LiquiTouch: Liquid as a Medium for Versatile Tactile Feedback on Touch Surfaces

Hendrik Richter
HCI Group
University of Munich LMU
hendrik.richter@ifi.lmu.de

Felix Manke
HCI Group
University of Munich LMU
manke@cip.ifi.lmu.de

Moriel Seror
HCI Group
University of Munich LMU
seror@cip.ifi.lmu.de

ABSTRACT
On interactive surfaces such as touch screens, tabletops or interactive walls, the addition of active tactile feedback has been shown to greatly improve user performance and subjective evaluation of the interaction. However, common electromechanical solutions to enable tactile stimuli on flat touch displays entail the use of costly, complex and cumbersome actuator technology. This especially holds true for solutions which try to address the full complexity of our sense of touch, i.e. our ability to experience warmth, coolness, pressure, stickiness or smoothness. In this paper, we propose the use of liquid as a medium for versatile tactile feedback.

We present LiquiTouch, a first prototype which emits actively generated water jets in order to communicate state, function and material properties of virtual touchscreen elements. We discuss the design implications and illustrate the potentials of using liquid to enrich and improve the interaction with touch surfaces.

Author Keywords
touch, liquid, water, tactile feedback, interactive surfaces

ACM Classification Keywords
H.5.2. User Interfaces: Haptic I/O

General Terms
Human Factors

INTRODUCTION
A *medium* is defined as 'a means by which something is communicated or expressed' [14]. When we get in contact with fluids in our everyday life, this non-solid matter forms such a medium and communicates rich sensory stimuli. The warm water washing around our feet at the beach, the power of a waterfall, the slippery edge of a swimming pool or the stickiness of honey are but a few examples. Liquid matter can create expressive haptic cues which inform us on surface structure, warmth, coolness, rigidness or pressure of elements in our environment. Moreover, liquids can evoke strong emotional effects such as surprise or relaxation, e.g. when having a water balloon fight or a warm bath after a long day. Researchers and designers in the fields of ubiquitous computing and tangible user interfaces (TUIs) try to transfer and use this sensual richness of our everyday world for the interaction with digital artifacts. Following this notion, we propose liquid as a means by which characteristics of virtual elements on touch-surfaces are communicated. Common solid tactile actuator systems are mostly designed to create a single type of tactile stimulus (e.g. vibration, stiffness or friction). We can overcome this limitation by integrating the versatile haptic properties of fluids such as temperature, viscosity or pressure. The creation of novel tactile stimuli is feasible by exploiting both the mechanical attributes of fluids and its immersive potential. In the paper, we present LiquiTouch, a prototypical touch-interface which incorporates water jets as a medium for tactile feedback. We specify the design space of fluid feedback and discuss possible steps to enrich and improve the interaction with virtual elements on touchscreens using liquid tactile stimuli.

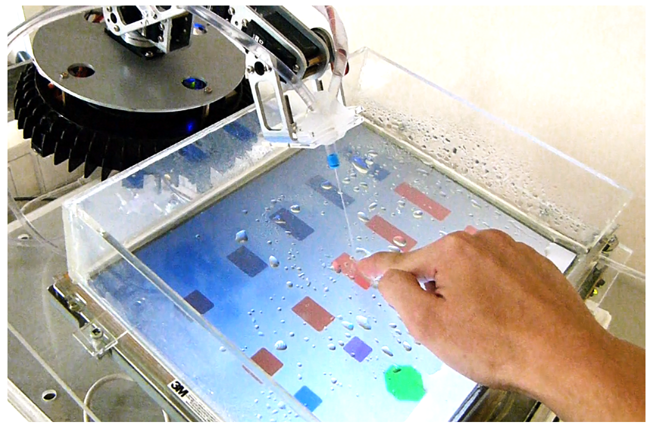

Figure 1. The LiquiTouch prototype. Directional water jets are sprayed in between the touch surface and the interacting user's finger to communicate tactile properties of GUI elements.

