# MightyTrace: Multiuser Tracking Technology on LC-displays

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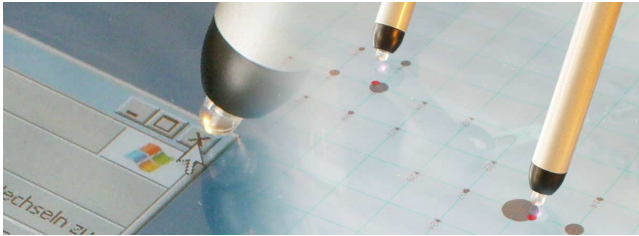
# MightyTrace: Multiuser Tracking Technology on LC-Displays

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## ABSTRACT

In this paper, we present a new technology to perform multi Tangible User Interface (TUI) tracking on standard LC-displays. A lot of existing technologies for tangible user interface tracking use back- or front-projection setups, but they suffer from poor image quality, shadow casting, non-ergonomic interaction, and/or large installations. Thus, we introduce a principle that allows using the InfrActables' technology [3] on a large LC-display. It combines simultaneous multiuser input on a display with the advantages of a large flat screen. We use infrared photodiodes (IR-LEDs) mounted behind the display's LC-matrix to track infrared diodes in front of the screen. After initial tests concerning the infrared transparency and sensor characteristics, we developed a proof of concept consisting of 384 sensors, which are addressed through a modular master-slave circuit. Using several interaction devices, multiuser interaction is possible.

## Author Keywords

Single Display Groupware, Tangible User Interfaces, CSCW, Interaction

## ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g. HCI): Miscellaneous.

## INTRODUCTION

Since a tangible approach to computer interaction has been

the focus of many researchers, a lot of different technologies exist today to track objects like bricks [1], [2], pens [3], or finger touch [4] on a surface. Most of the newer systems also provide means to simultaneously track multiple devices. What most systems have in common is that they either use a back-projection [5], or a front-projection [6], [7]. Even the new product from Microsoft [8] called "Surface" bases on a back-projection technology.

Front-projection as well as back-projection have specific advantages and drawbacks. A front-projection onto a horizontal interaction surface (tabletop) allows ergonomic working in a sitting position. However, the user also casts a shadow that prohibits a very precise interaction on the surface. Back-projection systems allow a more precise interaction, e.g. writing on a tabletop, but require space for the optical path length. This typically prohibits any ergonomic work in a sitting position or any application in laptop like devices.

In i-LAND [9], a 48" plasma-display was used to realize a tabletop setup. Here, a resistive overlay allowed tracking of a single user's input at a time. It did not provide any multiuser input. This means that even placing the forearm on the screen resulted in misinterpretations of the tracking – bimanual working was not possible.

In order to encounter this problem, two WACOM tablets were modified in such a way that they recognized multiple 'pucks' as input devices [10]. The update rate was less than 1 Hz but could be higher for a single puck. Although this system allowed recognizing multiple devices, the interaction surface was very small and thus not suitable for teamwork. Within [3], a back-projection tabletop system enabled several users to simultaneously write and sketch by using intuitive devices. Due to the back-projection, users could only work in a standing position.

## BASIC SYSTEM IDEA

In order to overcome the disadvantages associated with current back- and front-projection systems, we are following a new approach by using a standard LC-display as an interaction surface. This allows saving space and displaying a bright and sharp image even under wide viewing angles. We use slightly modified interactive electronics and readout methods as in the InfrActables' setup. Our integrated active electronics is also synchronized by an infrared trigger pulse. Every registered device counts

these trigger pulses and waits for its specific timeslots (Frames)., Two frames exist for each device, which are sequentially interrogated by the system (see Figure 1). The first frame of each device is used to determine its position, while the device's second frame is used to transfer its button state. In the first frame, the IR-LED always lights up while in the second frame it only lights up if the button is pushed.
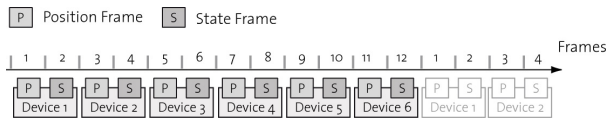


**Figure 1: A complete frameset and the devices with their specific timeslots (frames)**

Since all devices with their two specific frames are sequentially interrogated, they can be unambiguously identified by their frame numbers in the temporal sequence. However, using these devices on an LC-display requires an infrared transmissive LC-matrix. Behind this matrix, a large sensor array detects the infrared signals from all involved devices. Unlike in the InfrActables technology [3], all devices are tracked serially, while the InfrActables system uses parallel camera readout and thus captured all devices in each frame simultaneously.

