FlexTouch: Techniques for Extending Capacitive Touch Interfaces using Flexible and Conductive Materials

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ABSTRACT

FlexTouch enables passive, light-weight, tangible touch interfaces by extending the sensing capability of capacitive touch screens to ambient surfaces. It can support a variety of sensing and interaction possibilities by attaching conductive surfaces to the touch screen. In this paper, We demonstrate that our technique allows for easy fabrication of customizable touch sensitive interfaces via a variety of commercially available conductive materials. *FlexTouch* can not only support continuous 1D or 2D touch interaction, but also sense human postures and every-day objects. We evaluated the upper limit of sensing range and touch resolution with different layout configurations through series of user studies. Then we demonstrate the versatility and feasibility of *FLexTouch* through new applications in the domain of hand/body posture sensing, object and activity detection as well as enhanced VR/AR interactions and finally we evaluated the performance of these applications.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Capacitive sensing; touch interface; fabrication; continuous touch input; posture detection

INTRODUCTION

2D touch interface is a popular interaction modality on smart devices, which provides seamless, intuitive interaction between users and digital media. However, the interaction space is usually limited to the area where touch sensors are embedded, constraining natural user interactions to the surfaces of these smart devices. Easy fabrication of customizable touch sensitive interface would allow users to extend touch sensing capabilities beyond the surface of smart device into the surrounding physical environment, supporting various sensing and interactive applications.

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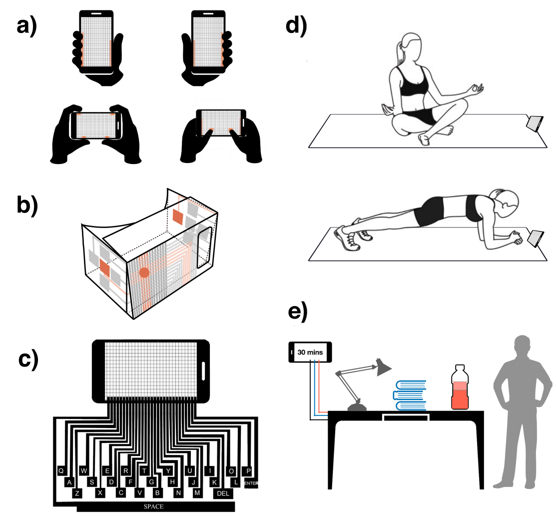

Figure 1. ***FlexTouch* can support various applications with different configurations through extending the capacitive sensing ability of touch screen to surrounding areas. a) Grasp gesture detection with extended frame attached on the edge. b) low cost two-dimensional touch panel of VR cut board. c) Ten finger text input with extended touch keyboard. d) Posture detection on the yoga mat with build-in capacitive sensing matrix. e) Smart health desk application detecting**

A large body of research explored the possibility of enabling various touch interaction methods on everyday surfaces or objects [26, 11, 12, 15]. These prior work share the same vision with us in easy and customizable touch interfaces beyond the capacitive touch screen, however, they require dedicated sensing platforms like the Arduino to power these touch interfaces and enable wireless communication with digital devices. The nature of these embedded systems create technical barrier for end users to fabricate easy and scalable touch interfaces.

Furthermore, researchers have been exploring and developing approaches to blend touch sensing capability with existing objects or surfaces in our environment [6, 8, 9]. talks about what's new about these techs, how are they better compared to e.g.Yang's work and acknowledge their contributions before talking limitations However, similar to prior work on fabricating capacitive interfaces, these approaches need the external power supply and computing resources.

Thanks to the Internet of Things advancement, smart devices are becoming ubiquitous in our everyday living. Many of these devices such as smart phones, smart watch and tablets carry capacitive touch screens. In close proximity to our work present in this paper, some researches demonstrated interesting sensing and interaction possibilities by expanding the sensing area of touch screen via attaching conductive materials. More specifically, prior work enable tangible interaction on 3D printed objects by extending cell phone capacitive touch screen via conductive materials [9, 17]. Even though these 'Extension Sticker' approach proposed allows for touch sensing beyond the surface of the touchscreen, it can only support the one dimensional touch widgets such as scroll-up, scroll-down sliders. Recently, Bodyprint and ... What is this?

