# Fl.UIs : Liquid-Mediated Vision Based Touch Surfaces

**Tim Campbell, César Torres, Eric Paulos**
Department of Electrical Engineering and Computer Sciences
University of California Berkeley
{timcam, cearto, paulos}@eecs.berkeley.edu

## ABSTRACT
Fluid User Interfaces (Fl.UIs) are liquid-based touch surfaces that use computer vision to detect and interpret a range of tactile user inputs. While Fl.UIs have less input resolution than digital touch screens, they provide an excellent low-cost solution for rapidly prototyping non-rectilinear screen designs as well as exploring novel surface interaction techniques. Fabricated on a laser cutter using low-cost materials, Fl.UIs use unique shape outlines to displace an internal colored liquid to regions-of-interest for a camera. This paper presents a set of software tools that help users rapidly design, fabricate and author interactions with Fl.UIs. The robust construction and an unpowered surface makes Fl.UIs well-suited for outdoor and public installations. Our Fl.UIs prototyping tool encourages these uncommon "screens" to emerge in complex environments (i.e. urban spaces, benches, tables, fountains, sidewalks).

### Author Keywords
tangible user interfaces; computer vision; digital fabrication; urban computing

### ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

## INTRODUCTION
Interactive surfaces are emerging in a wide variety of new environments. However, there is a natural tension between the physical constraints of current touch screen technologies and the dynamic surfaces found "in-the-wild." By reducing the requirement for high-resolution input, passive hardware designs can challenge current perceptions of touch devices and the available environments for surface interactions.

In this paper we present Fluid User Interfaces (Fl.UIs), liquid-mediated touch surfaces. In response to touch input, Fl.UIs create color changes by displacing an internally sealed colored liquid guided by the shape of the surface (Figure 1). A web-accessible computer vision system identifies these color changes and triggers action events that a designer can then use to create custom applications. The shape of the custom hardware defines how the fluid flows within the surface – thus defining the type of interaction. Fl.UIs also support a different level of pressure than more delicate capacitive touch surfaces, which allows for a wide variety of touch modalities (e.g. finger, hand, sitting, crawling, slapping, etc).

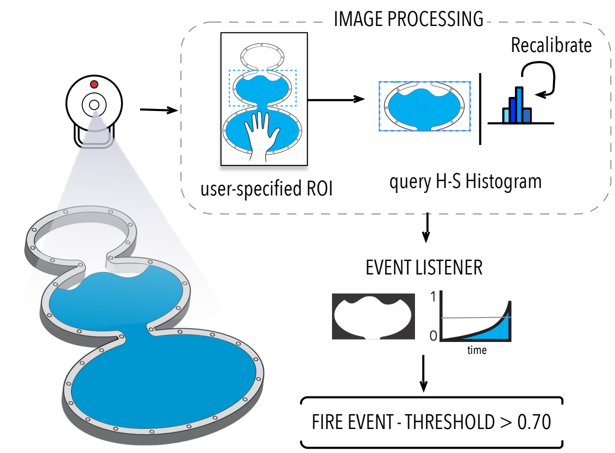


**Figure 1. A webcam is positioned to observe a Fl.UI, or fluid-mediated surface. Our web-accessible computer vision system listens for changes in the distribution of colored pixels in specified regions-of-interest (ROIs). When a user applies pressure to the surface and displaces the colored liquid, our system triggers an action event.**

Access to electronics prototyping and digital fabrication has redefined how we develop touch interactions [5], yet prototyping these interactions still requires off-the-shelf hardware or a fully-developed system. We present a design work-flow for Fl.UIs as a rapid prototyping tool for both hardware and software. Using a liquid to interactions challenges current forms of input and turns touch into a playful, colorful experience. Although a camera is needed to power Fl.UIs, the surfaces themselves are unpowered making them more reliable and easier to scale, maintain, and create.

## RELATED WORK
Vision-based touch screens promise cost-effective, large scale interaction. In an early example of diffuse illumination, researchers built wall-sized touch interaction with a rear-projection screen [10]. The Extended Multi-Touch project extracts multi-touch input passively using a depth camera [13]. Similarly, we decouple the sensing capability from the Fl.UIs surface and offset it to a low-cost webcam.


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Deformable surfaces have been explored in tangible interfaces [2]. Hennecke et. al. used simple marker patterns from pads to extract position, orientation and pressure on a touch surface [6]. Other system minimally augment a surface for touch detection. Frustrated total internal reflection (FTIR) uses edge-lit LEDs [3] and Moeller et. al. modified existing displays with additional hardware to enable touch capability [12]. However, many of these vision-based sensing techniques [1, 3, 7, 10] require underside or rear-mounted camera, limiting the form and environment of the system. For example, GravitySpace [1] achieved pose reconstruction from a user's contact with custom FTIR floor tiles but required an entire room underneath to place the camera sensor.

