FINGERCHIP™: THERMAL IMAGING AND FINGER SWEEPING IN A SILICON FINGERPRINT SENSOR

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Abstract

New silicon-based technologies have led to a breakthrough in fingerprint imaging, enabling lower cost hardware and smaller sensors. FingerChip™ technology, in fact, introduced two techniques for even smaller cost and size: thermal imaging and finger sweeping. The advantages of sweeping are described herein, including a larger virtual imaging surface. A discussion about integrating the sensor and a processor on the same chip concludes the paper.

Keywords: fingerprint silicon sensor, thermal sensor, finger sweep, fingerprint recognition, FingerChip™

I. Introduction

Hardware cost has always been the main limitation to the large-scale use of biometrics. Traditional (and more expensive) optical readers may be replaced in the near future by direct contact silicon sensors, which are much less expensive. Furthermore, new ideas within this exciting field are enabling companies to lower the cost to an even greater extent.

II. Main Sensing Techniques

A. Optics

Optical readers have been used for fingerprint capture for years [Fig. 1]. In the past, a CCD camera and frame grabber were the heart of the device, but now CMOS technologies and 'cameras-on-a-chip' can perform the whole job, drastically reducing the cost. But the fragile optical assembly still remains, and minimum size is restricted due to this.

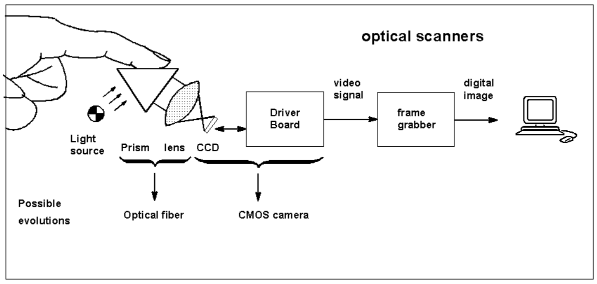

Fig. 1. Optical Scanners

B. Capacitance

Recently, a number of microelectronics and semiconductor companies developed a new concept: direct silicon sensing. Cost reduction is the main idea behind these developments. Instead of optics, the user directly places his/her finger on a piece of silicon containing an array of microsensors. While optical readers collect photons that are converted into electrons (a photo-electronic effect), direct silicon sensors use other physical effects.

The "capacitance effect" involves exploiting the difference of the electrical field (capacitance) between ridge and valley—directly linked to the difference of their distance from the sensing surface when a finger is placed on the sensor [1]. From these measurements, a relatively accurate image of the finger may be captured, from which identifying information can be derived. Other refinements to the base technology exist [2].

Despite their very certain application to the field of inexpensive fingerprint imaging, all capacitive devices suffer from an inherent vulnerability to electrostatic discharge (ESD), mainly due to their sensing method. Although steps have been taken to minimize this weakness, questions remain as to the commercial viability of these defenses.

C. Thermal

Thomson-CSF pioneered the use of thermal sensing for fingerprint imaging in the FingerChip™. The pyro-electric material in this sensor measures temperature changes and outputs an image. Interestingly,

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absolute temperature is not read, but rather temperature variation over a period of time ("integration time").

One of the main benefits is the ability to capture higher quality fingerprint images over a wide variety of finger types. Dry skin or minute features no longer present an obstacle to fingerprint imaging.

As a result of this pyro-electric effect, there are the following consequences:

- After a while, thermal equilibrium between the finger and the sensor is reached as no further temperature change occurs, and the image vanishes. This disappearance happens very quickly.
- Contrast depends on the temperature difference between the finger and the sensor. The best case is rather unusual as it happens at extreme temperature ranges, such as cars [-55°C/-67°F, +85°C/+185°F]. The worst case is produced if the finger and the chip are at exactly the same temperature. But even a very small temperature difference, as low as one degree, is enough to capture an image.
- Images are inverted depending on the relative temperature difference between the sensor and the finger. In this case, line endings become bifurcations (and the reverse). This must be taken into account by authentication software.

In real world terms, using a device that produces a vanishing image seems difficult, but a unique user interface, 'sweeping,' eliminates this effect (see below) and brings with it other benefits as well.

Please note that ESD is not an intrinsic problem with this type of sensor. In fact, the sensor cannot operate without a grounded upper layer [Fig. 2].

