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Design and Analysis of Micro Capacitive Structure Arrays using LabVIEW

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This work emphasizes on developing a LabVIEW based package to classify five types of fingerprint based on MEMS micro capacitive structure arrays. The SFinge software is used in obtaining a directional map generation profiles for fingerprints. Meanwhile, data from SFinge software will be translated into matrix and graph representation. The LabVIEW software is used in building graphical user interfaces to classify fingerprints into five types of classes based on singular points and orientation of the directional map profile. The block diagram was divided into two functions. The first function is to obtain indicators for each directional map orientation based on cores and deltas selected by the user. The second function is to obtain the capacitance, graph and matrix representation, fingerprint classification and the most relevant size of an array. The classification process for this work is to obtain the smallest capacitor size array arrangement for MEMS fingerprint sensor design. By using the LabVIEW software, it is found that the array size and structure need to be considered in fingerprint recognition. Based on the results obtained, the arrangement for a smallest sized capacitive grid of 8 x 8 array could only detect the plain arch pattern. Thus, a larger capacitive arrangement of 12 x 12 is more relevant but it is limited to two types of classification. Therefore, the 16 x 16 capacitive arrangement is the optimized size for fingerprint classification based on the findings. Results from this works show the effect for each window size and the arrangement for each capacitor plays an important role to get the most optimum fingerprint reading.

Keywords: capacitive arrays; MEMS; *LabVIEW*; *SFinge*

I. INTRODUCTION

MEMS consist of electrical and mechanical components of small size of micrometres to millimetres, designed together using integrated circuit (IC) technologies. There are various types of MEMS based sensors nowadays in the market. For instance, the one that is emphasized in this study is a MEMS capacitive based sensor for fingerprints classification. Fingerprints can be defined as an impression or mark appearing on the surface of the fingertips and can be used to identify an individual from a unique pattern or vortex lines formed at the fingertip. The fingerprint is an impression or mark appearing on the surface of the fingertip and is used to identify the unique patterns or vortex lines formed at the fingertip. The fingerprint are classified into five major classes which are plain arch, tented arch, left loop, right loop. The detection methodology manipulates the differentiation within the surface topographies of a finger valley pattern (Henry & Gaensslen, 2012). Other methods such as capacitive fingerprint sensor array detection recognize of tactile pressure and finger skin temperature were also demonstrated (Byeong *et al.*, 2018). Commonly, this sensor used for fingerprint detection has stacked of about 50 pixels per square micrometres (Ganji & Nateri, 2013). Each pixel having a capacitive pressure sensor

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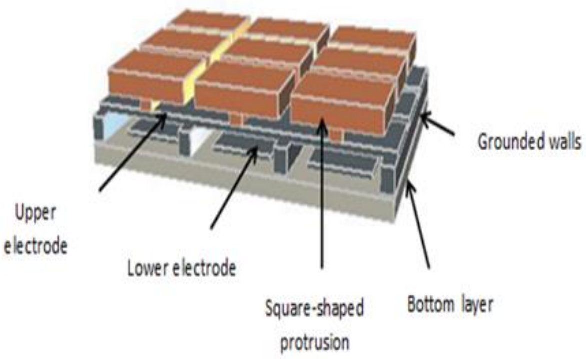
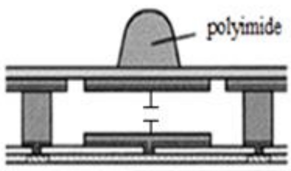
having movable electrodes based on the pressure given by the finger.

MEMS capacitive based fingerprint sensor is able to capture fingerprint images clearer regardless of the finger condition, either wet or dry. Each capacitor is arranged in close proximity to each other, thus the essential features of a fingerprint were not missed. Due to the distance between the skin and surface of the sensor, edges and valleys are found on fingerprints are identified and, therefore, a complete fingerprint pattern obtained (Sato, 2005). Furthermore, the projection of the fingerprint sensor helps to get the fingerprint images in a variety of finger surface conditions. However, the image will disappear shortly after the finger is removed from the sensor. A model of MEMS fingerprint sensor chip with a T-shaped projection by (Tartagni & Guerrieri, 1998) and fabricated structure is shown in Figure 1 (Sato, 2005). A novel electrostatic sensor based on the capacitive pixel arrangement also demonstrated by (Tang *et al.*, 2018). The displacement for the suspended structure is the main feature of the capacitive MEMS design. A wider beam structure is used for the fingerprint sensor to ensure that each valley and edge of the fingerprint will be detected.



(a)



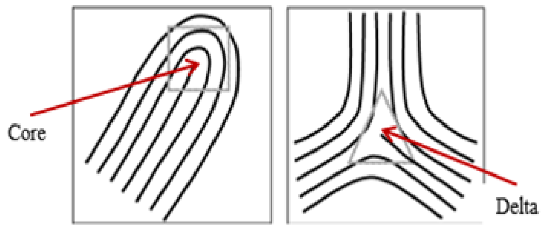
(b)

Figure 1. MEMS fingerprint capacitive sensor, (a) a T-shaped projection array, and (b) a component of capacitor which referred as one pixel (Sato, 2005)

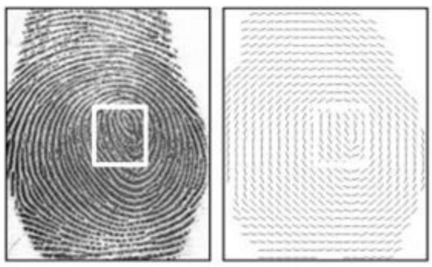
In this work, the image of fingerprints is obtained by reading singular points which consist of delta and core points, and directional map orientations that were generated by grayscale images depicted in Figure 2, based on the work by (Rahul & Patil, 2014). Moreover, since fingerprints consist of edges and valleys that are close to each other, an array of capacitive sensors are used to detect the primary classification of fingerprints. The arrays arrangement measures capacitance reading for each pixel based on the value between fix electrodes and movable electrodes cause by the fingerprint's edges and valleys.