RELATED WORK
Tactile Feedback on Touch Surfaces
The addition of artificial tactile feedback on touch surfaces to communicate characteristics of virtual elements and to acknowledge a users' action is a continual ambition of researchers and designers. Tactile feedback has been shown

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to greatly increase interaction speed, reduce error rates and minimize visual distraction [6, 2]. This especially holds true for dynamic and multi-tasking scenarios such as the use of mobile devices or in-vehicle infotainment systems [10, 17]. A multitude of technical solutions to generate tactile stimuli on touch surfaces is existing. Generally, most approaches can be classified into three categories: the actuation of the device or the device's screen as a whole [1, 17], the use of TUIs equipped with tactile actuators placed atop the screen [12] or the segmentation of the touch screen area into individually actuated elements [16, 9]. All of the aforementioned approaches use either electromechanical actuators or electrotactile stimuli to generate tactile feedback. In general, only a reduced spectrum of tactile stimuli such as vibration or friction can be generated by either type of actuator. Consequently, researchers still struggle to bring the expressiveness of the haptic feedback close to the resolution and richness of visual feedback coming from the touch display. Non-solid matter such as liquid could bridge the gap and create manifold tactile stimuli without the need to implement stimulators into the touch display. No rigid actuator has to be in contact with our skin, liquid tactile cues can be communicated 'over a distance'.

Liquid Input, Liquid Output

In general, liquid has been used as a medium for input *and* output in HCI before, examples for both categories are given in the following. Pier et al. [15] use water as interface media in VR applications. They explore the highly immersive nature of water as input device and point out resulting psychological aspects of the interaction such as relaxation and curiosity. In [18], the authors describe a playful VR application in which water is used as input sensor and to push back the player. *Submerging technologies* [3] are a collection of interactive water displays, using the capacitive characteristics of water for input sensing. Geurts et al. [5] present *Splash Controllers*, which let the user perform 'organic' gestural input by moving around receptacles such as bowls or buckets filled with water. *Mud Tub* [4] enables the player to manipulate mud in order to control a computer. The manipulation of the squishy and versatile material is described as particularly intriguing and natural by participants. Finally, special examples for interfaces using liquids as input medium are interactive urinals [13].

On the output side, the *Hydraulophones* by Steve Mann [11] are well-known examples for fluid-based instruments. Water fountains come out of multiple finger holes of the organ-like object. The person playing the instrument covers these holes and thus influences volume, pitch and timbre of the created tone. The expressive multi-dimensional flow of water is used for both manual input and acoustic/tactile output. As in instruments like the violin or the guitar, the tactile feedback is inherently coupled with the manual input, which forms an communication channel additional to audio. These multimodal events help the person play the instrument and to establish a personal connection to making music. Other non-solid tactile feedback systems incorporate directed ultrasound waves to create palpable force-fields [8] in mid-air. Again, no rigid actuators have to be in contact with the user's skin, the tactile stimuli are communicated 'over a distance'. This allows for haptic feedback in 'mid-air' to augment gestural input or to support interaction phases before or after the direct contact with the touch surface. Finally, fog displays [19] could be described as non-solid projection areas used for visual output. These fog screens use haze machines to create a semi-transparent wall of suspended non-solid particles. The resulting non-flat image appears to be floating in 'mid-air' with no visible connection to a solid background.

PROTOTYPE LIQUITOUCH

System Design

The prototype LiquiTouch is a touch system coupled with a water-nozzle-equipped robot arm (see figure 1). The robot arm is constantly following the position of the user's finger on the touch screen in a distance of 25 cm (9.8") and slanted from above. In the moment the user touches a virtual element on the screen, a water jet is shot at the spot where the fingertip and the screen meet (see figure 2).

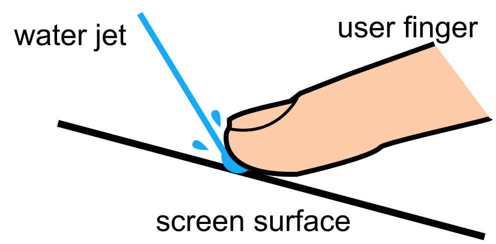

Figure 2. Location of the tactile stimulus on the user's fingertip.

