A Smart CMOS Sensor for Optical Touch Screen Applications

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1. Introduction

In this paper, we present a CMOS smart sensor for optical touch screen applications. The basic configuration of an optical touch screen is shown in **Fig. 1**. 2 miniature CMOS camera modules are installed on the upper corners of the screen. Each camera module is equipped with a CMOS sensing module and also an IR illuminator. The right, left and lower borders of screen are coated reflective material. When the finger is close enough to the screen surface, it blocks the light and creates a shadow on the left and right images. By a simple triangulation calculation, the finger position can be easily determined. **Fig. 2** shows a product equipped with such touch screen using this smart sensor. The fundamental advantage of such optical sensing is its scalability in function of screen size. It's especially cost effective for large size screen where conventional capacitive solution is too expensive.

Conceptually this is a simple image sensing system and can be implemented by a simple linear CMOS sensor aligned to the borders of the screen. But in practice, there are several critical issues: 1) camera modules are not always perfectly aligned to the borders during the manufacturing and a mechanical trimming is time consuming and instable; 2) for large screen, the deformation of the screen border is inevitable due to finger pressure and limited mechanical stiffness. A recalibration is virtually difficult and 3) strong parasite ambient light can disturb the CMOS imaging device and causes random dysfunction. It has been proposed[1] to use area image sensors in order to cover the borders with misalignment tolerance during and after the manufacturing. In order to be able to detect a pen tip with 2m screen diagonal, a resolution of 1600-pixel is needed in the measuring direction. In this case, solutions based on area sensors need sophisticated hardware to do image ROI readout and pre-processing, which is not fully compatible with the ultra-low cost uC generally used in such products.

Other problem is the ambient light perturbation on the image sensing and finger detection. When it's based on conventional image sensing, the output image will be inevitably influenced by ambient light. In some cases such as outdoor installation, under halogen lighting conditions, etc. the pixels can be saturated even when the finger cuts off the LED illumination's path. An imaging sensing method giving ambient light invariance is necessary to cover all the situations and also to simply the detection complexity and reliability. A traditional frame-subtraction based solution is efficient only when the image frame rate is high enough. This is also difficult for simple uC based solutions.

Another problem is with the reflective coating, the reflective coating is generally based on microball reflectors. An air gap is necessary to generate internal total reflection. This air gap is assured by a spacer frame printed on the microball painted surface. When this coating is imagined by a high resolution sensor, the air gap frame creates discontinuities in the image which should be removed by low pass filter before the finger tip detection. This operation is computationally heavy if it's done by digital hardware after the image sensing.

For resolving these problems, we have designed a smart CMOS image sensor by introducing the following on-chip processing features: 1) arbitrary shape single line readout on 2D pixel array, 2) temporal differential sensing in order to remove the static ambient light influence and 3) in pixel vertical binominal filtering in order to remove discontinuity on the reflective coating material. **Fig. 3** gives the general architecture of such device.

2. Arbitrary shape single line constructed and readout

As shown in **Fig**. 1, the pixels to be monitored are located in a single pixel line in the 2D image, which represent the borders of the screen. The single pixel line can have arbitrary shape due to the border misalignment and deformation. For this purpose, we have invented a column readout unit [2] at each column of the pixel array including: an address register, a comparator and an analog sample-and-hold circuit as shown in **Fig. 4**. The image reading is composed of 2 phases: 1) single pixel line construction and 2) constructed image line readout.

The single pixel line construction is explained with a simple example shown in **Fig. 5**. We select the 2D pixel array line by line by sending a line address to the vertical decoder and also to the column readout unit. The single pixel line configuration is loaded into the address register in each column readout unit. The column readout unit compares the received line address with the stored line address. The pixel value will be loaded into the line buffer only when these 2 addresses are matched. By scanning the image zone covering the screen borders, we can construct this single pixel line in the line buffer at the end. Then the constructed line can be scanned out by using a simple shift-register controlled multiplexer to output. So the smart sensor is operated like a linear sensor which contains only the pixels to monitor in the 2D image. The column readout units can be programmed in real-time in order to implement the necessary calibration and recalibration algorithm during and after the manufacturing.

