# FLATIR: FTIR Multi-touch Detection on a Discrete Distributed Sensor Array

Ramon Hofer
Inspire AG, ETH Zurich
hofer@inspire.ethz.ch

Daniel Naeff
ETH Zurich
naeff@student.ethz.ch

Andreas Kunz
Inspire AG, ETH Zurich
kunz@inspire.ethz.ch

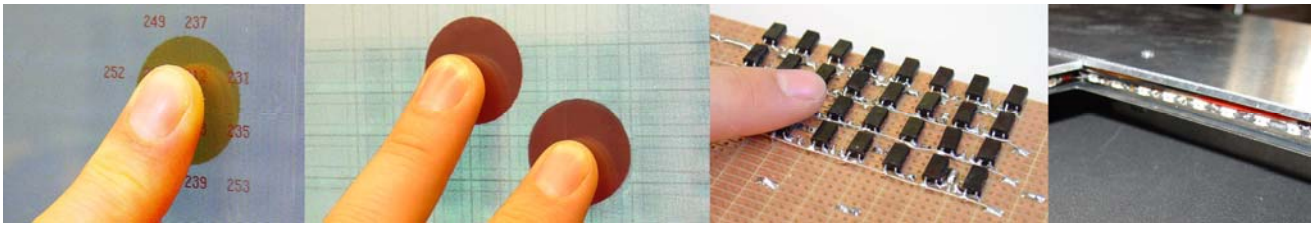

**Figure 1:** From left to right: Detecting touch by interpolating between triggered sensor values; Detection of multiple touch points by grouping sensor values; 4x8 sensor array, In-coupling FTIR infrared diode frame.

## ABSTRACT

In this paper, we suggest a new way to add multi-touch capabilities to an LC-display. For this, FTIR and IR-sensing behind the LC-screen will be combined. Using a large infrared sensor array mounted behind the LC-matrix, infrared light in front of the screen, which is strong enough to pass through the LC-display's components, can be detected The FTIR-technology is able to deliver such infrared light to the integrated sensors when touching the screen with the fingers. For the prototype, the key parameters of the FTIR principle were experimentally analyzed to optimize the sensor reactivity. The 4x8 sensor prototype can simultaneously detect multiple touches with an accuracy of around 1 mm and with an update rate of 200 Hz.

## Categories and Subject Descriptors

H.5.m [**User Interfaces**]: Information interfaces and presentation (e.g. HCI): Miscellaneous.

## General Terms

Measurement, Experimentation, Human Factors

## Keywords

SDG, FTIR, Multi Touch, CSCW, LCD, Interaction.

## 1. MOTIVATION

In creativity sessions, it is crucial to have an intuitive interaction for not distracting the user from the task to be solved. Thus, it is important that the tools for capturing and visualizing volatile ideas for further discussions allow intuitive handling. On a workspace, the interaction is often done by using fingers, e.g. for moving around a piece of paper, for pointing, for clarifying etc.

IT-supported collaboration systems typically rely on projections and support various kinds of interaction, while a few of them also allow multi-user interaction. Systems exist, which allow interaction using finger touch, even identifying multiple users. However, since most of the systems use projections, they need much space behind or in front of the screen. Only few systems are capable of tracking multi-touch on LC-displays. Also most of the systems are disturbed by additional objects on the screen which are not part of the interaction itself, but are used for the task itself, such as laptops, books and other resources.

Thus, the scope of this paper is to introduce a technology, which can be integrated into LC-displays and which allows touch interaction without affecting the system by other objects on the surface, not being relevant for touch, but required to solve a given task.

## 2. RELATED WORK

Multi-touch is a research topic since the mid 80s. Lee et al. [1] already designed a multi-touch tablet surface with front projection in 1985. It was capable of sensing pressure and location of multiple touch points by using capacitive areas. DiamondTouch [2] uses capacitive coupling to track up to four different user's multitouch inputs and uses a front projection. SmartSkin [3] uses reference signals on an antenna grid, which are distorted by finger touch and by specially equipped objects, but is not suitable for backlight illumination. Other approaches are the use of ultrasonic waves as done in [4].