In this paper, we present *FlexTouch* a technique for creating 2D continuous touch sensitive surfaces leveraging conductive materials. *FlexTouch* leverages a variety of conductive materials such as copper, ITO and silver as well as fabrication techniques such as conductive inkjet printing to creative various 2D passive conductive patterns that can be easily attached onto the edges of capacitive screens.

We built a customized Android kernel for *FlexTouch* to capture the raw capacitive sensor matrix built-in the smart devices, and apply signal processing and machine learning to capture 2D touch location when touch points from capacitive screen is being extended onto other surfaces. FlexTouch can support a variety of applications including hand/body posture sensing, object/activity detecting as well as enhancing phone based virtual reality experiences. In general *FlexTouch* extend the capacitive sensing capability of the touch screen to everyday object and ambient surfaces. Our contributions in this paper are as follow:

1. We create techniques that leverages a variety of conductive material and ink jet printing to fabricate conductive extension of phone touch screen to support continuous 2D touch sensing on ambient objects and surfaces

2, We implement customized Android kernels to capture raw capacitive touch sensor data and apply signal processing and machine learning towards this data to support versatile sensing and interactive applications

3. We evaluated this method's upper limit including the coverage area, detecting different materials and conducted user study to benchmark the performances of proposed sensing applications including hand/body posture sensing, object and activity detection as well as enhanced virtual reality applications.

RELATED WORK

We categorized three groups of literature's related to *FlexTouch*. Firstly, we discuss a broader set of works that intersects with our application domain: enabling touch interaction on everyday surfaces and objects. Then we narrowed down to a specialized area of literature on enhancing interaction on surfaces near touch screens or mobile devices. Then we review prior work in the field of capacitive sensing related to our sensing method.

Touch Interaction on Everyday Surfaces and Objects

Many researchers have explored various methods or techniques to enable interactive interface on everyday surfaces and objects. We categorize them with their sensing approaches.

One popular method to enable touch interaction on everyday surfaces or objects is through projecting the 2D user interfaces using projector which can be combined with computer vision to recognize user interactions. For example in the projects including Everywhere Display Projector [14], Light Wedgets [5], Light Space [20], and WorldKit [21]. the aurhods used projectors displaying the user interface on everyday surfaces and uses RFB or depth camera to sense user touch interactions on everyday surfaces.

Acoustic is another popular way to sense user Touch interaction. Researchers recognizes a discrete set of touch events on everyday objects by passing a frequency-sweep signal through a pair of piezoelectric transducers [11, 12]. Other methods support acoustic sensing on various objects such as window [13], desktop and other surfaces [**?**]

Another common method is through electrical approaches. Electrick [26] and Pulp Nonfiction [25] enable touch input on everyday surface or object using Electric Field Tomography (EIT) with printed conductive materials on everyday surfaces and objects. Touche [15] enhances touch interface on the human body or everyday objects through measuring the electrical profiles with a frequency-sweep signal. Midas [16] fabricated customized capacitive touch sensors to prototyping interactive object with a circuit board milling machine.

textcolorredTalk about good things of this approaches first? Also I think this limitation is too general, I would recommend discussing pros and cons of each tech from prior work at the end of each paragraph above However, above solutions relay on power supply and external computing resources including additional sensors, signal processor, communication module and the host machine learning machine.

Capacitive Sensing

need to add more related work... The key element of such application is the transmit electrode and receive electrode. Capacitance exists when these two electrodes are separated at a distance. The two electrodes, together with the ground, and human body, form a capacitance sensing system. The physical properties can be estimated by measuring the changes in capacitive coupling between the human body and the receive and transmit electrodes.

Enhancing Interaction around Mobile Devices

Modern mobile devices are embedded with rich sensors and actuators. Researchers have explored approaches and techniques enhancing the interaction around mobile devices with customized sensors via active and passive techniques.