3. Differential image sensing

Since the arbitrary line can be constructed in a very short time (several microseconds), it's possible to implement a temporal differential sensing by using the column readout unit. For this purpose, 2 line buffers are integrated instead of one. We make fast dual image captures which will be stored in the double line buffers. The IR illuminator will be power-on only during one of the captures. A 500mA LED driver is integrated on the chip which is directly controlled by the on-chip timing generator. The measured ambient light suppression ratio is better than 80dB. **Fig. 7** shows an example where a tiny LED reflection is correctly detected on a 60W lamp!

4. Vertical low pass filter by using binominal averaging

Most of reflective coating is based on cube-corner principle, so air-gap is necessary. The spacer to create the air-gap can not reflect light so some discontinuity will be seen on the image. If no precaution is taken, then it can cause dysfunction by detecting the spacer as finger. To cope with this problem, we integrated a binomial filter by connecting together alternatively the photodiodes in the odd-even lines as shown in **Fig. 6**. This binominal filter has been introduced by MIT team at early smart image sensing devices to realize Gaussian filter. The number of binominal operations can be programmed with the on-chip timing generator according to the width of the air gap frame.

5. Conclusion

2 devices with 1600x256-pixel and 1200x128-pixel both of 4.8um pitch 3T pixel in 0.18um standard 1P3M CMOS process have been successfully designed and manufactured since 2008. No microlens is used. The image output is implemented in analog form by using differential format. This has been motivated by low EMC problem and also easy wiring. The main characteristics are summarized in **Tab**. 1. Large number of such devices has been produced with excellent yield. The device has been demonstrated as only device capable to operate in all light conditions, even facing to direct Sun shine.

6. References

[1] EP1628196A1, "Position Sensor using Area Image Sensor", EIT Co. Ltd & Xiroku, Inc. 2003

[2] WO2010/0705594A3, "MATRIX SENSOR", New Imaging Technologies Sa & Xiroku, Inc. 2009.

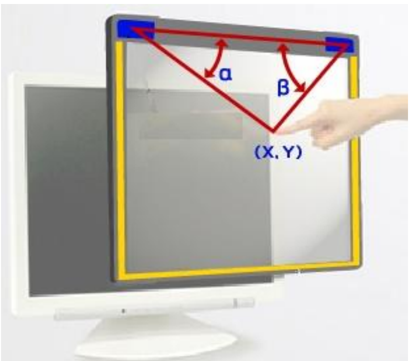

Figure 1. Basic principle of optical touch screen.

Figure 2. Optical touch screen applications for this smart sensor.

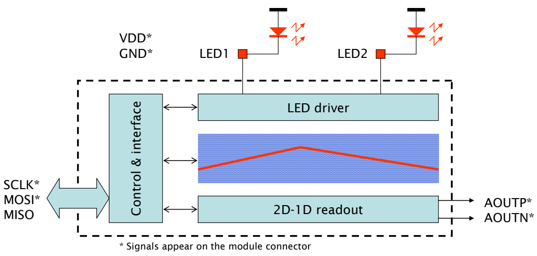

Figure 3. Global architecture of the smart optical touch screen sensor. The output is in full differential analog format in order to reduce wiring complexity and EMC problem.

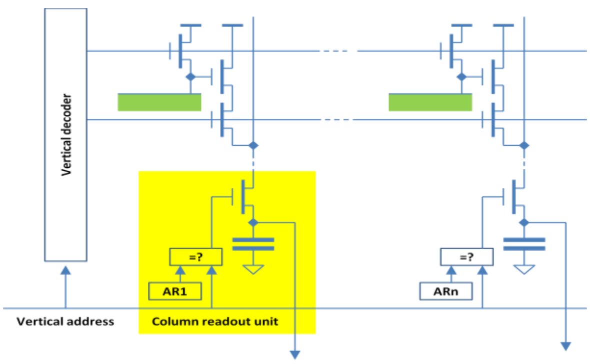

Figure 4. Structure of Column Readout Unit for arbitrary shape line construction.

