

# Scanning FTIR: Unobtrusive Optoelectronic Multi-Touch Sensing through Waveguide Transmissivity Imaging

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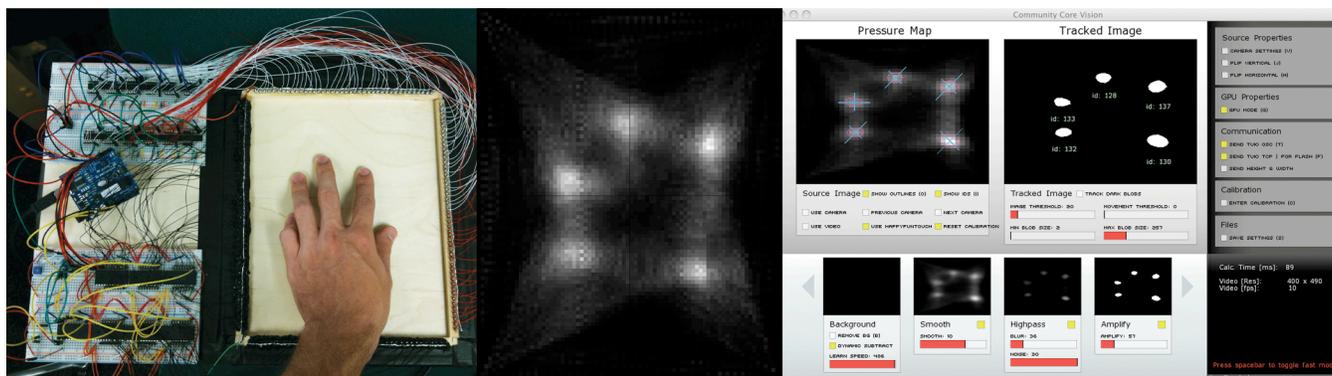


Figure 1. Scanning FTIR Prototype Screen showing reconstruction of waveguide transmissivity image and blob recognition pipeline.

## ABSTRACT

We describe a new method of multi-touch sensing which can be *unobtrusively* added to existing displays. By coupling individually controlled optoelectronics to the edge of a planar waveguide, our scanning approach overcomes prior disadvantages of optoelectronic multi-touch sensing. Our approach allows for a completely transparent touch surface and easy integration with existing LCD displays.

## Author Keywords

Multi-touch, Frustrated total internal reflection, touch, tactile, interfaces, input devices

## ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User Interfaces—*Input Devices*

## General Terms

Design, Experimentation

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## INTRODUCTION

Multi-touch input has hit the mainstream. The demand for these systems is pushing multi-touch to modalities from the camera-based wall-sized installations seen on CNN, to the iPhone's capacitive screen. It should come as a surprise that this demand has yet to push multi-touch to the desktop/laptop arena, though this is due, in large, to the lack of size-appropriate technologies. Recent developments in optoelectronic multi-touch sensing are beginning to bridge this gap, but suffer from ambient lighting noise and non-trivial display integration [4].

We aim to tackle both those issues with a novel form of FTIR multi-touch sensing. It is theoretically resilient against ambient lighting issues and can be easily integrated with existing displays. Because the touch surface itself has no electrical components, it can be made exceptionally clear. Our edge-sensing approach allows a touch screen to be placed anywhere a pane of glass can go.

## MULTI-TOUCH TECHNOLOGIES

Many types of touch-sensing technologies have been created over the years. Three different sensing techniques are employed in the majority of systems.

### Resistive

Resistive touch screens employ layers of electrically resistive material separated by a thin insulating layer of air or microdots. Touching the surface connects the resistive layers, and the voltage generated can be analyzed to determine the position of the touch on the screen.

Jazzmutant's Lemur [5] incorporates a resistive multi-touch screen with a LCD panel, but is limited to applications requiring low precision. High-precision, pressure sensitive, resistive multi-touch input was recently demonstrated in the UnMousePad [11].

### Capacitive

Capacitive touch screens embed electrodes on a touch surface to create a two-dimensional network of capacitors. Touching the surface will change the capacitance of the grid around the finger, which is then measured electronically and converted to an x,y position.

For smaller screen sizes, capacitive multi-touch sensing is the current de-facto industry standard. While it offers no pressure information and cannot be used with a regular stylus, capacitive technology has been commercialized in products such as Apple's iPhone. RIM, maker of the Blackberry, recently applied for a patent on a hybrid resistive/capacitive touch screen which would allow for stylus use and zero-force capacitive sensing [7]. The N-Trig Duosense also offers stylus recognition and capacitive multi-touch sensing by use of an electronic pen [10].