Researchers has explored attaching active sensor to mobile devices to enable interactive user applications. SideSight [2], in particular, added a sensor board with multiple linear arrays of discrete infrared (IR) proximity sensors on the edge of the mobile device to extend the touch interaction to the surface around the device. Toffee [22] enables around device interaction through acoustic time-of-arrival correlation method with piezoelectric transducers. iGrasp [4] and IrotateGrasp [3] used capacitive touch sensors on the edge and back of the mobile device to recognize the grasp postures for adaptive keyboard layout and screen rotation. These approaches demonstrate promising applications space, however, adding external sensors requires power source and processing unit which create scalability barriers for adoption.

As an alternative, researchers explored leveraging the built-in sensors to enhance the interaction on or around the touchscreen. Acoustruments [10] constructed various sensing units that can detect hand interaction around mobile devices such as touch, proximity and rotation by measuring the acoustic signal transmitted in an enclosed, pipe-like pathway from the speaker to the microphone. UbiTouch [19] enabled touch interface on surrounding surfaces using build-in proximity and ambient light sensors. Wang and colleagues presented a virtual keyboard tehcnique on the surround surface of mobile devices through harnessing multipath fading with multiple build-in microphones [18].

Capacitive touch sensing panel provides an high-resolution method for sensing user hand interactions. Related work explored enhancing tangible interaction on the touch scree via Clip-on Gadgets, which extends capacitive touch points on the phone to physical controllers via conductive materials [24]. This approach provides haptic feedback via the controllers while allowing for interactive applications via phone capacitive touch screen. In close priximity to our work, Kato and his colleagues took one step further to fabricate 3D printed conductive gadgets with haptic feedback patterns [9]. User interaction with these gadgets can be sensed via the capacitive screen when they are placed onto the phone. In addition, they also presented an technique named ExtensionSticker which allows input sensing to be transferred to ambient surfaces [8]. They also discussed an VR application where this techniques is utilized to enable interactive VR applications [7]. The challenges here is these prior work usually blocks out a area of the screen for attaching conductive tapes which limits user's natural interaction with the digital contents. In addition, These techniques using extension stickers only allow for 1 dimensional touch sensing on the areas connected to the touch screen.

In this paper, we present FlexTouch, a techniques that allows users to create flexible and customizable touch sensitive gadgets that can be easily attached onto the phone for rapid prototyping of interactive applications. Different from prior work which either partially block the mobile phone display we combine transparent materials such as ITO which can be easily attached onto the phone in an unobtrusive way. In addition, we apply signal processing and machine learning directly to the raw value of the capacitive sensor to enable 2 dimensional continuous finger location on ambient surfaces. This advancement from prior work dramatically enhances the expressiveness of user interactions.

SENSING PRINCIPE OF TOUCH SCREEN

There are tow sensing solutions of current capacitive touch panel: self-capacitive and mutual capacitive touch sensing methods. The mutual capacitive touch sensing method is more widely deployed because it's robustness in multi-touch applications [23]. Shown in Figure 2, the touch panel is generally made of multiple layers above the display screen. A substrate glass etched with the sensing lines is attached. Then a layer of insulating material etched with the driving lines is placed on top. Finally, a bonding layer and a protective layer are placed on the top of the stack.

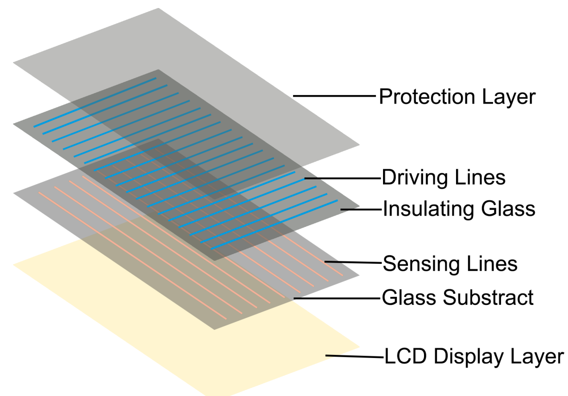

Figure 2. The multi-layered structure of current capacitive touch panel.