## FEASIBILITY TESTS

### Matrix transparency
In order to evaluate whether an infrared sensor array can track IR-LEDs in front of the LC-display, several feasibility tests were performed.
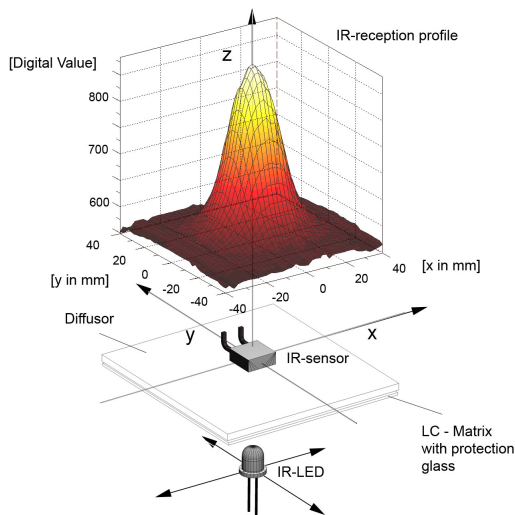


**Figure 2: Digital sensor values measured in the x,y-plane behind LC-matrix & diffusor (digital values represent the voltage drop at the IR-sensor). For the test setup, one digital step equals ~0.005 V (0V ≡ 0 / 5V ≡ 1024)**

The test setup consisted of a standard 20" LC-display with modified background lighting. The existing neon illumination was replaced by arrays of white LEDs, since

the oscillation frequency (50 kHz) of the original illumination caused interferences. Next, we placed an IR-LED (same as in device) directly on the glass in front of the matrix. Behind the glass, the LC-matrix, and the diffusor, we mounted an IR-sensor and measured the relative digitized sensor values for different positions of the IR-LED on the screen in the x,y-plane (see Figure 2). The goal of this preliminary study was to find out, whether the complete optical path (IR-LED, glass, LC-matrix, diffusor, sensor) has rotation-symmetric characteristics, since this would simplify the analysis algorithm. Additionally, we used this preliminary study to determine the maximum possible distances between two sensors in order to have a reliable tracking. For this, the sensors' reception areas have to overlap sufficiently wide enough to avoid or to minimize any detection errors. As a result, we decided to place the sensors' centers at a distance of 20 mm.

### Dependency of LC's IR-transparency on displayed colors
We measured how the colors displayed on the LC-display influence the infrared transparency. We found that a black display absorbs most infrared light, while white absorbs much less (see Figure 3). When comparing black and white display contents, the maximum tracking error in horizontal direction in the x,y-plane is 3 mm. This can be partly compensated by using multiple sensor values for position computation at the same time.
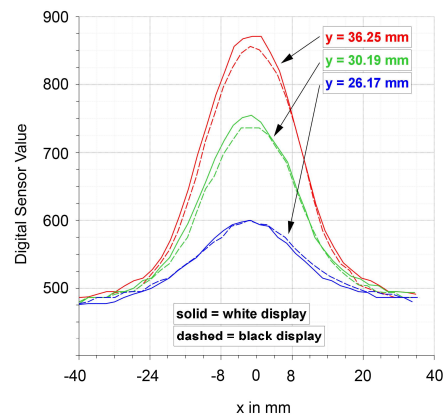