Research work that even integrated photosensitive pixels into the TFT-matrix is described in [5]. Thinsight [6],[7] uses infrared sensors behind the LC-matrix of a laptop display to track multiple finger touches. An emitter is mounted close to each sensor, which radiates infrared light through the LC-matrix. All objects (not only finger touch) on the screen reflect a certain amount of this light, which can then be detected. MightyTrace [8] also uses a sensor array behind the LC-display, but tracks only active devices and does not support touch. HD Touch [9] is another work, which uses LC-displays for displaying the image. It is able to detect touch and TUI input on an LC-screen by using a web camera behind the LC-screen. But since cameras are used, the system needs a lot of space behind the screen and has a low update rate. Several other research works use cameras to track multiple touches and objects, such as PlayAnywhere [10] and Lumisight [11].

Recently, much research was done in the field of frustrated total internal reflection (FTIR). FTIR systems are able to acquire touch blobs at high spatial and temporal resolutions. In addition, they are scalable to very large installations [12]. Typically, the technology is used for detecting finger touches [13] by using standard webcams that are sensitive to infrared light.

ThinSight also uses specialized IR-sensing electronics like we propose. The difference is, that we use another optical principle and thus achieve “immunity” against unwanted disturbing objects such as coffee mugs laptops and so on. This is achieved by taking advantage of the FTIR principle that requires a very good optical coupling between objects and tracking surface. Metallic or “hard” objects will not trigger the sensors.

Analyzing these different solutions, it can be distinguished between multi-touch technologies, which use specialized tracking electronics like DiamondTouch or ThinSight, and systems that use a camera-projector setup to detect touch. Most systems use either front or back projection and require a lot of space for the light path. In case of a front projection, shadow casting could also be a problem for precise user interaction. In addition, projection systems need darkened rooms in order to generate an acceptable image quality. Furthermore, camera-based tracking systems are typically limited to 30 Hz tracking rate (for low-cost systems).

However, since FTIR is easy to set up, it is interesting to examine a setup that combines the advantages of FTIR and compact, bright LC-displays.

# 3. BASIC IDEA

The basic idea is to combine FTIR and an IR-sensor array for infrared light detection. However, since the IR-sensors have a fixed exposure time, considerations concerning light attenuation have to be performed. This was less necessary with camera-based systems so far, since in there the camera’s exposure time could be adjusted and intensities could be integrated over time. In addition, the IR-light only had to pass through an acrylic screen and intensity, size and shape of detected blobs were less relevant.

## 3.1 FTIR (frustrated total internal reflection)

If light is coupled into a thin acrylic glass plate from the side, most of the rays are internally totally reflected and do not exit the plate. Only a small amount of light leaves the acrylic. This occurring effect in nano-scale has an exponentially decreasing amplitude of the emitted IR light wave vertical to the acrylic surface, known as evanescent wave. The amplitude decreases typically to zero after a distance D of approximately the wavelength of the light used (Figure 2). If a finger is put to the surface and enters the evanescent field, light is scattered out of the acrylic and can be measured by the sensor. The penetration depth of the evanescent field into the air depends on various factors, such as incidence angle, media indexes and wavelength. D is in the range of nm.

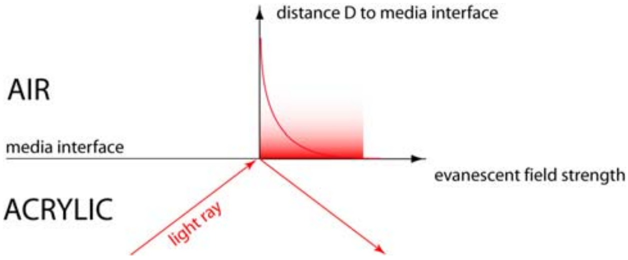

**Figure 2:** Schematic of a total reflection with its evanescent field decreasing with distance D to the media interface.

Additionally the incoming ray is shifted relative to the outgoing ray for a specific distance which is known as the Goos-Hänchen-shift [14], but which is not very relevant for our analysis.

### 3.1.1 *FTIR shadowing*

To observe the FTIR tracking principle, we set up a standard configuration using an acrylic with attached IR-LEDs on its side. Using a standard webcam, we observed the following effect.

By using wet paper, a large touch area can be applied to an FTIR acrylic. Since the water on the paper generates a very good coupling of the two media, we easily generate a large area of decoupled rays. As shown in Figure 3, the wet paper decouples almost all light after a distance of in our case 14 mm (center of paper is black). At each touch point of the fingers, a certain amount of IR-light is decoupled. At the secondary touch points (where the paper is positioned), already some energy of the rays is lost and the amount of intensity is not as strong as at the first decoupling points.

This observed effect has to be taken into consideration when using a discrete sensor array, since intensities directly influence the position determination (see next chapter).