The driving and sensing lines are often made by Indium Tin Oxide (ITO), that is a highly transparent conductive material. They are oriented in a row-column matrix with amounts of junctions. With a thin insulating layer between the driving lines and sensing lines forming a gap, the coupling mutual capacitance is formed at each junction[1]. The driver IC drives each driving line (row) and scans all the the sensing lines (columns) to measure the capacitance value at each row-column intersection. This procedure is repeated for all the driving lines as one entire cycle as Figure 3 a) shows.

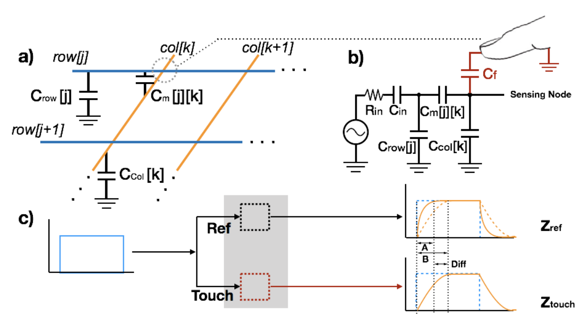

Figure 3. a) Explanation of capacitive sensing structure of row-column matrix.b) Equivalent circuit of each junction. c) The measurement of capacitance of each junction.

The finger touch increases the mutual capacitance of the touched electrodes. To detect the touch events, the driver IC measures the capacitance of each electrode intersection by comparing the source signal injected to the driving line and returned signal from the sensing line. The equivalent circuit and measuring method are illustrated in Figure 3 b) and c). The widely spread method to detect the mutual capacitance of each junction is to measure the charging time to reach a certain threshold of the signal returned from he sensing line.

FLEXTOUCH

FlexTouch extends the capacitive sensing method of commercially available touch screen to surrounding areas through a single conductive thread or frame attached on each sensing electrode. The attached conductive material, acting as a "touch event", changes the electric field around the capacitive sensing junction. However, other conductive objects including the finger can still change the signal profile of the sensing electrode intersection when contacting with the extended thread or part. In this section, we explain the working principle, implementation and various of design configurations of *FlexTouch*.

Working Principle

The conductive thread attached on the touch screen draws some currents passing from the driving line around the corresponding junctions. So it takes more time to charge both the inner circuit and the attached conductive thread. In other words, any attached conductive material increases the mutual capacitance of the capacitive sensing node. However, when people touch on the conductive thread, human body draws more currents from the touch screen that further increases the mutual capacitance. We present simplified equivalent circuits shown in Figure 14.

$$V_{out} = \frac{C_{mc}}{C_c} v_{in}(1 - e^{\frac{-t}{RC}}) \tag{1}$$

$$C_{mc} = \frac{C_m C_c}{C_m + C_c} \tag{2}$$

$$C = C_r + C_{mc} \tag{3}$$

$$C^{'} = C_r + C_{mc} + C_e \tag{4}$$

$$C^{''} = C_r + C_{mc} + C_e + C_f \tag{5}$$

Implementation

We implemented FlexTouch on a Huawei P20 and a Huawei P10 phone. By rooting the Android operating system and modifying the driver of the touch screen controller IC in the kernel source code, we extracted the raw capacitive sensing data: 32 by 16 px 10-bit image across a 5.8 inches surface at 100 fps for Huawei P20, 28 by 16 px, 10-bit image across 5.1 inches surface at 20 fps for Huawei P10.

Design Spaces

STUDY: COVERING AREA

Every capacitive sensing technique can only be sensitive a certain range of measured capacitance introduced by the finger touch.

We studied and evaluated the maximum covering distance of *FlexTouch*.

figures/FlexTouch_circuits.png

Figure 4. Equivalent circuits of *FlexTouch* a) original touch capacitive sensing junction, b) by adding a conductive thread, c) with touch on the conductive thread attached on the touch screen.