**Figure 3: Digital x-sensor values of different displayed colors (black and white) at different y-positions**

### Inclination of the emitter (stylus)
Since no IR-LEDs are available with an optimal Lambert radiation characteristic, we were interested in the geometrical error that could occur if the IR-LED is placed on the screen non-perpendicularly. Figure 4 shows the displacement of the detected infrared spot along the x-axis when tilting the stylus by a certain angle. Although there is a measurable deviation, it does not irritate the user. This is because the tracking is done in the image plane. Typically the user expects the displayed point on the extended centerline of the stylus. Thus, an offset between the interaction plane and the image plane is not as disturbing as

it would be for normal tracking systems, which always display the detected point perpendicularly underneath the stylus' position in the interaction plane.
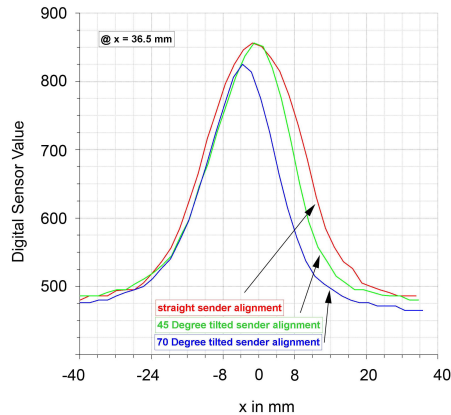


**Figure 4: Digital IR-sensor values at different inclination values of the emitter (stylus)**

The idea of using IR-sensors behind the LC-matrix to track IR-LEDs in front of the screen is feasible, because:

- The LC-matrix is transparent to infrared light in general.

- The determination of position is possible by using the measured values of at least 3 sensors combined with a lookup table holding the sensor values at different positions to finally triangulate the position.

- The influence of the displayed color can be reduced by reading out multiple sensors.

- The dependency on stylus inclination is even supportive.

**THE PROTOTYPE SETUP**
Six modules with analog-to-digital converters (ADCs) AD7829 from Analog Devices are mounted behind the diffusor (Figure 5).
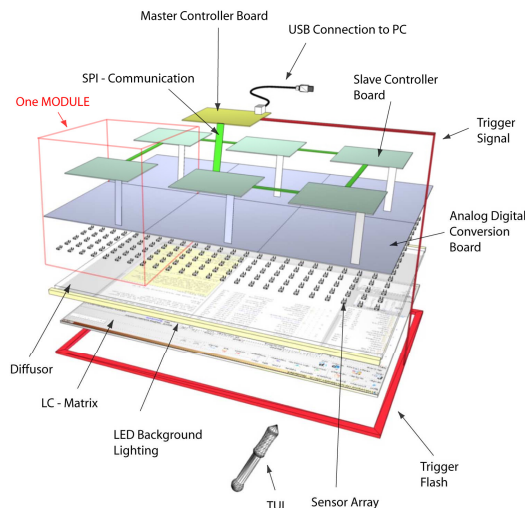


**Figure 5: Component setup of the prototype**

Each module consists of 8 ADCs and 64 sensors. The module's dimensions are 160 mm x 160 mm and represent the area of IR sensitivity. 6 modules are used to cover the whole LC-matrix of the 20" display. The modules are mounted next to each other without any gap. For larger screens, more modules can be added to cover the panel.

**Analog-to- Digital Conversion Boards**
For the proof of concept, we use a common 20" LC-display from Phillips. The reflector film behind the diffusor was removed in order to integrate the IR-sensors (SFH235FA from Siemens). The SFH235FA has a wide aperture angle and contains a daylight filter. Each of those sensors is operated in a reversed-biasing mode at 2.5 V. Depending on the IR-intensity, the photo current causes a measurable voltage drop to 0 V. This voltage between 0 V and 2.5 V can be measured by the ADC. The values are converted to digital values from 0 to 255 (8 bit). For the prototype, we use ADCs different from those in the test setup, in which we used the internal 10 bit ADC of an ATMega16 microcontroller. We also adjusted the IR-sensor voltage drop in such a way that it would cover the whole 8 bit range, which was not the case in the test setup.
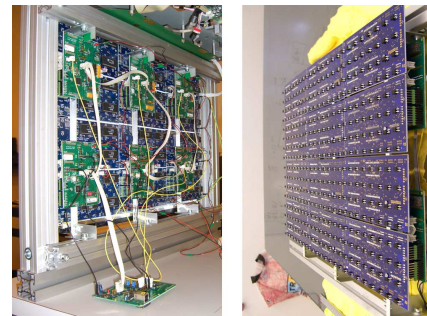