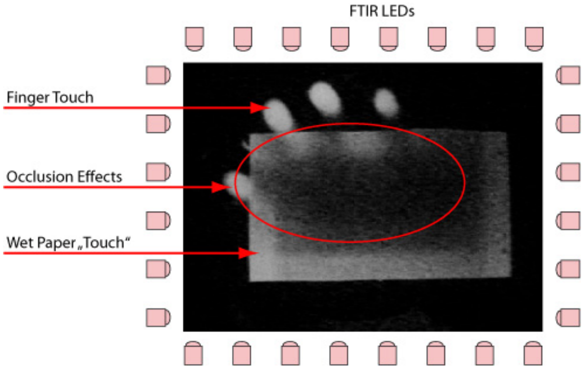

**Figure 3:** Decoupling occlusion seen by a standard webcam. Fingers touch surface while a wet paper is used for simulating a large touch area.

## 3.2 Discrete Sensor Array

Since the LC-matrix of standard flat screens is partly transparent to infrared light, we can detect infrared light in front of the screen by using a large sensor array. This reduces the construction depth of the tracking technology compared to camera and projector based systems. For our prototype, we use a sensor array of 4 x 8 analog sensors directly behind a small region (40 x 80 mm) of a standard LC-display to detect infrared light (IR-light) in front of the screen. The infrared light has to pass through all the elements (LC-matrix, diffuser films, and diffuser) of the LC-display, until it can be detected by the sensors (Figure 4).

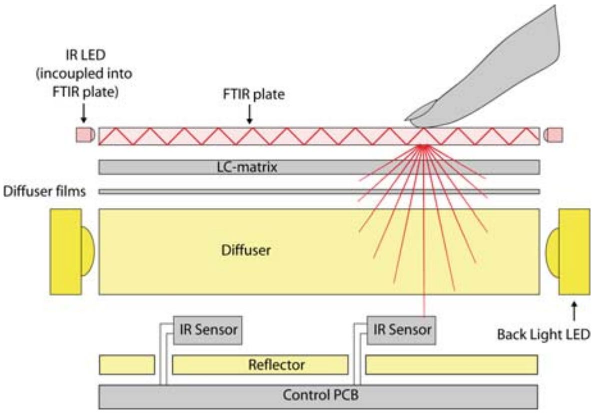

**Figure 4:** FTIR setup in front of a standard LC-screen with integrated IR sensors. The original cold cathode fluorescent light tube was removed, since it produced an oscillating IR background noise. It was replaced by white back light LED stripes.

# 4. FEASIBILITY TESTS

For the envisioned combination of FTIR and IR-sensor array, feasibility tests were performed first, since the amount of light that has to be decoupled from the FTIR system needs to be strong enough to pass through all component layers of an LC-screen. Thus, the first requirement is that the peak sensor value generated by a finger touch is as high as possible.

By knowing the position-intensity curve of finger touches relative to the sensor, it becomes possible to interpolate between all active sensor values and to compute the position of touches (Figure 5). This defines the additional requirement that a single finger touch ideally triggers more than one sensor. This is needed in order to perform a good interpolation between these sensor values – in fact to improve the tracking accuracy. For doing so, a wide decoupling cone and thus a wide position-intensity curve is required.

The concept of FTIR can be separated into two relevant aspects:

- In-coupling of infrared light from the IR-LEDs into the acrylic
- Decoupling from the acrylic to the infrared sensors

For preliminary influence tests, neither the LC-matrix nor the diffuser was used in order to properly measure the occurring effects caused by the matrix itself. The setup shown in Figure 5 is used to record position-intensity relations. When analyzing the involved effects, we maximized the sensor reactivity in order to capture also slight changes and to make sure the sensors also got triggered in a fully equipped (including LC-matrix and diffuser) setup.

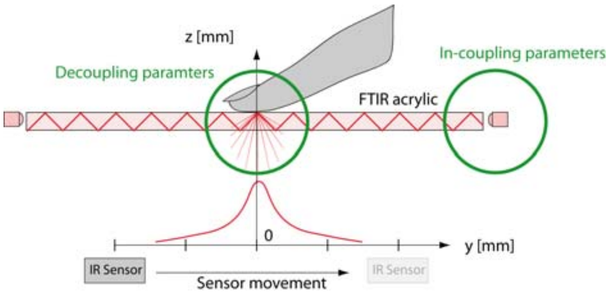

**Figure 5:** Test setup: The sensor is automatically moved in small steps underneath the static finger position while the sensor values (intensities) are measured

Various measurement series were taken with changed in-coupling and decoupling parameters each.