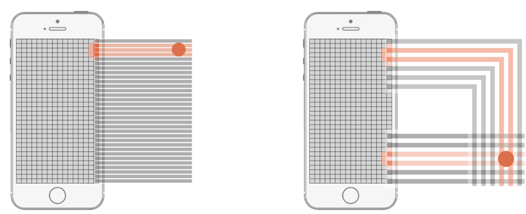

Figure 5. *FlexTouch* can support various applications with different configurations.

Experimental Setup

We evaluated independent factors including different conductive material, length and width on the extending distance. We tested different width (1.4 mm, 2.7 mm, 5.4 mm), length (0.01m, 0.02m, 0.05 m, 0.25m, 0.5m, 1m, 1.5 m), material (copper, ITO layer, printed conductive silver ink and conductive carbin ink).

Result

Figure 7 shows us the effect of extended length on the signal strength under different configurations of different width and conductive materials.

Signal noice of each electrode is around ....

Initial Result

Maximum Distance. In general, the effective measuring distance is 1 meter.

The relationship between thread width and covering distance. [suspicion] The wider the longer.

Figure 6. Tested materials for covering area.

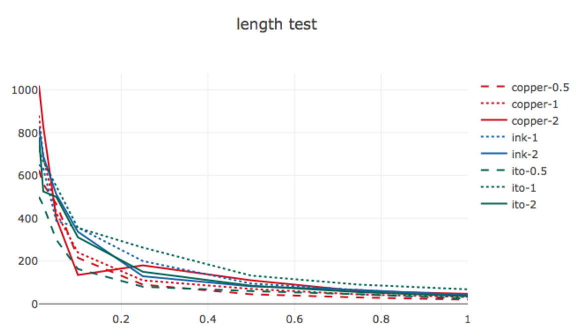

Figure 7. The signal strength by length under different configurations.

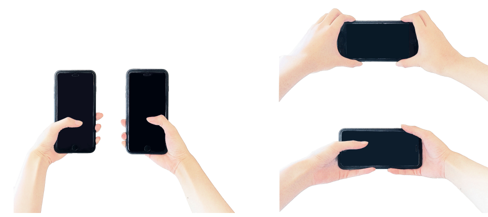

Figure 8. Example FlexTouch applications, on the left hand side, FlexTouch recognize which hand is holding the phone and triggers hand oriented user interfaces. On the right hand side, FlexTouch links certain hand postures to applications, for example, when the user is holding on to 4 corners of the phone, the photo app is automatically opened. what's the right hand side bottom image trying to demonstrate? This figure need to add specific applications to the phone screen see description in the example app section

THEORY BEHIND THIS [This is Yuntao's Job.]

Material

Copper, carbin and ITO.

Independent Sensing of Each Sensor Unit

Different setups of independent sensing of each sensor unit. Button, Slide bar, two-dimentional touch panel.

Crossing Sensing between Sensor Units

How sensor units affect each other. The relationship between other factors on the crossing sensing between sensor units.

Sensing Everyday Objects

Tests of how to sense everyday objects. Conductive? Any objects? how to modify.

Adding Capacitence

Adding additional conductive materials will change the capacitance of the sensor unit.

The functionality of cobination of

Coding Pattern

Each application can be initilized with the initial pattern of the raw image.

EXAMPLE APPLICATIONS

Gesture sensing on the edge of the phone

FlexTouch extend the capacitive touch sensing capabilities to around the phone edge to enable hand gesture sensing. This extend sensing space interacting with ditigal contents on the screen without blocking the digital contents. Below we describe 2 examples.

In Figure 8a hand side demonstrate an example where FlexTouch can sense can differentiate between left and right hands of users to naturally arrange type interfaces. 8b demonstrate an example where flextouch detects specific hand gestures to trigger applications such as photo apps.

In general we can support sensing of 8 different hand postures (figure**??**) to support a variety of end user applications.