Unfortunately capacitive and resistive touch technologies are not without their downsides: the metal electrodes embedded in these types of touch overlays reduce screen visibility. This can be overcome to some degree with the use of transparent electrode materials such as Indium Tin Oxide. However, due to ITO's high resistance, sensors with transparent conductors cannot be made very large [11].

### Optoelectronic

Touch screens using optical effects to determine touch vary considerably in their specific implementation details. The general principle is this: a light *source* is directed toward an *active area*, and a light *sensor* is used to analyze some property of the light after it has interacted with the *active area*. There has been considerable work done in the field of optoelectronic touch and multi-touch technologies over the past 3 decades. We will briefly discuss the prior work and how our approach fits in the optoelectronic touch-sensing ecology.

In a 1972 patent, Johnson and Fryberger [6] describe a touch actuable data entry panel through which a plurality of beams may be propagated transverse to the normal viewing of the panel. Detection of the absence of a beam indicates a touch point has interrupted the beam.

In a 1982 patent, Mallos describes a CRT-based touch technology [8]. The scanning beam of a CRT couples light into the waveguide when a finger is touching the point where the CRT is currently firing. An edge sensor can detect this in-coupling of light; touch position is then determined by comparing this signal with the current location of the CRT raster.

Microsoft's Surface [9] and Camera-based FTIR [2] both incorporate infrared tracking cameras behind a projection screen to determine touch position.

Thinsight [3] uses a 2-dimensional array of proximity detectors (i.e. source/sensor pairs) positioned behind an LCD.

FLATIR [4] uses a 2-dimensional array of sensors behind an LCD panel to detect touches using the same FTIR principle as camera-based systems.

We can broadly categorize the many types of optoelectronic touch technologies in to two types. Those with active elements behind the screen itself, *obtrusive*, and those without, *unobtrusive*.

### Obtrusive Technologies

All camera-based techniques require space behind the screen in proportion to screen size, for the camera, and are thus obtrusive. Thinsight and FLATIR are also *obtrusive* techniques, both requiring sensors to be integrated within or behind the display itself.

Obtrusive optoelectronic methods are very sensitive to ambient light issues. Because they incorporate sensors behind or embedded in the screen, the amount of light falling on the screen affects their ability to detect touch.

Display integration presents another issue with obtrusive technologies. Camera-based systems require a projector to be used for visual feedback. This is both bulky and costly, limiting its usefulness to large installations. FLATIR and Thinsight successfully integrate with LCD panels, but not without significant modification to the panels themselves.

### Unobtrusive Technologies

Unobtrusive optoelectronic technologies are limited to the various disclosures provided by Johnson and Fryberger [6]. They are theoretically more resilient against ambient lighting, and offer much easier integration with displays. Unfortunately, the prior work shows no multi-touch embodiments of these disclosures.

### SCANNING FTIR

Despite the plethora of optoelectronic approaches, prior research did not yield an unobtrusive method of optoelectronic multi-touch sensing. Obtrusive methods are sensitive to ambient light changes, difficult to integrate with existing displays, and in the case of camera-based systems, can be quite bulky.

We take a new spin on an old technology to achieve an unobtrusive method of optoelectronic multi-touch sensing. SFTIR is a novel application of the FTIR phenomenon. We will introduce FTIR principles, and then describe our contribution.

### Frustrated Total Internal Reflection (FTIR)

Total internal reflection is a well known physical process by which light is trapped within a medium of high refractive index (relative to the surrounding material). This total internal reflection can be interrupted when a material with higher refractive index than the medium comes in contact with the medium, causing light to escape the medium.

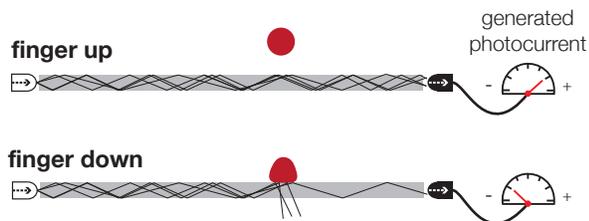


Figure 3. Touch Sensing across an FTIR scanline.

As Johnson and Fryberger describe, this principle can be used to detect a finger in contact with a platen waveguide as shown in Figure 3.