## 4.1 In-coupling parameters

In Table 1, the most relevant in-coupling parameters and their effects on the position-intensity curve are listed. The two main physical effects to achieve better in-coupling are increasing IR-light energy and increasing the amount of total internal reflection points.

**Table 1:** Parameters and their effects on the measured position-intensity curve.

| **Parameter** | **Effect on intensity curve** | | **Physical explanation** |
|---|---|---|---|
| | **Amplitude** | **Width** | |
| | | | |
| Increasing IR-LED intensity | ++ | 0 | Photon energy increase |
| Increasing number of IR-LEDs | | | More total internal reflection points |
| Decreasing distance between LEDs | | | |
| Increasing LED emission angle | | | |
| Decreasing acrylic thickness (Figure 5) | ++ | ++ | |
| Increasing inclination of LEDs | + if optimal angle<br>- otherwise | 0 | |
| Acrylic edge taper | + | + | |

The thickness of the acrylic glass has a high impact on both, the measured IR-intensity (amplitude), and the width of the IR-light cone (see Figure 6). This effect can be explained with the increased amount of total internal reflection points, since the ray's traveling distance from reflection point to reflection point is decreased.

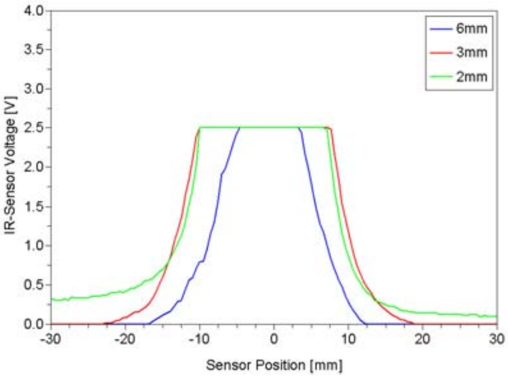

**Figure 6**: Thinner acrylic plates cause more total internal reflection points and thus a wider and more intense position-intensity (sensor voltage) curve. Measured without LC-matrix and diffuser. A flat top means that the sensor is saturated.

## 4.2 Decoupling parameters

Increasing the amount of received IR-light can be done by increasing the touched surface to include more total reflection points or by enhancing the touch coupling. In Table 2, decoupling parameters are listed as well as their effect on the position-intensity curve.

**Table 2:** Parameters and their effects on the measured position-intensity curve.

| **Parameter** | **Effect on intensity curve** | | **Physical explanation** |
|---|---|---|---|
| | **Amplitude** | **Width** | |
| | | | |
| Overlay | ++ | ++ | More total internal reflection points (increase of touch area) |
| Higher touch pressure | | | |
| Decreasing touch inclination angles | | | |
| Wet or dirty fingers | ++ | 0 | Enhancement of touch coupling |
| Increasing distance sensor-acrylic | -- | ++ | Increase of radiation area (up to a certain distance, this obviously depends on used LEDs) |

In order to further explain some of the effects in Table 2, the finger inclination and its coupling to the optical refraction index of the acrylic are further explained.

The inclination of the finger when touching the interactive surface has a significant influence on the reflection of the IR-light. The smaller the angle is (measured against the surface), the more IR-light can be detected. A smaller inclination angle corresponds to the fact that more reflection points in the acrylic are covered and thus a larger blob is visible to the sensors, which also reflect a higher amount of IR-light.

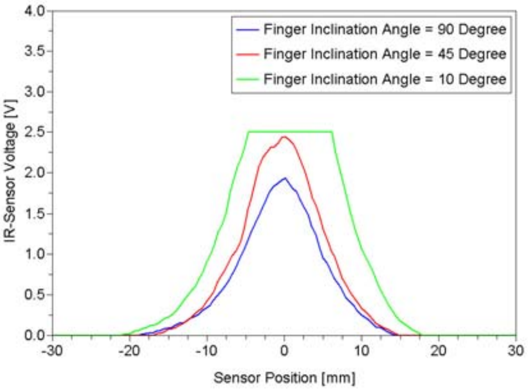

**Figure 7:** Finger inclination angle: The more a finger is inclined towards a perpendicular position the less sensor intensity is caused. This is because the touch area is changed when changing the fingers inclination.

The sensor signal can also be increased by adapting the refraction indices of both media. Here, an overlay on the interactive surface could be used. The problem with most overlays like silicone is their tendency to adhere. This causes a hysteresis as described in [15]. On the other hand, an increase in the width of the decoupling cone occurs, which for our case would be positive since it triggers multiple neighboring sensors at the same time (see Figure 8). However, due to the disturbing hysteresis effect we decided not to use any overlay.

