers) displace the liquid, press the latex onto the acrylic or glass, causing more light to reflect, revealing the shape of the touching object in bright white to the camera underneath.**

The light is predominately absorbed by the black liquid so that almost no signal is picked up by the camera when nothing is touching the surface. Whenever objects press onto the surface, liquid is displaced and the white latex is moved towards the acrylic, causing light to be reflected at points where the user is touching. The shape of the touching object becomes visible from the underneath and can be imaged by the camera. The contrast between object contours and the background is very high as light is reflected to a much higher degree by the white latex.

As shown in Figure 1, from this signal minimal computer vision algorithms are needed to compute touch. Only lens correction, connected component analysis are needed to compute fingertip locations. The high contrast between touching fingers and the surrounding black liquid makes binarization, smoothing and rectification steps unnecessary. Further, the ability to capture object outlines through the surface allows contour-based algorithms such as the Sobel filter to be utilized.

**Figure 3: Building steps. Left: pouring an even distribution of the black liquid onto the acrylic and placing the latex sheet on top. Right: sealing panel with aluminum frame and silicon sealant.**

## 4. Surface Material Properties

Building a sensor with the approach outlined above is straightforward and can be carried out with limited cost and expertise. In this section we uncover some of the tradeoffs that different material configurations can cause for the sensing fidelity. In particular, surface elasticity, air pressure, liquid viscosity and volume of the liquid. We have experimented with many of these aspects in order to find a 'sweet spot' that gives us the right balance of sensing precision, display capabilities and feel.

### 4.1 Surface Malleability

Surface malleability depends largely on the material used for the pouch and its thickness. In order to detect fingers and other objects the material needs to be relatively thin (we used 0.4 mm thick latex) and elastic. If the material is too thick or rigid, object outlines can become imprecise. Furthermore, object outlines in close proximity can become *fused* (Figure 4, left). Using a material that is too thin for the pouch will not block light shining onto the surface from top and therefore reduce the image contrast and sharpness of the sensor image. Further, thin or elastic material will deform according to the liquid motion and cause *rippling* effects distortions in the projection (Figure 4, right).

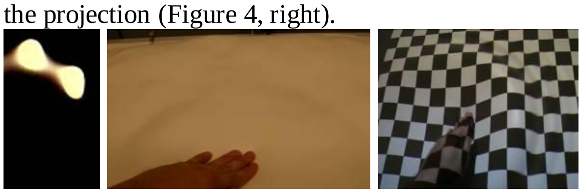

**Figure 4: Left: finger tips *fused* together. Middle: ripples caused by a user's touch. Right: Distortion caused by rippling effect.**

### 4.2 Surface Tension

In addition to the material qualities, surface malleability is affected by the amount of tension used in stretching the material. More tension can reduce the rippling and fusing effects. However, too much tension again reduces precision in sensing contours. Too much tension prevents the liquid from filling concave holes in or in between objects, for example the archway of a palm pressed onto the table. Too little tension however, causes a delay in relaxation of the surface *(deformation hysteresis)* and also leads to *motion blur* in the camera image (Figure 5). We achieved the best results with a mild tension that allowed depressing the surface with nearly zero force but prevented the material to ripple or cause motion blur.

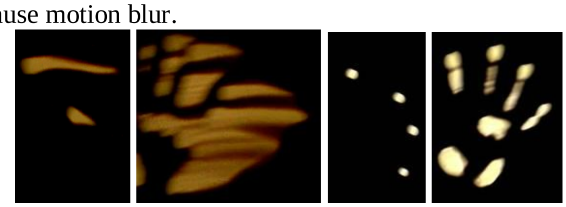

**Figure 5: Left: motion blur caused by to little surface tension. Right: corresponding image with more surface tension.**

### 4.3 Liquid Viscosity, Color and Tint

The rippling, deformation hysteresis, motion blur and fusing effects are also directly dependent on liquid viscosity. We use water dyed printer ink but other fluids are applicable as well. Also using substrates, such as gels is an option. In general terms, viscosity is the resistance of liquids to flow. High viscosity fluids (e.g., crude oil) flow slower than low viscosity fluids (e.g., water). In consequence high viscosity fluids can be used to reduce the rippling and fusing effects. However, due to their resistance to flow they can increase motion blur. We are still experimenting with viscosity but have found printer ink to be a sufficient first step.

Equally important as viscosity are liquid color and opacity. Using a black, completely opaque liquid has the advantage of crisp object contours and high contrast between areas being touched and the background. However, other colors and levels of opacity are permissible, which can give more detailed depth-based contours (e.g. see Figure 6 left).

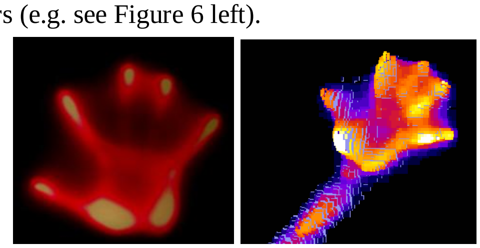

**Figure 6: Left: obtaining more detailed pressure information based on modifying the liquid's color, opacity and volume. Right: height-map of pressure derived from pixel intensity**

## 4.4 Volume of Liquid

Precision in pressure sensing and amount of derived pressure information largely depends on the volume of the liquid. The HapticLens [11] project demonstrated how the liquid displacement principle can be leveraged to extract relief information of objects depressing a malleable surface (albeit not table sized). Increasing the liquid depth and implicitly the liquid volume greatly extends the ability to measure pressure as shown in Figure 6. Using a thick layer of partially transparent liquid allows simple approximations of pressure using pixel intensity. However, while the resulting imagery seems promising, the increased liquid volume can lead to high deformation of the projection surface increasing the rippling effect.