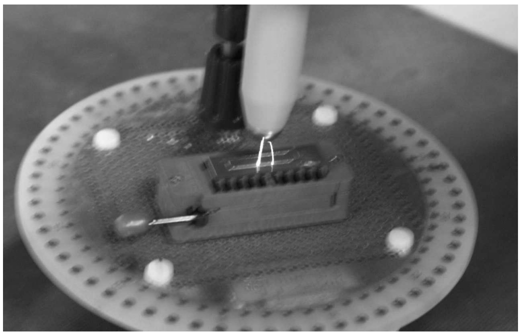

Fig. 2: The FingerChip™ withstands >16kV ESD

III. Protection

Usually, silicon devices are sealed in a package to isolate them from the environment. The situation is quite different for a fingerprint reader: the silicon must be exposed. Coatings have been developed to protect the silicon, but the physical effect used by the device must be sensed through the protection. Thus, this layer must be as thin as possible.

The protective layer must also protect the silicon from ion contamination and mechanical abrasion. Moreover, protection is needed to fight the oils, greases, and other materials regularly deposited by fingers. Therefore, the coating must be as thick as possible to provide better resistance, but this may, of course, lead to less sensitivity.

So, for each sensor, the protective layer is essential, and the real difficulty is finding the optimum thickness.

Thermal sensing offers a significant advantage in that heat transfers quite well through a comparatively thick protective layer.

IV. Size does matter

Silicon sensor cost depends very much on the area of the chip, because the cost of a silicon wafer does not depend at first order on the number of candidates. Essentially, the cost of the wafer is shared between the good dies; the smaller the die, the lower each one will cost. A secondary effect is also important: yield decreases with the area because the probability of having one defect on a die directly depends on the area.

However, tradition dictates that a sensor with a large imaging surface is required. Based on the size of a finger, an optimal area exists, roughly 13mm x 15mm = 1.9cm^2. This is a very large chip, even with the cost savings mentioned. Is there any way to reduce the area?

V. Sweeping technique

Imagine if we could sweep a finger over a sensor to capture an image; that is, if a full fingerprint image could be reconstructed from elementary slices taken during the sweeping. We could reduce the sensor area by a factor of 5, and thus the cost, while retaining a larger *virtual* imaging surface. In fact, it would be possible to produce larger images than with a standard "touch" chip, with more information and more minutia as the final image size is limited only to the memory space allocated to image storage.

The only requirement: make sure enough images are captured during the sweeping process so recovery exists between the slices. If not, it is impossible to reconstruct the full image.

Sweeping also offers the following advantages:

- Cleaning: The sweeping action cleans the device. You will not get the build-up that occurs in the corners of a "touch" sensor.
- No latent prints are left behind for others to use fraudulently.

VI. Sweep + thermal=no vanishing

Sweeping causes the ridges and valleys to alternatively pass over each pixel in the sensor, inducing continuous temperature changes. Thus, the slices have a regular contrast during sweeping, and the vanishing effect disappears!

This combination of thermal sensing and sweeping provides both better images *and* lower cost: a rather unusual combination.

VII. Acquire and reconstruct

Reconstructing the image is an additional step for sweeping-type sensors because today's software algorithms typically require the full fingerprint [Fig. 3]. Reconstruction is done in software, but a dedicated processor can also be applied to this, as it requires minimal CPU power. Moreover, this processor could reconstruct images in real time during a finger sweep.

A. Acquisition

Before reconstruction we have to perform acquisition. To do this, a simple loop analyzes each incoming slice to decide whether or not a finger is in contact with the sensor. This is an easy task that can be done in different ways.

One simple solution is to use a histogram. When there is nothing on the device, the histogram is very sharp. When a finger is present, standard deviation increases. To make the system reliable, start and stop are validated only if several consecutive slices show the same effect, so as to avoid sensitivity to noise.

B. Reconstruction

Reconstruction is quite simple, once you realize that you simply have to search for the same pattern in two consecutive slices. Any program able to detect such a pattern will be able to reconstruct the whole image. First, a piece of the slice is selected, for instance, a few lines, and then a search for the closest match in the next slice is performed. The simple sum of the absolute value of differences at pixel level is very efficient for this search: after trying several positions, keep the best one (i.e. with the lowest value). If it is zero, it is exactly the same pattern. MPEG video compression chips already perform this type of search.