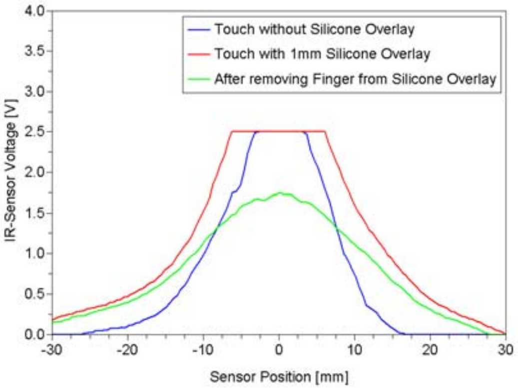

**Figure 8:** Hysteresis effect of a silicone overlay on a 6 mm acrylic: Because silicone adheres quite well on the FTIR acrylic it sticks to it for a short time (around 3 s) after being touched.

# 5. RESULTS

## 5.1 Prototype Construction

Based on the position-intensity curve measured in the experiments through all components of the LC-display, a sensor distance of 10 mm was chosen, because this distance would cause multiple sensors to be triggered by a single touch point. Above IR-sensor array, diffuser and LC-matrix of a 19” display, a 3 mm FTIR acrylic was placed (413 x 311 mm). The distance to the sensors from the acrylic equals 15 mm. IR-LEDs (880 nm) were mounted in a frame around the FTIR acrylic in distance of 7 mm to each other. The power consumption is around 1.5 A at 12 V.

For the acquisition of the sensor data, we use an Atmel AtMega644 microcontroller with 4 external Analog to Digital Convertors (ADC), which are addressed using an SPI bus. Each ADC acquires 8 sensor values from 0 to 2.5 volt and converts each to a 0 to 256 bit value. The data is sent to a PC via USB (see Figure 9). The driver software, interpolates in order to calculate the position of the finger touch. The interpreted finger touches can be used by a target application through an API.

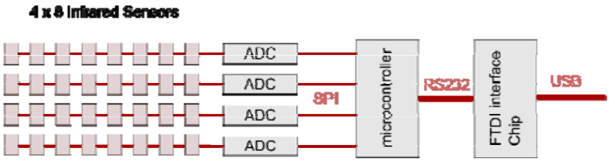

**Figure 9:** Demo software showing the triggered sensor values (grey dots) with their values and the interpolated position (cross).

## 5.2 Performance

A single touch point triggers 4 to 9 sensors at a time. We achieved accuracies of around 1 mm and can distinguish between multiple touch points that are at least 20 mm apart by using software interpretation. We achieve update rates of 200 Hz and more on the applikation side. On the hardware system it self we sample with rates up to 2500 Hz. Our graphical rendering PC is not as fast as to process all of this data.

Touches with low finger pressure are likely not to be detected accurately since the decoupled light is too weak (see Figure 10). Objects with weak coupling factor like metal or wood are not tracked. This also holds true for fingers that are completely dry. Our experience shows, that the best performance and ergonomic behavior produces a firm touch with 45 degree inclination and slightly sweaty fingers. Like with other FTIR systems, FlaTIR should not be exposed to direct sunlight since this would also trigger the IR-sensors.

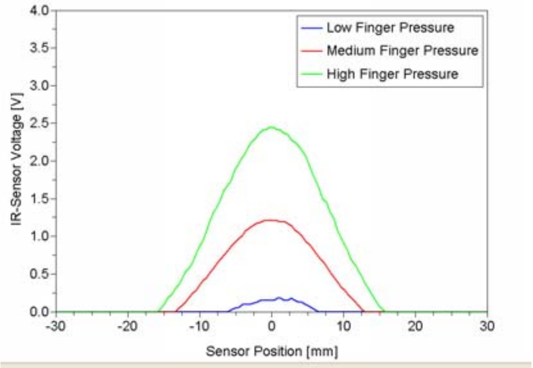

**Figure 10:** Position-intensity curve for different finger pressures measured through all LC-components: Finger pressure influences the sensor signal because the touch area increases with higher pressures, and thus causes a higher IR-decoupling.

Since FlaTIR is still in the early stage of development, we did not develop any application software, yet. The demo software we realized is used for development and just displays the sensor values and computes the interpolated center based on the position-intensity curves determined with the measurements (Figure 11).