Several projects have explored the use of liquids as sensing or output mediators. Sylvester et. al. explored the use of soap bubbles as an alternative, playful, and ephemeral tangible user interface material [15]. MudPad uses magnetic fields to control stiffness in ferrofluids [8]. Harrison et. al. constructed active pneumatic UI components that used the air connection for both sensing and actuation [4]. Most similar to our work, Hilliges et. al. constructed a liquid displacement surface that masked a flexible nylon sheet with opaque ink for high precision touch and shape detection [7]. We add a robust surface construction to Hilliges' technique and then utilize fluid displacement for an *overhead* camera setup.

Though mediated surfaces have made touch detection viable, extracting meaningful information from computer vision systems remains a challenge. Fl.UIs use principles for prototyping computer vision applications to create a direct manipulation interface with a plug-in architecture [11]. Although we sacrifice 2D input, the Fl.UIs workflow is a full-featured prototyping tool for non-experts as well as professional interaction designers to create low-cost, bespoke touch surfaces.

## THE FI.UI DESIGN PROCESS

In this section, we decompose the Fl.UI design process into two components: a) the physical design and construction of the Fl.UI surface, and b) computer-vision prototyping system for detecting input.

### Physical Design

The Fl.UI hardware is a simple layered construction of a liquid sandwiched between two layers of plastic and sealed with a cork gasket (Figure 2). We use the outline of the hardware to guide fluid movement to a region-of-interest for the camera. Fl.UIs displace pigmented liquid away from a user's point-of-contact but still replicates the user's interaction in a principle we call *spatial redundancy*. Since vision-based system have problems with occlusion, providing alternative areas with equivalent information greatly improves the reliability of the signal.

#### *Designing form factors*

Two shapes were helpful in the design of Fl.UIs: *wells*, which are larger chambers of liquid, and *channels*, which constrict flow between wells. Figure 4 shows a "barbell" design that mimics the functionality of a button by channeling fluid from one well to another.

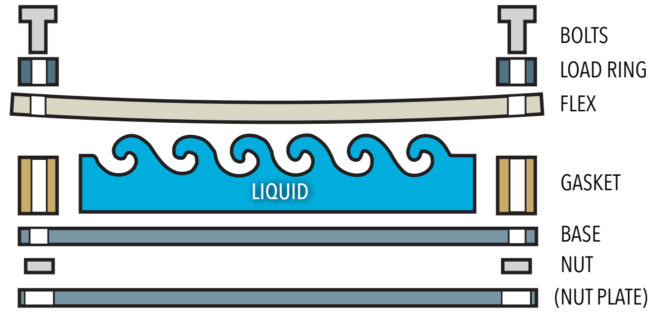


**Figure 2. A top-input Fl.UI configuration. A liquid is sandwiched between a flexible ( FLEX) and rigid ( BASE) plastic, sealed with a cork material ( GASKET) and low-profile bolts.**

To facilitate rapid iteration, the required components of a Fl.UI can be extracted from a single closed Scalable Vector Graphic (SVG) path. Using the paper.js library[9], we generate the five solid layers as laser cutter-ready files from this single path. Script parameters allow a user to specify bolt sizes, material depths, and ring thickness. This approach supports design tools that produces SVG graphics, allowing users to quickly iterate on Fl.UI form factors.

#### *Techniques for construction*

In general, the construction of a Fl.UI mimics standard pressure vessels. Fluid is sealed between the base and a flexible plastic using a gasket ring and bolts spaced approximately 25 mm apart (Figure 2); a **LOAD RING** between **FLEX** and **BOLTS** ensures uniform loading.

We chose materials and processes available to the Maker community. The cutting operations used a 50 Watt laser cutter; all acrylic was 3 mm thick continuous-cast acrylic, which cuts easily and remains rigid under pressure. The semi-flexible material was 0.05" (0.127 mm) thick Mylar film. For the **GASKET** we found cork blended with a rubber compound (McMaster #9304K42, 1/16" sheets) cut well and remained tough and pliable even after extended use. To ease assembly we regularly used an optional **NUT PLATE**, which had cutouts to capture the nuts. Layers were stacked to an overall height of 12.50 mm, including low-profile M3$\times$10 **BOLTS** and **NUTS**.

