Characteristics and Application of the Fingerprint Recognition Systems

I. Plajh, M. Cifrek, S. Tonković

University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
Email: mario.cifrek@fer.hr

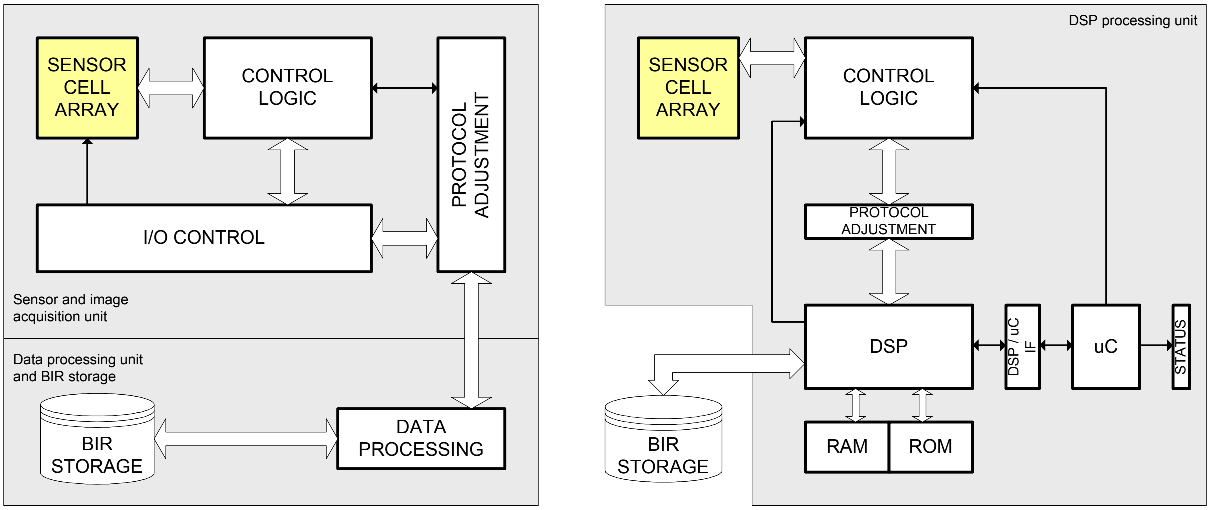
Abstract. *Fingerprint recognition systems functionality relay on the processing power of the underlying system that implements efficient algorithm for the fingerprint image analysis rather then on the image data acquisition principle efficiency. In this work basic method of the capacitive measurement principle used in most of the systems are analysed. Results lead to the conclusion that some system improvements are also possible through the modification of the existing method.*

Keywords: fingerprint recognition system, capacitive measurement principle, capacitive sensor array.

1. Types of systems and their architecture

Fingerprint recognition systems are mostly explored from the image analysis point of view [1], [2]. However, characteristics of the systems are strongly dependent on the system architecture and the measurement principle implemented. There are two global parts of the biometric fingertip recognition system that could be roughly outlined: one is responsible for the image acquisition and another is responsible for the processing of the collected data. Figure 1 shows two basic types of systems architecture, dependent and independent, each containing acquisition and processing unit.

Most common applications of the systems represented on Figure 1 are given in Table 1.



a) b)

Fig. 1. Dependent and independent system basic architecture. a) Dependent system includes two separated parts of the image acquisition and processing of the collected data (typically PC, Workstation, etc.). b) Independent system uses DSP processor embedded into the system. Storage of the biometric identification records (BIR) [3] in second case is external because of the possible memory limitations in the system.

Table 1. Areas and systems where represented architectures could find appliance.

Dependent architecture	Independent (embedded) architecture
Fingerprint recognition software design	Cellular phones
Sensor functionality analysis	Personal digital assistants
Fingerprint feature analysis systems	Car control and security
Workstation security solutions	Home control and security
Network security solutions	Future chip card solutions

2. Measurement principle

Texture of the fingerprint, formed by cured alternation of the ridges and valleys has to be transformed into the digital image. For this purpose, the distance between sensor surface and finger ridges or valleys is transformed to the discrete information, and from this information grey level representation of discrete levels is given on the output.

Formation of the sensitive capacitor array that is capable to acquire enough data for fingerprint validation is possible only on silicon substrate. Each capacitor in the array is made of a metal plate positioned close to the sensor surface (S_1), the first dielectric layer ε_{r1}, which is in fact passivation and protection layer of the sensor, the second dielectric layer ε_{r2} made of air between skin surface and sensor surface, and finally, skin surface, which represents the second capacitor electrode S_2 (Fig. 2). Resulting capacitor is serial combination of particular capacitors, C_1 and C_2:

$$C_{common} = \frac{C_1 C_2}{C_1 + C_2} = \varepsilon_0 \frac{\varepsilon_{r1}\frac{S_1}{d_1}\varepsilon_{r2}\frac{S_2}{d_2}}{\varepsilon_{r1}\frac{S_1}{d_1}+\varepsilon_{r2}\frac{S_2}{d_2}} \qquad (1)$$