Since we use 3mm acrylic we have a slight offset between interaction layer and image layer. Compared to the size of the finger this offset is small and seems not to be distractive.

As in every touch system dirty fingers cause smudges on the interactive surface. Depending on the amount of dirty the tracking is influence more or less. One of the most impact have choclate fingers. Since choclate adheres almost perfect to the interactive surface, decoupling occurs even without any touches.

To improve the sensing all the brightness enhancement films have been removed. The system still tracks firm touches with the films mounted, but the performance was not convincing. Removing the films on the other side has little influence on the optical performance. Without the brightness enhancement films the picture is less bright and intense. Removing the diffusion film on the other hand will cause the image to float in fornt of the sensors, therefore we did not remove that film.

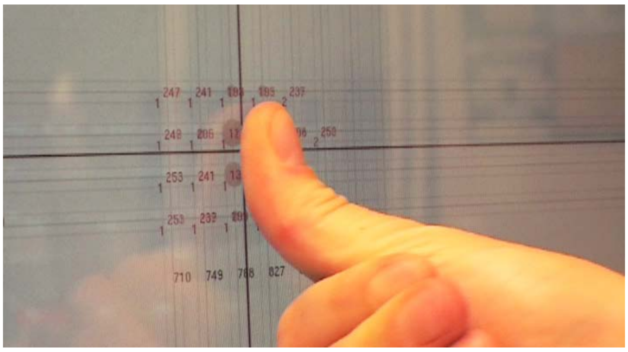

**Figure 11:** Demo software showing the triggered sensor values (grey dots) with their values and the interpolated position (cross).

## 6. CONCLUSION

FTIR-technology being described e.g. in [12] is widely used. Camera and projector based designs allow an easy integration, but have a limited practical usage because they require a big housing for the light and camera path. Thus, we suggested a new way to sense decoupled IR-light from an FTIR acrylic by using a sensor array behind an LC-matrix. Our contribution is the analysis of the involved effects when detecting this FTIR light with a discrete sensor array behind the LC-screen's components. For the proof of concept, we also built a small prototype. The results show that on a standard 19" display multiple touches can be detected with 1mm resolution and update rates of 200Hz and more.

## 7. FUTURE WORK

We are currently working on a sensor array, which provides a larger touch sensitive area to an LC-display. The goal is to evaluate if there are possibilities to equip large LC-displays with such sensor arrays. To collect such a large amount of sensor values, we use the same Master-Slave system as presented in the MightyTrace system. Sensors are collected and filtered on Slave Boards and sent serially to the Master Boards, where the data is prepared for transmission via USB to the PC. Theoretically we computed, that we will achieve hardware updaterates of 400 Hz on a 40 inch display at 15 sensors active at a time. Depending on the graphical renderer this will result in similar update rates as achieved here.

We already performed some initial measurements to see what influence larger acrylics have on the sensor values. We equipped a large acrylic with two IR-LED strips on the short sides and measured the sensor intensity at a touch point in the middle. Next, we compared this with the standard acrylic size we already used in the initial tests. We observed a lost in sensor intensity at the same touch pressure of around 50%; also the width of the curve decreased by 40% (see Figure 12). This means that more in-coupled light is required as well as an even smaller distance between the sensors. This is very tricky to realize since the amount of sensors increases with the power of 2. Also new ways have to be found how to couple in more light into a 3 mm acrylic. A possible solution could be high power IR-sources and light guides.

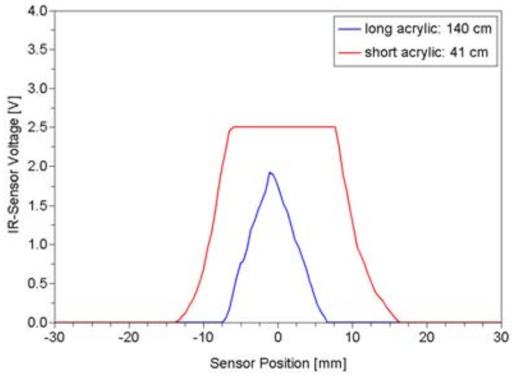

**Figure 12:** Sensor values for the same touch pressure on different acrylic sizes.

We will also investigate the observed occlusion effects when tracking multiple touch points. Here, we will estimate the influence on the tracking reliability in special multi-touch conditions, in which a lot of occlusive gestures could occur.

In the future, it is planned to combine the presented setup with a TUI tracking or additional touch detection system to improve accuracy. It might be even possible to combine our approach with a TUI technology like ThinSight [7],[8] or MightyTrace [9].

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