Optical Sensors Embedded within AMLCD Panel: Design and Applications

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Abstract
A new approach to data input into AMLCD panels has been conceived and demonstrated. This integrates an array of TFT optical sensors into the a-Si backplane of the AMLCD. The concept, design considerations, and specific applications such as touch panel input, hand recognition, and image capture will be discussed.

1. Introduction
The man-machine interface is becoming a significant part of computer systems. Until now the dominant tools are keyboard and mouse. The use of touch panels with display applications is expanding. It has the advantage of easier and faster entry of the information, and a more interactive approach. Touch panels allow the use of "soft-buttons" which can easily be reconfigured. Applications include point of sale, ATMs, ticketing kiosks, and medical systems. Mobile applications include PDAs, smart-phones, and Tablet-PC. Entry of data is also a major task. This is achieved by optical scanners, or by hand character recognition while writing on the panel (e.g. Tablet-PC).

In all above cases there is a need for a method to "see" the outside world. Optical sensors could be a way for proper interaction, as long as there is ambient or artificial light. They behave like a camera, but without a lens.

We developed an array of optical sensors embedded within the active plate of the TFT structure of an active matrix liquid crystal display (AMLCD). In the following paragraphs we describe the design of the optical TFT sensors, the readout methods and basic algorithms. Applications include touch panel, hand recognition, scanners, and similar applications, all embedded within the AMLCD structure.

This paper is based on two types of demonstration systems that were reported earlier [1, 4]. The first system was a 2.4"x2.4" display, and had an array of 60x60 sensors. The second system was a full size XGA display (14.1") with an array of 256x192 sensors. In this paper we will repeat some of the information of the 14.1" XGA demonstrator and update on new applications and findings. Recently three other groups showed similar concepts [5-8] some are using poly-silicon active matrix which is less photosensitive.

2. System Description
The integrated optical touch panel was embedded in the design of a 14.1" AMLCD display. The display is a normally white AMLCD with TN structure (non-compensated) used for laptops. It is assembled into a desktop frame with a stand (Fig. 1). The panel properties are detailed in Table 1.

An optical TFT sensor array was embedded in the design of the back-plane. The array includes 256x192 sensors, which are located at the corner of every 4th blue pixel (pitch 1.116-mm). The sensor concept and electronic design was presented in the past [1, 3], and is shown in Figure 2.

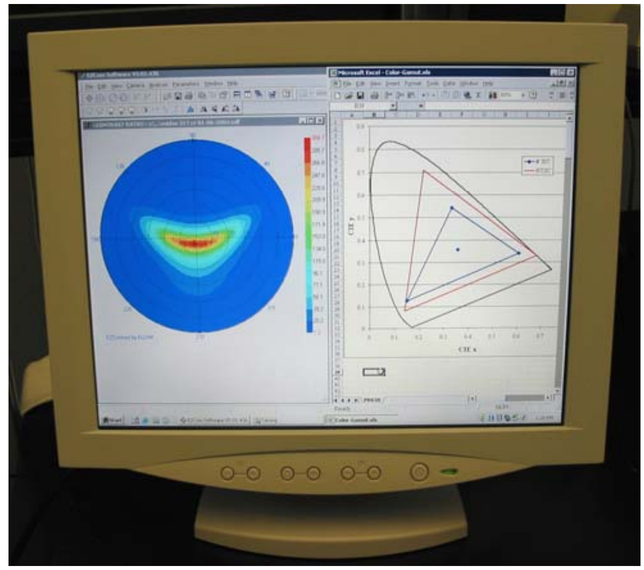

Figure 1 - Photo of the integrated optical sensor AMLCD (14.1"). Data on the screen represent its optical properties

Care was taken in the design to improve the sensor signal to noise level. The blue color filter covers the sensor area. The blue pixels without sensors were partially obscured to minimize artifacts, but still maintain high panel transmission.

Parameter	Properties	Units
Display type	NW- TN (14.1")	
Resolution	XGA (1024x768)	
Pixels structure	Stripes RGB	
Brightness	140 (min.)	Cd/m^2
Contrast	300:1 (typ.)	
Sensor array	256 x 192	
Sensors pitch	1.116	mm.

Table 1 - Display properties

The readout of the sensor is done from the bottom side of the panel, where the ledge of the active plate was extended by a few millimeters to allow bonding of interconnect flex. A special low-noise readout chip was developed for this design with 256 input channels, a charge amplifier and a multiplexer. The serial output signal from the readout chip is converted to a digital signal in an A/D converter. The chip is attached to a PC board (the analog board). The display row driver pulse enables the readout of the sensors. The chip has noise reduction circuitry and is connected to a differential amplifier for gain and dynamic range adjustment.