Dependencies of variable parameters (temperature T, relative humidity $rH\%$ and pressure p) could be explained through the following relations:

$$\varepsilon_{r2} = f(T, rH\%, p) \qquad (2)$$

$$d_2 = 0,\ldots,0.05mm \qquad (3)$$

$$S = \iint_A f(x,y)dA \qquad (4)$$

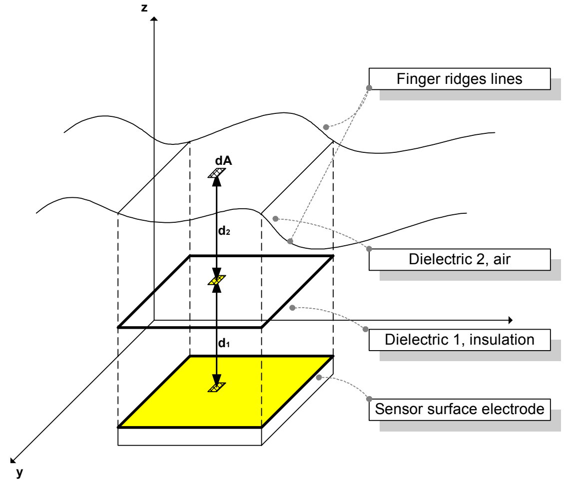


Fig. 2. Capacitor made of sensor surface electrode and fingertip surface.

Sensor formed in this way is dependent to a number of factors. First, when finger pressed on the smooth sensor surface, space between finger valleys is fulfilled with air that is captured in the major part of the connection surface and any circulation of the air is impossible. Since finger surface is live biological tissue, some processes make dielectric constant of this air variable to the temperature of the tissue and relative humidity that is result of sweating. Additionally, small skin particles of dead skin cells falling from *stratum corneum* introduce error to the measured discrete value.

All this parameters form microclimate conditions on the sensor surface and these conditions influence image quality with some constrains of the grey level dynamics. But the influence of finger surface shape and the distance between sensor capacitor electrode and finger ridges and valleys on the final pixel value could be minimized. If the capacitor electrode on the sensor surface is small enough, the following conditions could be valid:

$$d_2 \approx \overline{d_2}, \quad S_1 \approx S_2 \tag{5}$$

The conditions above presume that the average distance between sensor capacitor electrode $\overline{d_2}$ and finger surface above that electrode does not change rapidly. The surface of the bounded finger surface area S_2 is approximately the same as the surface of the electrode on the sensor side, S_1. With these constrains, common capacitance could be expressed with:

$$C_{common} = \frac{C_1 C_2}{C_1 + C_2} = \varepsilon_0 \frac{\varepsilon_{r1} \frac{S_1}{d_1} \varepsilon_{r2} \frac{S_2}{d_2}}{\varepsilon_{r1} \frac{S_1}{d_1} + \varepsilon_{r2} \frac{S_2}{d_2}} = \varepsilon_0 \frac{\varepsilon_{r1} \varepsilon_{r2} \frac{S_1^{\;2}}{d_1 \overline{d_2}}}{\frac{\varepsilon_{r1} S_1 \overline{d_2} + \varepsilon_{r2} S_1 d_1}{d_1 \overline{d_2}}} = \frac{\varepsilon_0 \varepsilon_{r1} \varepsilon_{r2} S_1}{\varepsilon_{r2} d_1 + \varepsilon_{r1} \overline{d_2}} \tag{6}$$

The formed capacitor is just one part of the sensor system that is responsible for conversion of the distance between finger ridges, valleys and sensor surface into the variable amount of electrical charge. If capacitor is connected to the source of the constant voltage, amount of charge will be deployed on the capacitor electrodes. This amount is dependent on the capacitance of the capacitor and on the average distance between finger and sensor surface as explained above. If the sensor capacitor cell array is observed it could be stated that since distance is the parameter that influences capacitance variances most significantly, charge on the single sensor cell member will be variable to this distance mostly.

Figure 3 represents the entire acquisition principle. Digital output is formed in the counter.