**Figure 6: Final hardware. Left: the slave and master boards in green and the blue ADC boards. Right: the sensor array.**

**The Control Units (Master and Slaves)**
Each ADC module is connected to a slave board, being equipped with an ATMega644 microcontroller at 20 MHz. Each slave board is connected to the master board via a serial periphery interface (SPI). The master is also equipped with an ATMega644. In addition, it uses an FTDI FT232R chip to communicate with a PC via a USB interface. It also generates a 455 kHz modulated signal for the IR-LEDs to trigger the interaction devices. The ADCs and the control units are completely integrated into a modified LC-display's housing (see Figure 6).

**Data transfer**
Each sensor signal is between 0 V and 2.5 V, depending on the received IR-light's intensity. The ADCs convert those voltages into 8 bit digital values. The slave boards work in parallel and collect all digitized values. Each of them is connected to an ADC module. In order to reduce the amount of generated data, the slave microcontroller pre-filters the 64 bytes of sensor data. If the values are below a

certain threshold, they are considered as useless for the localization of a device. Such filtering suppresses unwanted ambient IR light e.g. from dimmed halogen lamps. The process of collecting and filtering data is triggered by the master. The master starts its cyclic procedure by first sending an infrared START trigger signal to the devices. All following trigger signals are NEXT encoded. After the devices receive this START trigger signal, they start counting the trigger signals. Each device waits until its defined frame is triggered by a NEXT signal. If a slave filters out some useful data, it is transferred to the master via the SPI bus. The data includes the ADC value and the sensor's absolute coordinates. For each bit sent by a device, the master requests data from each slave. After the master requested data from all slaves, the NEXT frame is triggered until a predefined amount of frames is reached. For tracking 4 styli and 2 other interaction tools, 12 frames are needed. The master saves all collected data until all frames are processed. The master is now ready to send the data to the PC. To avoid data collision and buffer overflows, the PC always requests data from the master. If a complete set of frames is acquired, it is ready for transfer. The more useful data the slaves collect, the more time it takes to transfer it via SPI and afterwards from the master to the PC. The system's response is very fast (2.2 kHz trigger frequency, resulting in a >100 Hz overall tracking frequency). For the determination of a device's position, an algorithm consisting of vector addition, triangulation, consideration of intensities, and sensor profile adjustment is used.
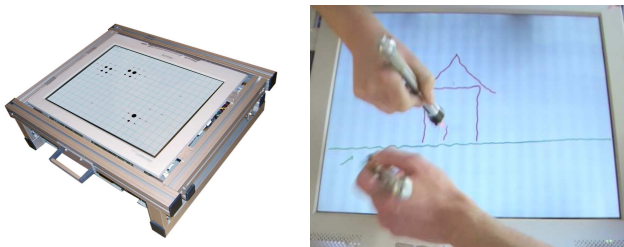


**Figure 7: Left: Mighty Trace Prototype using a 20''LC-display. Right: simultaneous drawing**

## RESULTS

Our first 20" prototype (see Figure 7) can track several IR-LEDs at once. The update rate depends on the amount of visible IR-LEDs. We achieve update rates of more than 100 Hz when tracking six devices. The position accuracy of the tracked IR-LEDs has an error of up to 3 mm. This depends on the inclination of the diode (pen), on the displayed color, and on disturbing infrared light from direct sunlight.

## CONCLUSION

We presented a new technology that is able to track several devices simultaneously on a standard LC-display. The first results are very promising. Because of the new technology's modular design, it can be applied to large LC-

displays, which typically have a better image quality than projection systems and also require less space.

## FUTURE WORK

The used LED background lighting is not bright enough. In a future version, we shall test LEDs mounted directly on the sensor PCB. By adding special blocking filters or using other wavelengths, we also want to make the system more insusceptible against environmental influences like sunlight. A protection of the LC-matrix against mechanical impact will be realized soon. The integration of the trigger flash onto the ADC board PCB will also be realized.

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