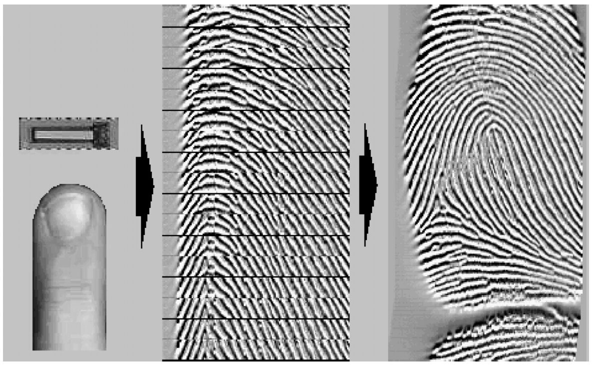

Fig. 3: Sweeping reduces the area of silicon, and thus the cost. (FingerChip™)

As a result of this process, reconstruction occurs, generally, in less than 0.2 s on a Pentium 233 MHz. In fact, more time is spent detecting the finger's end, as you need to be sure it is not an artifact such as a crease between two parts of the finger.

Reconstructing on the fly —that is, making the reconstruction during image acquisition— may save a significant amount of memory because you don't need to store all the slices to later perform the computation on. Only the memory space for the resulting image is needed.

VIII. Authentication on the fly

Sweeping offers yet another advantage: authentication during acquisition, resulting in a positive verification even before the end of the finger sweep, if enough minutia or other identifying material have been found. A negative answer would of course be delayed until the end of the sweeping to make sure additional data is not received. This process leads to an ergonomic success: the user gets an answer even before he or she finishes sweeping—there is no waiting for the result.

The drawback is the processing power that it requires, because you have to grab the slice, perform feature extraction, and match, all at the same time. However, with constant advances in digital signal processors and other microprocessors, this is certainly possible.

Sweeping may lead to an evolutionary change to fingerprint matching, especially when compared to the traditional sequential method of grabbing an image, extracting features, and then matching.

IX. CPU + Sensor: Is a single chip a viable solution?

Combining both the sensor and the processor into the same design would be very interesting. However, problems occur when trying to integrate more functions on the same chip to lower the overall cost.

Fingerprint sensing typically requires a resolution of about 500 dpi; that is, a pixel pitch of 50 microns. Actual CMOS processes in production are 0.35 microns and smaller: these are too accurate for a fingerprint sensor, and are expensive. Therefore, manufacturers of silicon fingerprint sensors tend to use old technologies (e.g. 0.8 microns, 6" wafers) to reduce cost, as these technologies have a much lower cost per square mm.

Generally, the microprocessor requires an expensive (sub-micron) process in order to have a powerful chip that processes data within, let's say, one second. If the (low) cost of the sensor process is 1 unit per mm^2, then the cost of the microprocessor process is 5 units per mm^2, because at least 3 generations separate the two processes (Here, we are comparing a 0.8µm process with 0.25µm).

Remember that at the same time, the processor area, for the same function, can be roughly reduced by a factor of $(0.8/0.25)^2=10$ (in fact, it is more than that when we consider other parameters such as interconnect density), by moving between processes.

However, this scheme doesn't work for a fingerprint sensor, because the finger won't be getting any smaller! So, we just increase the cost of the sensor by using the latest process.

Cost	**Sensor process 1/mm^2**	**Processor process: 5/mm^2**	**2-Chip Solution Cost**	**1-Chip Solution Cost**
Square Sensor (200mm^2)	Ss 200	Sp 1000	Ss + Pp 400	Sp + Pp 1200
Linear Sensor (40mm^2)	Ls 40	Lp 200	Ls + Pp 240	Lp + Pp 400
Processor (40mm^2)	N/A	Pp 200		

This is why a two-chip solution, separated into processor and sensor, will prevail in the short to medium term, as manufacturers wait for the new technologies today to become old (and less expensive) tomorrow, thus reducing this dramatic cost effect.

X. FingerChip™: Thermal imaging + sweeping user interface

Thomson-CSF Semiconducteurs Spécifiques has patented the sweeping method combined with thermal sensing. The first product of the FingerChip family, FC15A140, has been available since late 1998, and a new, smaller, all-digital design is slated for release by the end of 1999.

XI. Conclusion

Finger sweeping in combination with thermal sensing offers significant advantages for price reduction in the long run, when volume production is large enough to compensate for the usual high development costs of any microelectronic product. Moreover, lower size will enable even further portable applications. Direct silicon sensing promises to be the way forward for the next generation of fingerprint sensors.

References

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FingerChip is a trademark of Thomson-CSF Semiconducteurs Specifiques.