The technical components of the system are depicted in figure 3: A graphical user interface is presented on a 15" TFT display (a). The user's touch input is detected by a transparent surface capacitive touch overlay[1] (b). Both are controlled by a standard PC (c), which also controls the tactile characteristics of the GUI elements. Meanwhile, a submerged pump[2] in a canister holding distilled water (d) constantly fills the tubing system with water. When a virtual element on the display is touched, the position and the tactile characteristic of the object are transferred to a microcontroller[3](e). This element controls a valve[4](f) which regulates the flow of water in order to create diverse tactile stimuli (see chapter). A robot arm[5](g) equipped with a water nozzle - stemming from a water pistol - directs the jet to the fingertip on the screen. Finally, a frame made of acrylic glass around the inclined touch area (h) collects the water and a tubing carries the water back to the canister. Currently, the spatial resolution of the liquid feedback is approx. 0.5 cm (0.2") with a total latency of approx. 200 ms.

Stimulus Design

In general, a high number of different tactile cues can augment a virtual GUI element on the touch screen. Tactile cues

[1] 3M MicroTouch System SCT3250EX
[2] Barwig 0333 12V TYPE 03
[3] Arduino Uno R3
[4] 21JN1R0V12
[5] Arexx RA1-PRO

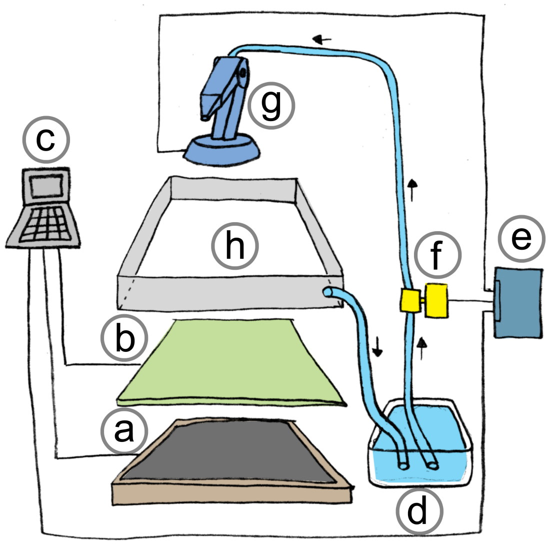

Figure 3. Technical components of the LiquiTouch prototype. Details in the text.

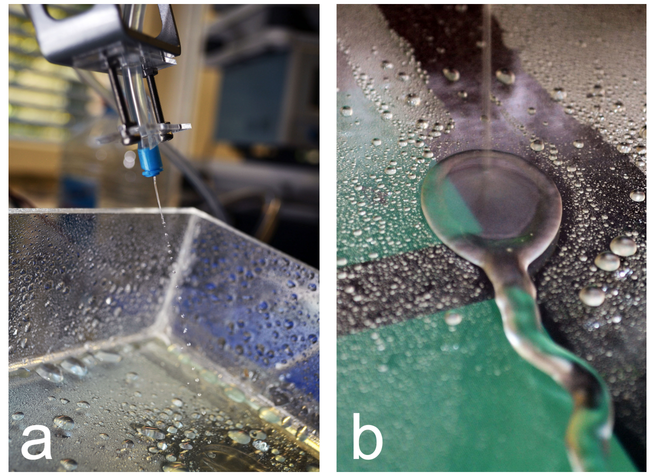

Figure 4. a: Single water droplets deliver tactile impulses with varying frequencies. b: Local effect of liquids on the screen.

can communicate *physical characteristics* such as surface structure, temperature or hardness; they also can communicate *semantic information* such as function, state or structured non-visual messages (e.g. 'tactons'). The full richness of stimulus design with liquid is discussed in the next section. For a start, we decided to implement tactile surface characteristics of GUI elements using the following parameters:

Pressure: By opening and closing the solenoid valve of the system in very short intervals, we generated a form of *pulse-width modulation.* This principle stems from electrical engineering and is based on turning the flow of particles on and off at a fast pace (e.g. 500Hz). The longer the on-periods compared to the off-periods, the more particles are flowing and the higher the power. We implemented this principle to be able to dynamically change the pressure of the water jet.

