

An LED-based Multitouch Sensor for LCD Screens

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ABSTRACT

In recent years, a large number of multitouch sensor concepts have been presented. Particularly optical sensors are highly popular due to their versatility. However, especially camera-based systems often require a significant amount of space behind the screen and are not well suited to flatscreen-based setups. While integrated sensors for flatscreens have already been presented, they are mostly complex, expensive or both.

To address these problems, a novel type of multitouch sensor is presented which extends a common LCD monitor with multitouch capabilities without significant depth requirements. The sensor consists of a homogeneous matrix of cheap, mass-produced infrared LEDs. The LCD surface remains unmodified, resulting in a pleasant haptic experience for the user.

Author Keywords

multitouch, sensor hardware, optical sensor, led sensing

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: Miscellaneous

General Terms

Experimentation, Human Factors

INTRODUCTION

In the last few years, research in multitouch systems has been steadily rising. A large fraction of this research is focused on developing sensor systems which enable the detection of multiple contact points on an interactive surface. Existing sensor designs can be roughly grouped in two categories, electrical and optical. Electrical sensors are predominantly used in commercial devices, while optical sensors are mostly used in custom-built setups and research prototypes.

Most optical systems which are currently in use are based on an infrared camera. While this approach allows for easy con-

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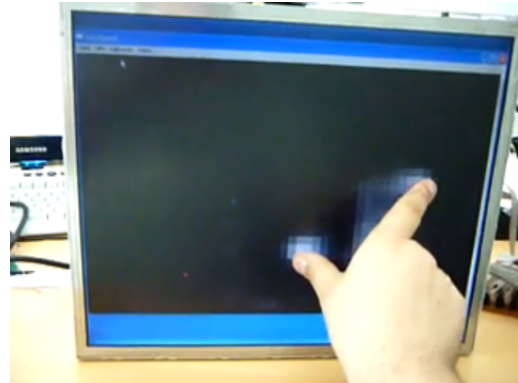


Figure 1. Sensor in operation

struction, it has the drawback of requiring significant depth behind the screen to enable the camera to view the entire surface. Additionally, the display in such a setup usually has to be projector-based. Some recently published setups try to mitigate these limitations by replacing the camera with a dedicated, screen-sized light sensor that can be integrated into a flatscreen display. However, these systems have so far been prohibitively expensive.

In this paper, we present a novel optical multitouch sensor which addresses these drawbacks. The sensor is constructed from mass-produced infrared LEDs and is therefore cheap to manufacture. Additionally, it can be completely hidden behind the display without the need for any front-mounted components.

RELATED WORK

One well-known multitouch system was invented by J. Han in 2005 [1] who used the optical phenomenon of *frustrated internal total reflection* (FTIR) for creating a multitouch-sensitive surface. On top of a projection surface, an acrylic panel is placed into which infrared light is injected from the sides. A rear-mounted camera can detect the infrared reflections triggered by finger contacts on the acrylic plate.

The FTIR technology not only works for video projection screens but for LCD screens as well. These screens are mostly transparent to infrared light. The acrylic plate is placed on the surface of a LCD panel. Infrared light emissions from finger contacts can again be captured by a rear-

mounted camera. The main drawback of any camera based solutions is the distance between diffusor and camera chip which cannot be reduced arbitrarily. Therefore, it is currently not possible to construct a flat multitouch monitor based on FTIR *and* cameras.

One possible approach for a flat multitouch system was presented by Microsoft with ThinSight [4]. In this setup, an off-the-shelf LCD display is extended with sensor PCBs, each populated with an 5×7 array of infrared distance sensors. Every sensor contains one IR emitter and receiver within a single package. Therefore, the sensor resolution is equal to the dimension of the sensor matrix. The main drawbacks of this approach are the large number of relatively expensive distance sensors and the asymmetrical package which prevents the matrix from being packed densely. Additionally, complex modifications to the LCD screen assembly are needed to reduce infrared interference from the screen's backlight.