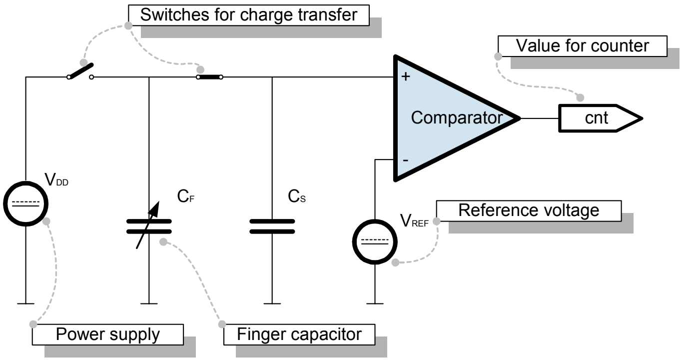


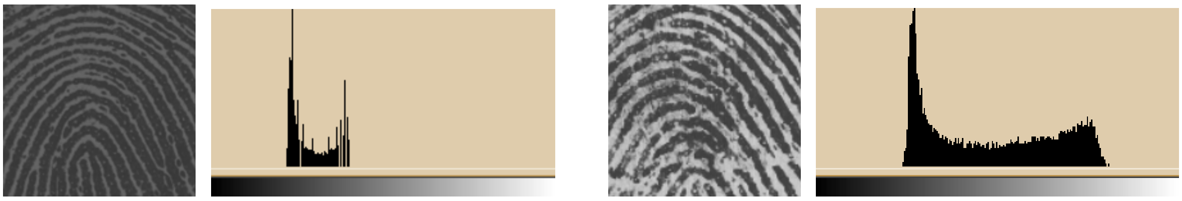
Fig. 3. Capacitive measurement principle. A small metal electrode and the surface of the finger form the capacitance C_F. Valleys and ridges on the finger will yield varying C_F values. In order to acquire the value of C_F, this capacitance is charged and discharged with the manipulation of the charge transfer switches. This circuit serves as a charge pump, increasing the voltage of C_S with each charge cycle. The voltage of C_S is compared with the reference voltage V_{REF}. If the voltage of C_S is greater than the reference voltage, the value of an 8-bit counter, which counts the number of charge cycles, is stored.

The influence of the microclimate and macroclimate conditions is not so significant that information about the distance could be lost in the acquisition process. Of course, extreme conditions like high or extremely low temperature or very high humidity cause inoperability, but such conditions are rare. In majority of cases, the temperature ranges from 0°C to some 50°C, and humidity from 50% to 70%. These conditions are proper for the system operation.

With slight modification needed for the implementation in silicon, principle explained in this paper was used for building various fingerprint image acquisition sensors by various vendors (Infineon, Authentec, VeriTouch, SGS Thomson, Sony).

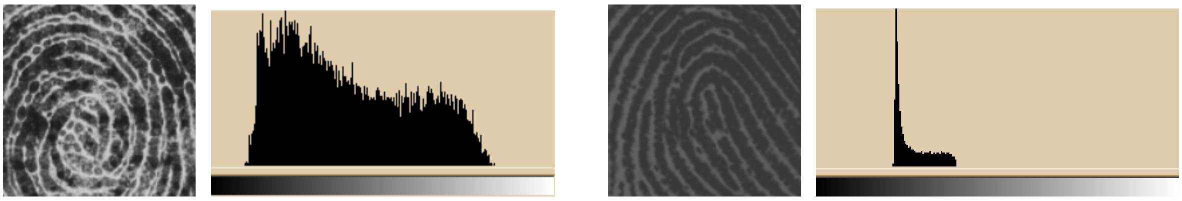
3. Results

Images representing part of the fingertip surface measured with the modified system containing Infineon FingerTIP™ [4] sensor with variable reference voltage from 2.5 V to 4 V and EPP interface are compared. Typical results are shown on Fig 4. Smaller reference voltage causes narrow image histograms with mean value reaching up to 60% of the value with higher reference voltage.



a) Mean Value = 73.41 Std. Deviation = 15.51

b) Mean Value = 121.97 Std. Deviation = 46.38



c) Mean Value = 101.83 Std. Deviation = 48.16

d) Mean Value = 67.27 Std. Deviation = 12.88

Fig. 4. Samples of the acquired values with capacitive sensing array of 150 × 150 capacitors. Mean values and standard deviations are given for each histogram.

4. Discussion and conclusion

Presented results are typical samples where variable dynamics of the output images requires strong image pre-processing algorithms at the input stage of the fingerprint recognition system. Influences of environmental parameters are avoidable with careful system design, but physiology of the finger is one unavoidable factor that contributes to dynamic variations. Customizing the capacitive principle through the modifications of the sensor cell electrode geometry, reference voltage and counter resolution could bring solutions that provide analysis systems with images more suitable for faster and optimised processing. With this, requirements for the system computational power could be decreased.

References

[1] Jain A, Pankhrati S. Automated Fingerprint Identification and Imaging Systems. Department of Computing Science & Engineering, Michigan State University, 1999.

[2] Jain A, Pankanti S. Biometric systems: Anatomy of Performance. *IEICE Trans. Fundamentals*, E84-D (7), 788-799, 2001.

[3] BioAPI Consortium. BioAPI Specification Version 1.1. http://www.bioapi.org, 2001.

[4] Infineon Technologies. FingerTIP™ FTF 1100 MF1 V2.0 CMOS Chip and System, Databook 3.3, 2000, Published by Infineon Technologies AG, CC Applications Group St.-Martin-Straße 76, D-81541 München