For the mediating fluid, we used either water or vegetable oil dyed with acrylic ink or oil color, respectively. Non skin-colored pigments were used to minimize ambiguities with the computer vision system. The exact volume and proportion of liquid-to-pigment was determined empirically using the CV system as feedback. Tuning the Fl.UI was made easier by inserting a hypodermic dispensing needle (McMaster #6710A26) under the **GASKET**. The material cost of each Fl.UI is approximately $15 (USD) per square foot, though overall footprint and layout efficiency matter greatly.

### Software Design

In order to allow for a true plug-and-play environment, we designed a computer vision prototyping system that runs on a modern web browser (Figure 3). Using the HTML5 `getUserMedia` API, we extract video from a computer's

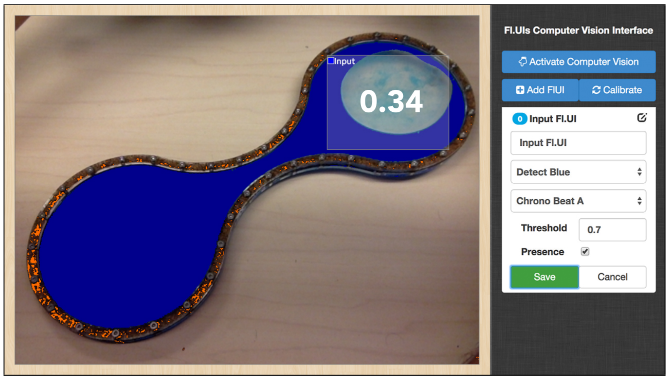


**Figure 3. CV Web Interface - In this interface, the user has specified a region-of-interest (input) and a query color (blue). When the computer vision routine is activated, pixels classified as blue are overlaid with a blue pixel. This interface has one event listener observing the "input" ROI that fires when more than 70% of pixels are blue.**

built-in or peripheral webcam and classify color using a color back-projection routine [14]. With this system, a user can bypass setting up and using a development environment and simply point their camera in order to interact with multiple Fl.UIs.

Our interface is divided into three modes:

- **Design**: users select areas on a webcam feed to listen for color changes. They can specify a query color as well as trigger parameters. Events are exported as JavaScript events; in our applications, we trigger sounds to play/pause or change volume.
- **Calibration**: users select sample color regions to recalibrate the system. While color backprojection does relatively well at identifying colors, changes in lighting disturb most computer systems. Pixels in the sample region are used to repopulate a hue-saturation histogram. Assuming a stable camera setup, color samples in a stable location within the environment can be used to automatically calibrate the system.
- **Active**: Pixels are classified as belonging to a distinct hue using the Hue-Saturation histograms derived from the *Calibration* mode. The system evaluates the distribution of colored pixels in each region-of-interest, which is then used to trigger user-defined events (*e.g.,* more than 70% blue pixels detected). Our system is able to provide real-time classification on five hues at 28fps with limited lag (40ms) on a modern laptop browser. Webcam pixels are overlaid with their classified colors for better system state visibility.

## PROTOTYPING INTERACTIONS

In this section, we give an overview of design considerations for Fl.UIs and novel interactions that arise from fluid properties. The most salient property of a Fl.UI is the "waterbed effect," a playful interaction that occurs when applying pressure on a large, flexible portion of the Fl.UI. This property can be controlled by the a) stiffness of the `FLEX` material, b) thickness of the `GASKET`, and c) area of the region-of-contact. Additionally, the designer can tune these parameters to change the responsiveness of the Fl.UI, from light touches to hard stomps.

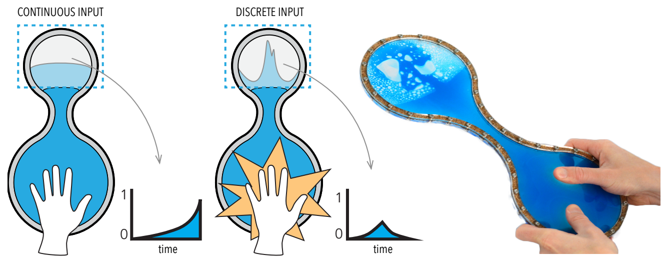


**Figure 4. A barbell Fl.UI design. A single channel between two wells can be used to provide continuous or discrete feedback. Each type of feedback gives a unique input-output coincidence profile that can be used to fire action events by the computer vision system.**