FLATIR by Hofer et al. [3] presents a different approach which combines elements from both previously described setups. An FTIR-enabled acrylic plate is placed in front of an LCD panel. Instead of a camera, a passive IR sensor matrix made from photodiodes is integrated behind the display which detects emissions from the FTIR surface. While cheaper than ThinSight, this setup suffers from the drawback that an acrylic surface creates significantly more friction than a LCD panel surface, thereby providing a poor user experience. This is especially pronounced for interactions like dragging.

J. Han has also presented a standalone LED-based multitouch solution [2]. This setup converts a common visible-light LED matrix display into a multitouch sensor. This approach is based on the phenomenon that an LED can not only be used as light emitter but also as light detector. While this effect has been presented as early as 1973 by F. Mims [5], it has seen little use until recently.

THEORY OF OPERATION

The presented system is related to Microsoft's ThinSight and Han's LED multitouch and combines the advantages of both systems. The sensor is placed behind the LCD panel like ThinSight but the sensor matrix only consists of LEDs as in Han's setup. This allows to use the possibly cheapest optical components available as sensor elements. Furthermore, the matrix density can be increased as the LEDs can be moved closer together while maintaining an equal distance in vertical and horizontal direction. A schematic overview is given in figure 2.

During one measurement cycle, a single LED is emitting light while one adjacent LED is simultaneously measured through an analog-digital converter (ADC). An object such as a finger in close proximity to the screen will reflect some of the emitted light back to the receiving LED, thereby inducing a photocurrent. The photocurrent in this measured LED is proportional to the amount of incident light at those wavelengths which the LED is sensitive to. As an approxi-

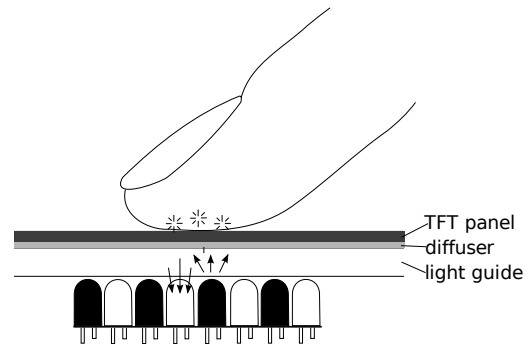


Figure 2. Schematic view of sensor and panel assembly

mation, infrared LEDs are sensitive to the same wavelengths which they emit.

As with many kinds of optical sensors, ambient light from various sources such as ceiling lamps or the LCD backlight can pose significant problems. E.g., fluorescent bulbs emit a wide range of wavelengths including the near-infrared spectrum which can be received by the LEDs. As the presence of various LCD panel components such as the diffuser in between LEDs and object creates a significant amount of noise due to additional reflections, any external influences need to be filtered out. Otherwise, the signal-noise ratio would fall below any usable value.

To this end, the signal driving the emitting LEDs is modulated with a 40 kHz square wave. Therefore, the photocurrent induced in the measuring LEDs is also modulated. By adding an analog band-pass filter tuned to this frequency before the analog-digital converter, the ambient light component can be removed. Depending on the source, the intensity of ambient light is either constant or modulated with a significantly different frequency, e.g. 50 Hz in the case of fluorescent lights.

TOPOLOGY

One important design goal was that the system should be scalable across a large range without modifications to the hardware. To meet this requirement, a modular master-slave approach was chosen. The master device stores sensor and calibration data and communicates with a variable number of slave modules. A cascaded SPI¹ bus topology allows the chain of modules to be extended easily without having to modify the hardware. The slave modules were designed to be tiled horizontally and vertically without breaks in the regularity of the sensor matrix, i.e. the distance from one LED to an adjacent LED is constant even across module borders.

Both the master and slave devices are implemented using Xilinx Spartan FPGAs². An additional ARM7 microcontroller is used for communication between the sensor hardware and the computer.