#### SFTIR Screen Layout

To bring the approach shown in Figure 3 to the multi-touch domain, we arrange complementary linear arrays of sensors and sources along the perimeter of an optical waveguide, as shown in Figure 4. The single sensor/source pair of Figure 3 can then ideally be considered as a “slice” through any sensor/source pair in Figure 4. Even though they are not rectilinear, like in a CRT, we will refer to these slices as *scanlines*, because they are iteratively sampled to detect touches. For reconstruction purposes, we classify each scanline as either horizontal or vertical.

#### Scanning the Array

To scan the sensor array we switch on one source at a time and take readings from each of the sensors opposite it. Each

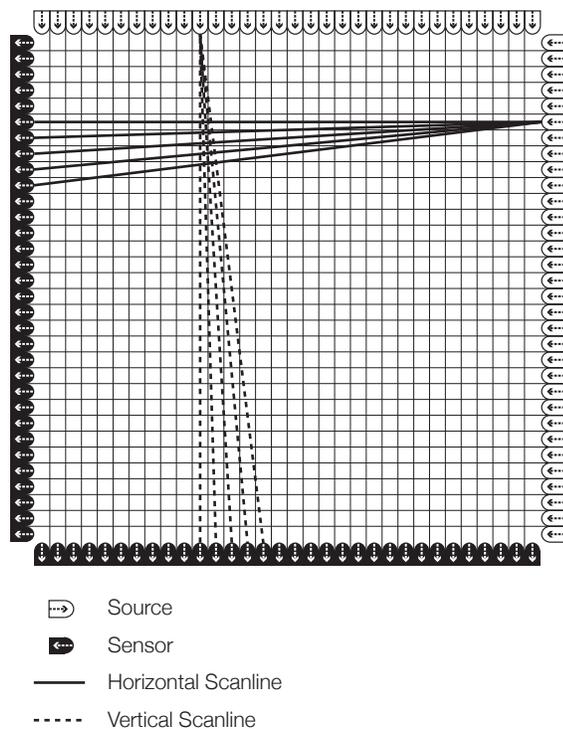


Figure 4: SFTIR screen layout, with complementary linear arrays of sensors and sources. A small subset of both horizontal and vertical scanlines are shown for illustration.

sensor reading can then be associated with a scanline for that source. For each source on top, the associated scanlines are vertical; for those on the right, they are horizontal.

#### Waveguide Transmissivity Imaging

Given the sensor readings for each scanline, we can reconstruct a two-dimensional image of the waveguide transmissivity. We discretize our surface into a grid. Each grid cell is then associated with two sets of *scanlines*, one set containing all the *horizontal scanlines* that intersect the given cell, and one set of all its intersecting *vertical scanlines*. The value for the cell is then given by the average value of the *horizontal scanlines* multiplied by the average value of the *vertical scanlines*. After this, the grid values are normalized and drawn into a pixel buffer.

#### PROTOTYPE IMPLEMENTATION

Our present implementation consists of an 8”x10” sheet of 3/32” thickness acrylic. We surround the acrylic with sensors and sources as shown in Figure 4. Optoelectronic components are spaced at about 5 per inch, giving us 42 source/sensor pairs on the short side and 49 source/sensor pairs on the long side. This gives us  $42^2 + 49^2 = 4165$  total source/sensor pairs. A series of TLC5916IN cascaded shift register LED drivers controls all the *sources* while all the *sensors* are multiplexed via CD74HC4067 16-channel analog multiplexers. An Arduino-based microcontroller controls the aforementioned as well as providing ADC functionality and communication over USB/Serial.

#### Integration with Camera-based Blob Detection Pipeline

After the two-dimensional waveguide transmissivity image is created, it is sent through a multi-stage recognition pipeline. This pipeline applies filters to the image, performs blob recognition, and generates x,y coordinates for recognized touch points. We implement this pipeline by extending the open-source Community Core Vision (CCV) toolkit [1]. A screenshot of the software can be seen in Figure 1, showing each stage of the blob detection pipeline.

#### Temporal Performance

Because the Arduino’s ADC can only sample at a rate of about 7 kHz, and a full update of the screen requires 4165 voltage readings, our screen refreshes ~ 1 Hz. While a 1 Hz refresh rate is too slow to be useful, our prototype serves as a proof-of-concept for Scanning FTIR. High-frequency scanning of the array is an engineering challenge to be overcome; the use of photodiodes in GHz range fiber-optic systems is an encouraging testament towards its possibility.