In order to make this unit independent of computer control, we selected electronic architecture, which includes a local DSP to house the software and control the different functions. An optional USB communication allows transfer of data and control by a host computer. A flash memory chip can store bright and dark reference maps for the automatic brightness or gain control (AGC) and noise reduction. This system can work either in a self-contained mode on the DSP or by computer control. A block diagram of the set-up is presented in Figure 3.

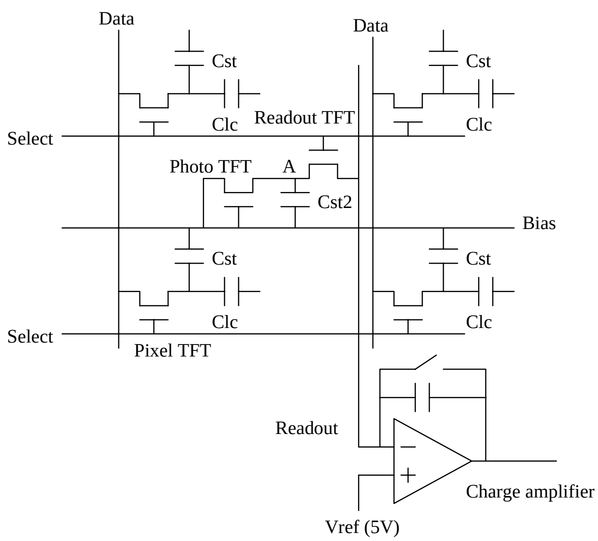

Figure 2 - Circuit diagram of four display pixels and one sensor circuit

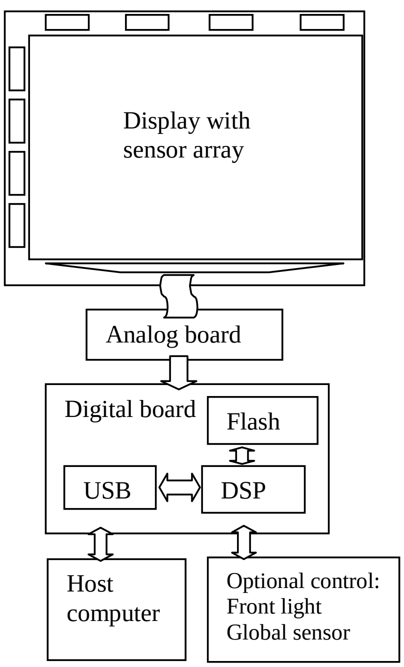

Figure 3 - Block diagram of the electronics system

3. Optical Performance

There were two major optical considerations when designing this display with embedded optical sensors:
(a) Maintain the display image quality
(b) Optimize sensor light collection and view-ability

To maintain the display image quality an attempt was made to minimize visual artifacts and loss of transmission. Based on the acuity and the contrast sensitivity of the eye [2], we decided to put the sensors in every 4th blue pixel. This gives lower visibility to the lower fill factor of those pixels, and least loss of transmission. More details are in [3]. We have sensors resolution of 1.116 mm. Using a resolution target printed on a transparency we tested the sensors resolution using the ambient room light. In Figure 4 we see the image captured by the sensor array. We see that pattern group -1 section 6 is still visible, which matches well to the sensors resolution of 1.1 mm.
The captured pattern demonstrates the imaging capability of the sensor array. In principle we could put sensor in each subpixel and get x12 higher resolution compared to the demonstrated display. This will imply more readout electronics and slightly lower display transmission. If we will put the sensors behind the Subpixels color filters we will have a "color camera" (without lens).

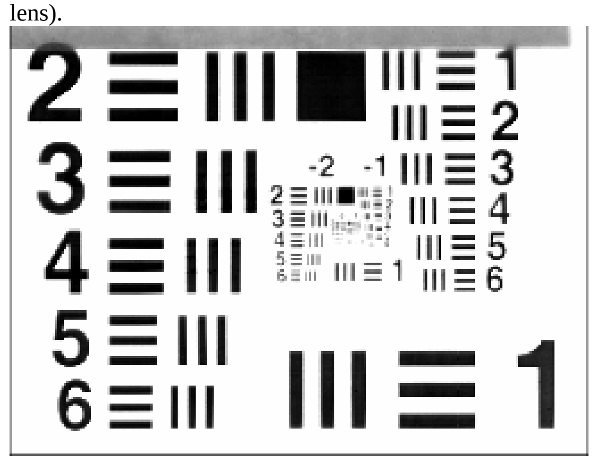

Figure 4 - Resolution target (USAF) viewed by the display panel with room-light.

In Figure 5 we see a typical set-up when the display with the optical sensors (on the right) is capturing an image of the finger. This image is displayed on a regular monitor (left).