¹Serial Peripheral Interface

²field programmable gate array

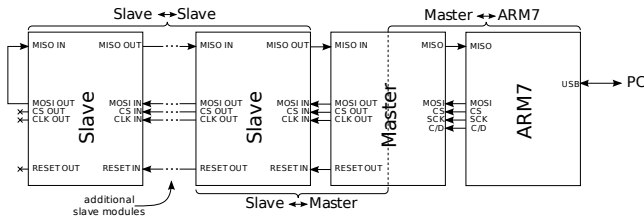


Figure 3. Module interconnections

The master device is separated into two logically independent parts which exchange data via dual-port RAMs, synthesized inside the master FPGA. One side forms the multi-touch sensor for which the master module acts as SPI master and initiates data transfers to the slave modules, while the other side provides the PC interface part. Here, the master module is a SPI slave for an additional ARM7 microcontroller that is used to transfer sensor and calibration data between PC and master module via USB.

To summarize, the system is composed of a variable number of slave modules, one master module and an ARM7 module. The proof-of-concept prototype was implemented with 6 slave modules organized in a 3×2 grid.

SLAVE MODULE

The core component of our sensor system is the slave module. Each module consists of two stacked circuit boards. The front board carries 256 evenly spaced 3 mm infrared LEDs in a 16×16 grid. The rear board carries the Xilinx Spartan II XC2S15 FPGA, the line/column drivers, the multiplexer and the analog components. The board is diagonally split into an analog (upper left) and a digital (lower right) part. Both boards are shown in figure 4.

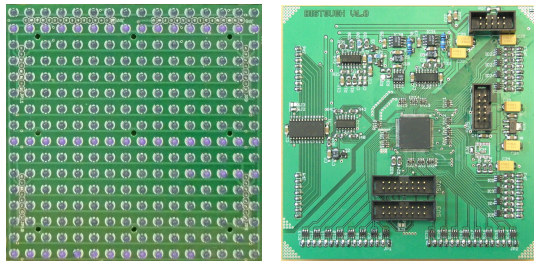


Figure 4. Front and rear view of one slave module

A block diagram of the slave module is shown in figure 5. A closer look at this diagram shows that there are 32 column drivers instead of the expected 16. The reason is that the LED field does not consist of a single matrix, but instead of two separate matrices which are interleaved row-wise.

At first glance, this may seem to be an unnecessary complication. However, as the emitting LED is driven with a square wave, the passive LEDs within the matrix would act as small capacitors and transfer the AC signal component to the row being measured. This signal would proceed to the receiving LED and render all measurements invalid, as

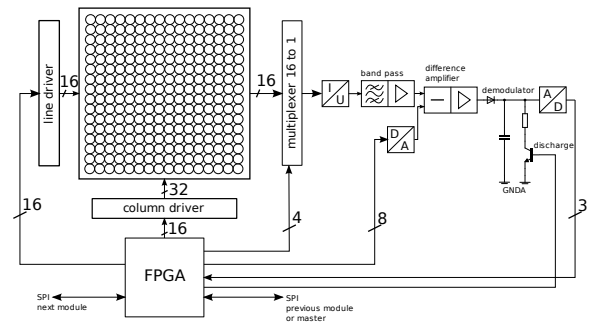


Figure 5. Slave module block diagram

the coupled current is significantly larger than the photocurrent induced by the incident light. When the LEDs are split into two interleaved matrices with one set of column drivers each, then the emitting LED can always be kept electrically separated from the receiving LED, thereby preventing these effects. The additional costs are minimal as the 32 column drivers are controlled pairwise by 16 FPGA control lines.

A circuit diagram detailing this method is shown in figure 6. The red path shows the current flow through the emitting LED, while the blue path corresponds to the photocurrent generated by the receiving LED and delivered to the the multiplexer. Green paths show the currently active row and column drivers.