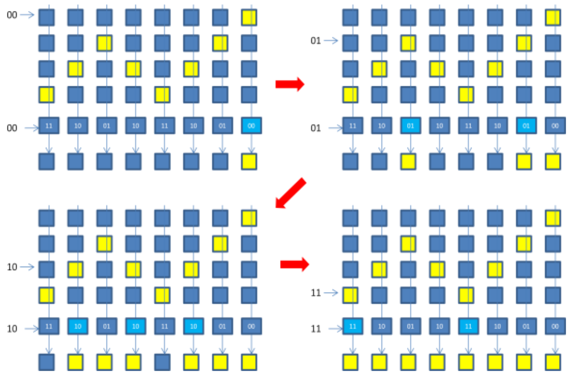

Figure 5. An example of the arbitrary shape line construction with the column readout units in Fig. 4

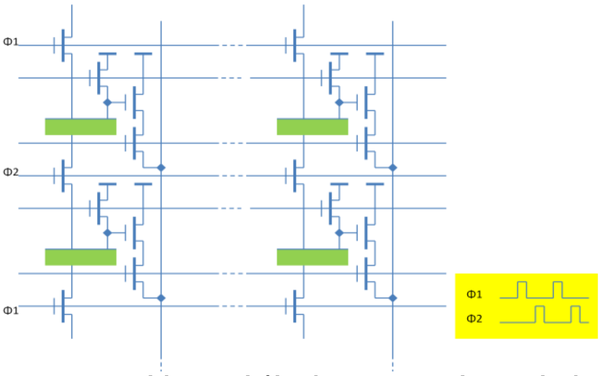

Figure 6. Vertical binominal filter by connecting alternatively the photodiodes in the odd-even lines.

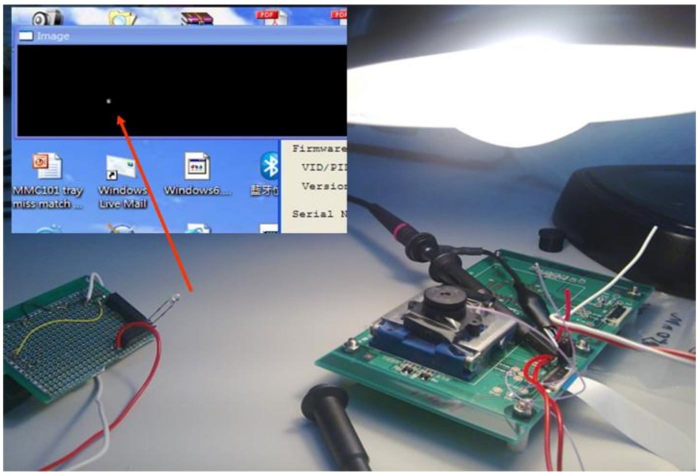

Figure 7. A tiny LED reflected on a 60W bulb clearly detected by the sensor in differential sensing mode.

Resolution		1600x254
System clock		12MHz
Power supply		3.3V(DC)
Power requirement	Active	<100mW@3.3V
Output format		Analog Differential
Sensitivity		>1.0V/lux-sec
S/N ration		>40dB
Noise		<1.5LSB
Pixel size		4.8μm x4.8μm
Special Features		· Ambient Light Suppression · 2D-to-1D Conversion · Binominal Filter
Chip size		7.9mmx2.4mm
Package		CLCC-48
Package size		14.22mm x 14.22mm

Table 1. Summary of main characteristics of the smart CMOS sensor.