## 4.5 Internal Pressure of Pouch

A final parameter to consider is the internal pressure of the pouch. Pressurizing the pouch makes it slightly harder to depress the surface but increases the tendency of the liquid to fill cavities and concave elements of touching object, hence reducing fusing and motion blur effects. Contours of objects appear more defined as the internal pressure forces the surface material to nestle against the depressing object.

Another option to control the rippling and motion blur effects is to pressurize the pouch with air in addition to a thin layer of liquid, so that an air gap persists in between the liquid and projection screen. In combination with modest surface tension this prevents the surface from producing visible ripples almost entirely. Motion blur is also suppressed effectively as the internal pressure counters adhesion between the acrylic and pouch material, thus speeding up contact relaxation.

## 5. Conclusions and Future Work

We have presented a new approach for rapidly prototyping multi-touch and object sensing surfaces. It works by liquid displacement inside a malleable projection surface. Our approach has the following qualities. 1) Soft and malleable surface that provides an organic feeling when touched. 2) Recognition of shapes and outlines of objects touching the surface with very high precision. 3) Works without additional IR illumination. This frees developers from the need of cumbersome soldering or mounting of IR sources. 4) Provides a high signal-to-noise image, which can be used for touch detection, contour and shape-based algorithms, and also pressure sensing. Our hope is that given the simplicity of the approach it will prove useful to researchers and DIY enthusiasts alike, allowing rapid experimentation with direct input tabletops.

There are of course tradeoffs with the approach. Being a camera-based system means that significant amount of free space is required behind the panel. Furthermore, the non-segmented pouch does require the panel to be positioned horizontally. Using a liquid filled cell structure might enable other non-horizontal and non-planar designs. Finally, the current design does not allow for rear-projected setups creating extra space requirements for a projector mounted above the surface. Occlusion of projected content by users' hands becomes a problem due to this limitation as well.

To date we have focused on the sensing side of the technique, having only ported simple third party applications to the system. These have allowed us to validate the speed at which the user can interact which currently is limited to 30Hz by our camera. Our aim is to begin to start to prototype applications that make use of the unique capabilities of the system in particular its pressure and shape-based capabilities.

## 6. References


[1] Apple. *iPhone Multi-touch* http://www.apple.com/iphone/technology/ [cited July 2008].

[2] Dietz, P. and D. Leigh. DiamondTouch: a multi-user touch technology. In Proc. *ACM UIST* '01. p. 219-226.

[3] Han, J.Y. Low-cost multi-touch sensing through frustrated total internal reflection. In Proc. *ACM UIST '05*. p. 115-118.

[4] Hodges, S., et al. ThinSight: versatile multi-touch sensing for thin form-factor displays. In Proc. *20th ACM UIST* '07.

[5] JazzMutant. *Lemur* *http://www.jazzmutant.com/lemur_overview.php*.

[6] Jordà, S., et al. The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces. In Proc. *TEI* '07.

[7] Kamiyama, K., et al., Vision-Based Sensor for Real-Time Measuring of Surface Traction Fields. *IEEE Comput. Graph. Appl*, 2005. 25(1): p. 68-75.

[8] Microsoft. *Surface* http://www.microsoft.com/surface/.

[9] Rekimoto, J. SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In Proc. *ACM SIGCHI* '02. p. 113-120.

[10] Rekimoto, J., et al. HoloWall: interactive digital surfaces. In Proc. *ACM SIGGRAPH 98 Abstracts and Applications*. 1998.

[11] Sinclair, M. The haptic lens. In Proc. *ACM SIGGRAPH 97 Visual Proceedings*. 1997.

[12] Smith, J.D., et al. Low-Cost Malleable Surfaces with Multi-Touch Pressure Sensitivity. In Proc. *IEEE tabletop* '07. p. 205-208.

[13] van Loenen, E. Entertaible: A Solution for Social Gaming Experiences. In Proc. *In Tangible Play workshop, IUI* 2007.

[14] Vlack, K., et al. GelForce: a vision-based traction field computer interface. In Proc. *CHI '05 Extended Abstracts*.

[15] Vogt, F., et al. A malleable surface touch interface. In Proc. *ACM SIGGRAPH 2004 Sketches* 2004. p. 36.

[16] Wellner, P., Interacting with paper on the DigitalDesk. *Commun. ACM*, 1993. 36(7): p. 87-96.

[17] Westerman, W., Hand Tracking, Finger Identification and Chordic Manipulation on a Multi-Touch Surface. 1999, University of Delaware.

[18] Wilson, A.D. PlayAnywhere: a compact interactive tabletop projection-vision system. In Proc. *ACM UIST* '05. p. (83-92).

[19] Wilson, A.D. TouchLight: an imaging touch screen and display for gesture-based interaction. In Proc. *ICMI '04*. p. 69-76.