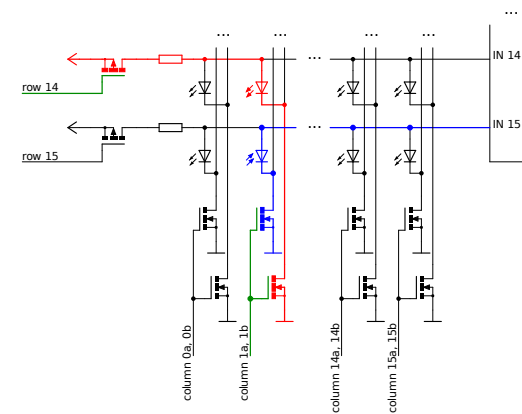


Figure 6. Interleaved LED matrices

CALIBRATION AND POSTPROCESSING

While some problems such as ambient light can be addressed in hardware, other issues require software-based solutions which will be discussed here. One such issue is calibration of the LEDs themselves, which is a two step procedure.

One major issue is that most of the emitted IR light is inevitably reflected directly on the panel, the diffuser and the lightguide, inducing a high photo current in the receiver LED and therefore resulting in a high signal amplitude. In comparison, the signal change caused by a finger on the panel is about 5% of the overall signal amplitude. Moreover, due to manufacturing tolerances, the sensitivity of each LED can

differ significantly. To provide an individual reference voltage for each LED, a digital-analog converter (DAC) is necessary. When an LED is measured, an offset value is sent to the slave module by the master. This offset value is then converted to a voltage through the DAC and used as second input to the difference amplifier. The amplified difference is then read back through the analog-digital converter. The offset value is calculated for every LED by successively approximating a digitized value of about 70 % of the ADC's range without any objects in proximity to the screen.

The second step is a simple normalization for which the minima and maxima of the desired signal have to be determined. In the former case, this is easily achieved by sampling and averaging a couple of consecutive raw frames without any objects on the screen, and in the latter case, a large gray board can be brought in proximity to the screen, for instance.

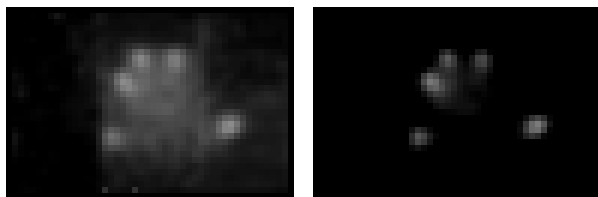


Figure 7. Raw sensor data before and after postprocessing

The data delivered by a calibrated slave module is now a 16×16 "pixel" grayscale image representing the intensity of reflected infrared light from objects outside the screen. Such a calibrated and normalized image is shown in figure 7(a). While the touching fingers are already distinguishable, a significant amount of additional reflections from the user's palm are visible. While this image can be directly used for, e.g., hover detection, an additional processing step is necessary for reliable touch detection. Due to the small image size, a difference-of-Gaussians (DOG) filter with a large kernel size can be applied without significant slowdowns. The resulting final image is shown in figure 7(b).

RESULTS AND OUTLOOK

In figure 1, our prototype is shown in operation. This prototype uses 3×2 slave modules which have been integrated into a 17" LCD screen. The modules cover a surface area of about 24×36 cm, thereby covering almost the entire screen. The sensor resolution is 48×32 pixels for a total of 1536 LEDs. Despite the large number of LEDs, the sensor only uses approximately 3 Watts of power during operation, which is negligible compared to the power draw of the LCD screen.

One area which still has room for improvement is the update rate. Currently, the system is running at approximately 10 Hertz which is somewhat slow for interactive systems. However, the system remains scalable without negatively influencing the operating speed and can be scaled up to 25 modules using the current master module design. An increased update rate will allow for even larger installations at interactive update rates.

The update rate can be improved by reducing the integration time, either by reducing the capacity of the integration capacitor and decreasing the number of cycles being integrated, or by increasing the modulation frequency while leaving the number of cycles unchanged. The former approach could result in degraded signal quality and more noise, whereas the latter would need re-tuning the analog bandpass filter and therefore extensive changes on the hardware.

In summary, we have presented a new approach for multi-touch sensing on flatscreen displays. Our method combines existing approaches to provide a thin sensor which can be integrated into the display panel and which is based on cheap, mass-produced components like common infrared LEDs.

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