Moving liquids from one well to another influences the input profile of the Fl.UI. That is, applying abrupt pressure to the liquid-filled well with a thin channel creates a turbulent jet of liquid, which can act as a momentary button. A steady press fills the receiving well linearly for continuous input, where analog resolution is defined by the region's pixel count. The width of a channel between two wells modulates the rate of diffusion. Using combinations of wells, channels and inclines we made a "barbell" construction (see Figure 4) that allows liquid to flow from one well to another. We demonstrate a multi-state input on a single Fl.UI in Figure 5 as another configuration of form. The smaller wells have been designed to fill incrementally as the user presses harder on the base. For momentary input, the liquid must return to the steady state configuration. This force is currently supplied by slightly elevating the Fl.UI ($< 15°$) or placing the Fl.UI on a vertical surface. One could also use bending or channels to mimic "latching switches," common in electronics, though this remains for future work.

The mediating liquid can also influence the type of input. In a large $600 \times 300$ mm rectangular construction mediated with vegetable oil, we found that an "oilfall" interaction could be used as a timing mechanism. Displacing a pocket of oil to the top of the Fl.UI would correspond in a slow movement down. Increasing both the fluid thickness layer and viscosity can create visceral interactions where the user must "sculpt" the fluid into the desired location.

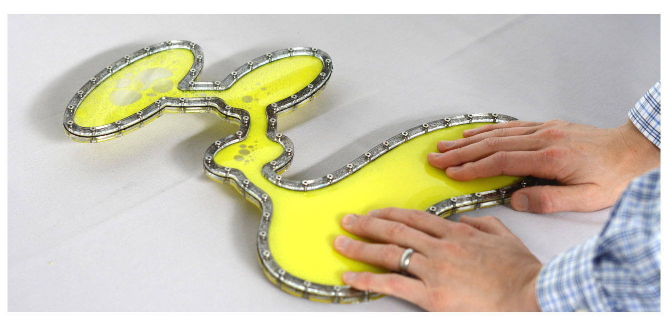

**Figure 5. A top-input Fl.UI configuration using two wells to create multi-state input. When the user presses on the lower well, fluid travels to multiple upper wells.**

## DISCUSSION AND FUTURE WORK

The solid construction of Fl.UIs affords rougher interactions than most input devices. By decoupling the sensing capability from the surface, Fl.UIs can function unpowered and eliminate the need for complicated wiring at the point of interaction. This can promote designs that can be embedded in new, uncommon environments such as playgrounds, park benches, or even underwater. Security becomes less of a problem since Fl.UIs do not have the perceived value of consumer electronics, and the low-cost construction makes them easy to replace or repair. We can also utilize the camera's field-of-view to create input ecosystems, distributing and linking interactions amongst several Fl.UIs in a single space.

Although the camera still requires power and installation, we anticipate that the trend of cost-effective IoT cameras will act as drivers of computer vision-enabled ubiquitous computing. At this time, we explore static and grounded Fl.UI installations to focus on fluid interactions. Ideally, the Fl.UI CV system should support moving Fl.UIs, and some initial computer vision SIFT tracking prototypes show promising results in this direction.

Fl.UIs are also ideally suited for educational and STEM programs. Students learning computational design could design and fabricate their own Fl.UI and then connect their hardware for inexpensive interaction. We assume access to a laser cutter, but such tools are becoming commonplace in shops and Makerspaces.

We initially aimed at using spatial redundancy to recover accurate 2D touch input from overhead video capture. Instead Fl.UIs use shape to create a more profound displacement of liquid away from the point-of-contact. As a result, Fl.UIs forgo the accuracy found in other liquid-mediated interfaces such as [7].

Fl.UIs could additionally benefit from a material that forms a permanent colloid with a liquid. Current liquid pigments fell out of suspension after a month of non-use. Currently, our construction process favors a watertight seal over assembly time. The "barbell" construction, for example, has 40 bolts that each require hand tightening. We have explored welding our layers together to minimize assembly time. Joining only Mylar `FLEX` layers could create a flexible Fl.UI for more wearable and non-planar applications.

## CONCLUSION

Fl.UIs are not designed to replace all current screen-based interaction techniques. Instead we envision Fl.UIs as a tool for prototyping "screen-like" designs that are both counter and complementary to established interfaces. Since the surface outline defines fluid flow, Fl.UIs tend towards bespoke and non-rectangular shapes. Our low-cost hardware lowers the barrier of entry and encourages exploration of liquid-mediated surfaces using web-based computer vision. Finally, we challenged the notion of a touch surface by decoupling the electronics from the point-of-interaction and constructing Fl.UIs for public settings. Fl.UI design tools have been made publicly available at `http://fluis.t-h-e.org/`.

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