Figure 5 – The right display has the sensors. The finger image is captured and shown on the left monitor

A typical display was tested for optical properties, color coordinates and viewing-envelop. Data is shown in Figure 1, where the images on the screen reveal its own performance.

One of the problems when using the display in touch mode is the contact of fingers with the front polarizers, scratches, finger prints, and pressure on the glass that destructs the LC cell. We tried to use a thin cover glass, and found that 1.1 mm thick will be adequate especially to absorb the finger pressure. The cover glass that we use has AR on the bottom and fine AG on the top.

The spectral behavior of the sensors is shown in Figure 6. The most sensitive range is the blue green. With the sensors behind the blue color filter there is some reduction in sensitivity; however, this gives more dynamic range at higher brightness before the sensors saturate. The blue filter on the sensor reduces the sensitivity to white light by about one-third.

The accuracy of the system is defined by the light level, nature of the light (it is better in diffused light), and the touch object shape and size. The algorithm is flexible and will work with finger, stylus, light pen, and laser pointer.

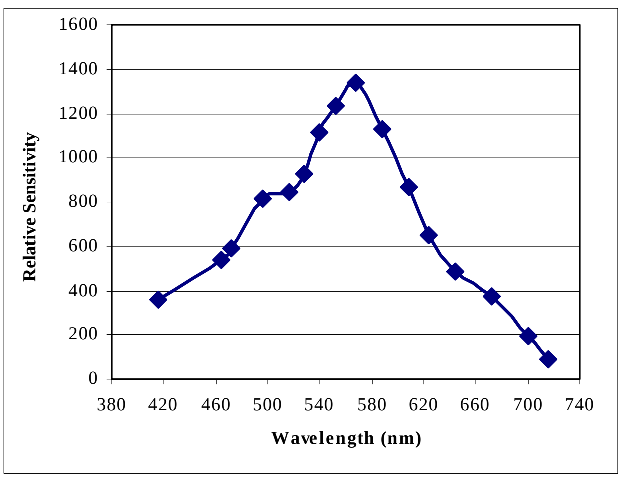

Figure 6 - Spectral behavior of the sensors

We were able to achieve adequate touch performance from the sensor array and electronics with one video frame (16.7 msec). However, use of a two-frame average reduces noise and improves performance. During a frame the light hits the sensor causing discharge of the sensor capacitor. A response from light or shade incident on an area already scanned in a frame will not be captured until the next frame. The two-frame average is an optional setting by software. Since our system is actually a camera without a lens, we used it to analyze touch by capturing sequential frames. Our research showed that a fast finger touch takes a minimum of 4 frames (~67 msec). However, for writing mode a one frame acquisition was sufficient with a stylus or a light pen.

4. Performance in dark environment

The sensor array can work with either a shadow of ambient light or with a light source. At room levels below 150 Lux the distinction between a hover and touch and the accuracy recording a touch is reduced. One solution is a light pen. We tested several commercial light pens (LED styli) and the algorithm performed well. A blue LED light pen is preferred, but other colors also work. A light pen that only illuminates on contact can be used for touch input. A pen that focuses the spot size with a reduction in height can be used as a z-axis for Tablet-PC or other applications that need more distinction between hover and touch, including in ambient light presence.

Another solution for operation in dark environment is a front light guide system. We installed a CCFL edge lamp to the cover plate. The lamp is turned ON when the average sensor reading is below a specified illumination level. A finger in contact with the cover glass out-couples the light and reflects it back towards the display (~500 Cd/m2). Future designs will replace the CCFL with LEDs. A stylus (shiny or white) used in “dark” mode should reflect light from the cover glass in contact.

5. Algorithms

Figure 7 is a general flow chart of the image processing algorithms. As mentioned above the algorithms reside in the DSP. We have the option of having the host computer software control the system through the USB. Image processing can be performed on the main processor. For mobile applications, and cost reduction the algorithm can be hosted in any system computer. The image of the sensors array and a cross showing the location of a touch is shown in Figure 7.

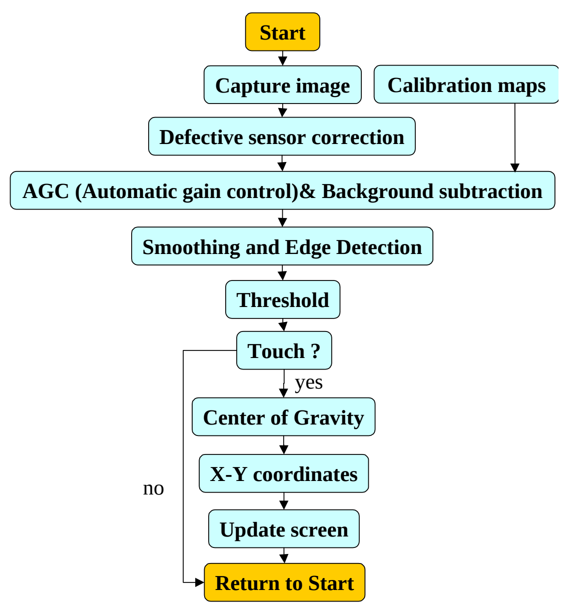

Figure 7 - Algorithm flow chart

6. System Properties

The embedded optical sensor technology is a new concept; and is unique among touch input devices. Features include:

- Improved display performance – higher transmission (even with the clear cover plate), and reduced ambient reflections

- Good registration between touch and display (they are integrated)
- Linearity and accuracy is uniform all across the display area
- Calibration is simple and stable
- Resolution is better than the pixel pitch with inter-pixel algorithm
- Lower volume and weight (important for mobile)
- Allows multiple touch (with software modification)
- High level of integration allows low cost (having readout combined with the drive chips, and the DSP replaced with an ASIC, or having software reside in a host computer)

Some limitations:

- Ambient light is needed to detect shadows – (solutions to dark environment discussed above)
- Performance can be marginal in highly collimated light.

7. Potential new applications

This system is actually a camera without a lens, therefore it has potential for imaging objects in close proximity. The number of sensors can be increased to have a sensor in each subpixel. Combining the display and imaging capability enables a number of potential new applications. For example, the image of a hand can be used as a security biometric for identity verification (Figure 10). With sufficient resolution, fingerprint recognition is also possible. The addition of a lenslets structure would improve the focal depth of each sensor. The display could also be used to image a barcode and for document scanning.

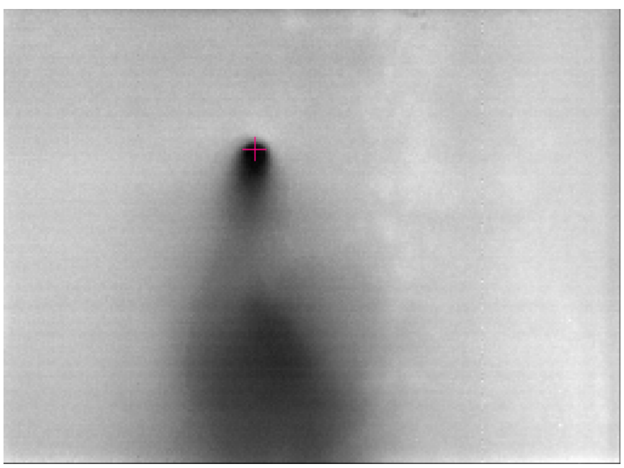

Figure 8 - Sensor array image of a touching finger with cross hair showing image processed touch location

Other unique properties of this technology could be used for new applications:

(a) Signature mode - fast writing with a stylus or light pen
(b) Multi touch – simultaneous touch input (Figure 9)
(c) Hover / touch and z-axis - Using a light pen or a stylus in the presence of enough ambient light there is a good distinction between hover and touch. This could replace touch pads and mouse buttons.
(d) Colors – putting the sensors behind the color filters permits recording color-specific data.
(e) Multifunctional – touch input can be combined with close proximity (color) imaging in the same system.

8. Summary

We have demonstrated the first AMLCD display with integrated optical sensors embedded in the TFT structure for touch and imaging capability. It works with both shadows from ambient light by a finger or stylus or with a light pen input such as from LED pen or laser. A cover glass can serve both as protective plate and a light guide for night mode. This touch technology does not degrade the display image quality. It is slim and lower weight, has good touch linearity and accuracy across the panel and has perfect registration with the display. This new technology has potential for many new applications.

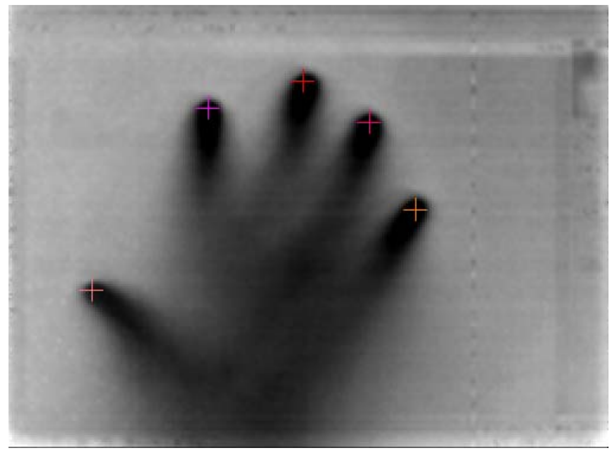

Figure 9 - Sensor array image of multi-finger touch. The algorithm generates cross hair for each touch location.

Figure 10 - Hand recognition system

9. Acknowledgements

The authors express their appreciation to the AU Optronics team for the design and manufacturing of the displays with sensor arrays.

10. References

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