#### Recognition Performance

Blob recognition works well in some cases and not as well in others. When the touches are near the center of the screen, the touch resolution is much better. Near the edges, the density of *scanlines* is much lower, so touches are more ambiguous.

Figure 5 A shows a clear example of this. We use gaffer’s tape to simulate 2 finger touches on the surface, since tape also activates the FTIR surface. There are clear shadowing

effects around the edge where visual hull artifacts from the reconstruction algorithm are apparent.

Figures 5 B and 5 C show the shadowing effect that a large touch area has on two touch points closer to the center of the screen. The two touch points are still visible, but no longer clearly distinguishable.

Since fingertips have a relatively small contact area, the shadowing effect due to fingertips on the surface is much less than our tape test targets.

We successfully achieve multi-touch input with an accuracy of better than 1 mm. Multiple touches can be distinguished if the touches are separated by around 5 mm. As with any FTIR based system, a flat finger press is required to activate a touch. Experiments in increasing the

sensitivity were promising, but a more robust experimental setup is needed to determine if the increased sensitivity is useful in practice.

#### Ambient Lighting Issues

The FTIR effect that we exploit is theoretically more immune to ambient lighting than other optoelectronic approaches. In practice however, excessive ambient light caused our sensor readings to fluctuate. After some testing, we realized that the non-active side of the phototransistor where the leads are connected is actually sensitive to light. Future work will attempt to resolve this issue with shielding.

#### CONCLUSION

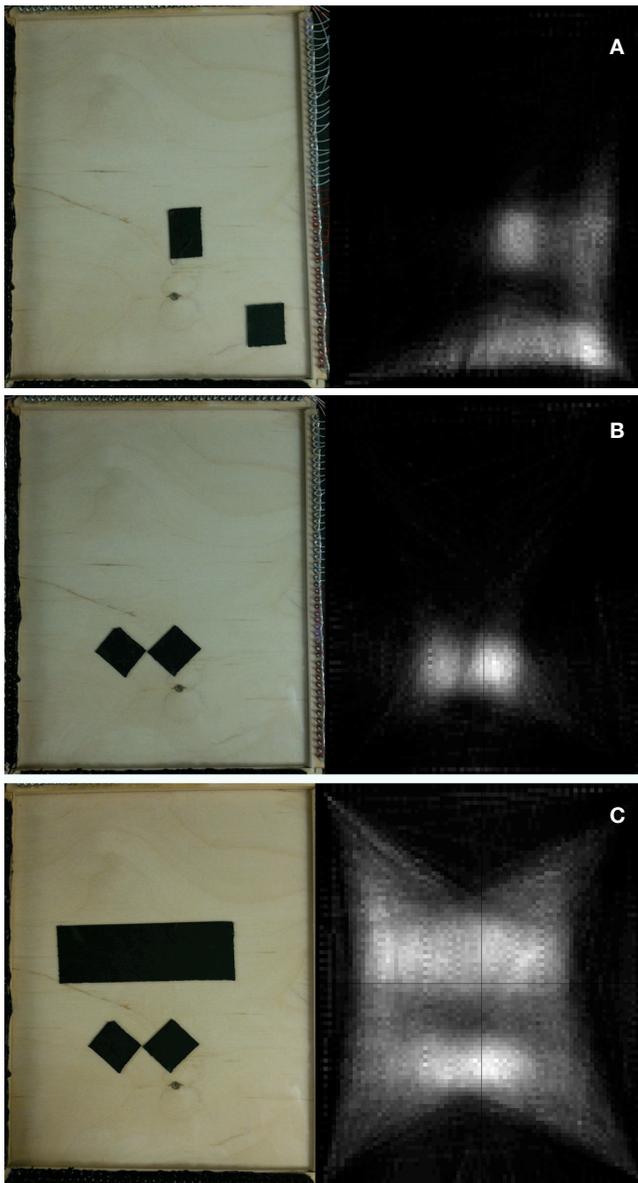
SFTIR is a promising optoelectronic multi-touch technology. It offers complete screen transparency, much easier display integration, and potentially better ambient light rejection than its optoelectronic alternatives. There are no active components in the touch surface, so screen wear is a non-issue.

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**Figure 5:** Gaffer's tape "test targets" showing various FTIR shadowing effects