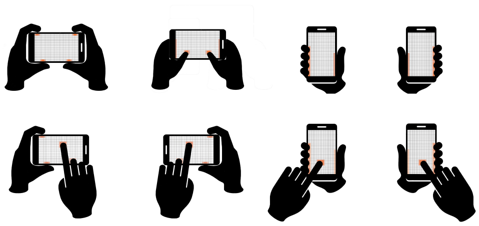

Figure 9. Hand postures recognition supported by *FlexTouch*

figures/back.jpg

Figure 10. Touch Interaction on the back of the phone while placed inside the pocket to silence phone during meetings

Touch interaction on the back of the phone

FlexTouch can also extend the capacitive sensing capabilities to the back of the phone. This allows user to interact with a phone while it is placed in the pocket. In Figure 10, we demonstrate an application where users can silence their phone during meetings leveraging capacitive touch enabled by FlexTouch on the back of the phone.

Full Size Keyboard

Leveraging the flexible ITO material of, We fabricate a full scale keyboard which can be easily attached onto the phone for fast input applications. This example is demonstrated in Figure 11.

Hand writing tracking panel

Given the 2D tracking capabilities of FlexTouch demonstrated in Figure 6, we can also track 2d hand writing as an input mechanism. This example is demonstrated in Figure 12

Phone based VR/AR touch interactions

Several project including the popular Google cupboard approach mounts phone onto cheap and disposable cupboards for VR/AR applications. Such approach greatly lowered the barrier for VR hardware and allows easy accesss for developers to test out their VR/AR ideas. However, Given the design of the cupboard approach, the touch screen is completely covered by the case and there is no easy way for user to interact

figures/keyboard.jpg

Figure 11. Inkject printed full size keyboard that can be easily attached to the phone

figures/writing.jpg

Figure 12. 2D tracking of hand written characters via FlexTouchwhy not just write on the phone directly?

figures/surfaces.jpg

Figure 15. Detecting objects on 2d surfaces as well as user interaction with these objects

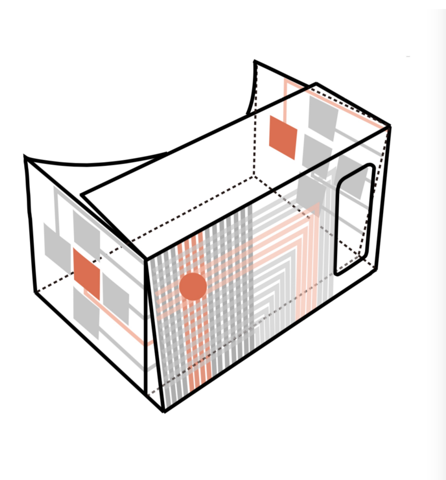

Figure 13. Enhancing Phone VR applications with 2D touch sensing area on the back of the phone

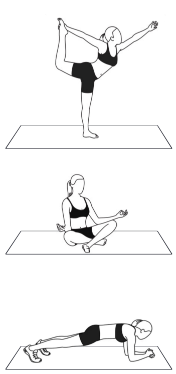

Figure 14. Recognizing user's posture on the yoga mat built by *FlexTouch*.put 3 images into the same row

with digital contents. Figure 13 demonstrate an example where FlexTouch wires out touch screen of phone to allow for touch interaction for Google Cupboard VR.

Smart Surfaces

The sensing range of FlexTouch allows it to extend to larger sensing areas such as the yoga met. Based on users physical contact with the mat, FlexTouch can detect and classify different user postures. Based on this functionality, we can build application to track users fine-grain physical activities. In addition, other ambient platforms can leverage this data to create smart applications. For example, we can adjust ambient lighting, temperature and music volume according to user's activity intensity.

Given the flexible and passive nature of FlexTouch, we envision it to be integrated into other large surfaces such as table and desk surfaces to detect the objects being places onto these surfaces as well as human interaction with these objects (Figure 15).

DISCUSSION

CONCLUSION

ACKNOWLEDGMENTS

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