Frequency: In addition to dynamic pressure changes, we implemented tactile impulses which are created by distinct water droplets (see figure 4). The frequency of droplet pulses is freely programmable, depending on the reactivity of the valves.

Rhythm: By combining both pressure/amplitude and frequency, we created more complex rhythmic liquid patterns to convey surface characteristics such as texture.

POTENTIALS

With the LiquiTouch prototype, we have only just begun to explore the prospects of creating programmable tactile stimuli with the medium water. The use of liquids opens a vast design space for haptic stimuli: The *temperature* of the liquid has effects on both perceptibility and subjective response to the stimulus. The *size of the water jet* determines the size of the body area that is in contact with the medium. The *target of the water jet* is not determined to be spatially identical with the location of touch on the screen. We could think of future interfaces incorporating the notion of 'remote liquid stimuli'. Other types of liquids with different *viscosity* such as oil or ferrofluid have an impact on force and stickiness of the feedback. *Colored liquids* could be used to occlude areas of the screen. *Additional modalities* such as sound or smell coming from the fluids could further enrich the interaction. The *amount of water* on the screen forms an auxiliary tactile modality which locally changes attributes such as smoothness of the surface (see figure 4. Finally, the *spills* that are coming from this non-sterile form of feedback could be described and used as unstructured particles of tangible bits.

An integral part of the design with liquid feedback is the notion of combination. One should consider combining liquids with different characteristics such as temperature or viscosity, one should also consider combining liquid feedback with common tactile feedback technologies such as deformable and organic surfaces.

LIMITATIONS

The use of liquids in a technical context has a lot of inherent difficulties. For safety reasons, the liquid has to be kept away from electrical components. Additionally, we could only use distilled water to avoid interference with the capacitive touchscreen. The prototype was built using off-the-shelf components, the tracking speed of the robot arm and the reactivity of the pump system are constantly improved. With our prototype, we encourage the exchange of physical matter (e.g. water spills). This determines the characteristics of feasible usage scenarios of the system.

SCENARIOS OF USE

The LiquiTouch system could be implemented in larger scale in an outdoor scenario to allow multiple users to interact with the screen. We can think of a public or artistic context such as an exhibition of novel user interfaces (e.g. musical instruments) incorporating new forms of rich multimodal feedback (comparable to Mann's Hydraulophones). We can also think of a playful scenario such as a swimming pool or a playground. Even underwater touchscreens with tactile feedback are conceivable. The system could be used to control water cannons in a amusement park or for vending machine input. In general, we want the LiquiTouch prototype to inspire designers and engineers of tangible and touch-based user interfaces to think about novel forms of haptic actuators and tactile stimuli.

FUTURE WORK

We are currently working on implementing dynamic temperature feedback by integrating an additional warm-water canister and tubing system. In the next step, we will focus on evaluating the psychophysics of the generated stimuli in terms of frequency, pressure and temperature thresholds. Perceptual evaluations and JND experiments will provide us with a basis for future implementations of liquid as tactile actuator. In the future, we want to rebuild our prototype in larger scale and implement it in an long-term usage scenario. The feedback of different user groups in-the-wild will help us to further elaborate our design.

DISCUSSION AND CONCLUSION

Our goal is to integrate the rich human senses to bridge the gap between both virtual elements and the physical environment. We propose the use of liquid as a means to communicate tactile feedback to the user interacting with a touch surface. Liquid is a tangible medium with rich haptic characteristics. Compared to common electromechanical and electrotactile systems, liquid can combine a large number of modalities such as pressure, temperature or viscosity. Additionally, the feedback particles can be conveyed 'over a distance' which could also allow for the augmentation of free-hand gestures.

In the paper, we presented a first technical prototype of a touch system with coupled liquid feedback. The described parameters pressure, frequency and rhythm can be used to augment virtual GUI elements. In addition, we described parameters for designers and engineers of future liquid feedback interfaces. In summary, we believe that liquid can provide a rich spectrum of non-visual cues. Integrating artificial non-visual cues into the interface helps 'making digital information (bits) tangible' [7], bridging the gap between both virtual elements and the physical environment. The use of liquid as a feedback medium supports the flow of information between computing technology and the users.

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