II. METHODOLOGY

Singular points and directional maps images are used as references to classify the fingerprint features according to several classifications. The first step is to describe the singular point on fingerprints which is the deepest point on the curve at the edge of the innermost. While delta is the centre of the triangular-shaped area where three different trends meet. The core is usually located at the border of the fingerprint. Deltas are short boundaries, branches, or disunity between the two borders across a finger.



(a)



(b)

Figure 2. Fingerprint image characterization, with (a) singular point of core and delta, and (b) directional map orientation generated by grayscale image (Rahul & Patil, 2014)

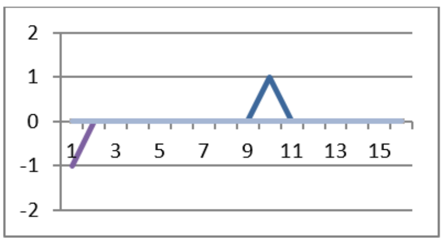
The second step, the directional map image is a separate image matrix in which each element represents the rotation of ridges on a fingerprint. Generally, only the ridges surface of the fingerprints considered for the classification process. On the other hand, the position and dimension details are ignored. In addition, directional maps images which consist of singular points that are frequently emphasized throughout this study. The other method for fingerprint classification based on Henry System is a systematic method for classifying fingerprints. As mentioned earlier, fingerprints are divided into five classes; right loop, left loop, whorl, arch, and tented arch, and each of the classifications has a unique integrated pattern (Nur & Ahmad, 2015; Hong & Jain, 1998).

A. Working Principles

The design of capacitive arrangement for MEMS fingerprint sensor requires directional map images of fingerprints. In these images, each pixel represents a capacitor that is translated into a matrix representation. SFinge software allows user to create the directional map images, as stated by (Cappelli, 2004).

$$A = \begin{bmatrix} a2,1 & a2,2 & a2,3 & a2,4 & a2,5 & a2,6 & a2,7 & a2,8 & a2,9 & \ldots & a2,15 \\ a3,1 & a3,2 & a3,3 & a3,4 & a3,5 & a3,6 & a3,7 & a3,8 & a3,9 & \ldots & a3,15 \\ a4,1 & a4,2 & a4,3 & a4,4 & a4,5 & a4,6 & a4,7 & a4,8 & a4,9 & \ldots & a4,15 \\ a5,1 & a5,2 & a5,3 & a5,4 & a5,5 & a5,6 & a5,7 & a5,8 & a5,9 & \ldots & a5,15 \\ a6,1 & a6,2 & a6,3 & a6,4 & a6,5 & a6,6 & a6,7 & a6,8 & a6,9 & \ldots & a6,15 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots \\ a15,1 & a15,2 & a15,3 & a15,4 & a15,5 & a15,6 & a15,7 & a15,8 & a15,9 & \ldots & a15,15 \end{bmatrix}$$

(a)



(b)

Figure 3. Matrix arrangement methodology with (a) the position of each pixel capacitors in a matrix, and (b) plot for tented arch classification

There are two types of representation for directional map images of a fingerprint; matrix and graph. These two representations are then translated using Microsoft Excel prior to integration with LabVIEW software. Figure 3(a) shows the position of each pixel capacitors in a matrix form. The value for each ridge = 0, core = +1 and delta = -1. For instance, Figure 3(b) shows the graphical representation for tented arch classification. The matrix obtained will be translated into a graph of two axes. The x-axis represents the value of the ridge, while the y-axis represents the values of the singular points. Microsoft Excel software is used to produce the graph for this matrix. The purpose of translating the matrix into graph representation due to singular points in matrix form is difficult to read caused by the numbers of rows and columns presented.

B. Governing Equations

A capacitor consists of two parallel conductive plates separated by an insulating material. When a voltage is applied to the capacitive plate, the electrical current will flow and the charging plate will be positively charged with respect to the supply voltage and the other plate will be negatively charged. The capacitor *Co* between the electrodes is obtained using Equation (1). The plate surface, *A* is equal to 50 µm. If there is a small deflection due to the fingerprint, the capacitance value of *C1* can be obtained using Equation (2). The *D* is the displacement of the diaphragm and is limited to 0.3 µm deflection.

$$C_0 = \varepsilon_0 \frac{A}{d_0} \tag{1}$$

$$C_1 = \varepsilon_0 \frac{A}{d_1} = \varepsilon_0 \frac{A}{(d_0 - D)} \tag{2}$$

In this work, the value of the charge is 23.1 pC, the supply voltage is 3.3 V and the capacitor is 1.5 pF. In order to distinguish between core and delta points at the ridges surface on fingerprints, the core is set to have a value of 1.7 pF, while the delta is 1.6 pF.

Table 1. Fingerprint classification table

Fingerprint Classification	Singular points	Directional Map
Plain Arch	None	Horizontal
Tented, left loop, right loop	1 core, 1 delta	Vertical, left, right
Whorl	0,1,2 core, 2 delta	Circular

Table 1 summarizes the classification information of the fingerprints. These data are very important for the next stage in developing the graphical user interface (GUI) to obtained capacitances value, representations and directional map images for the fingerprint.

C. Fingerprint Classification Rules

The classification process can be divided into three groups based on singular points and directional map characteristics.

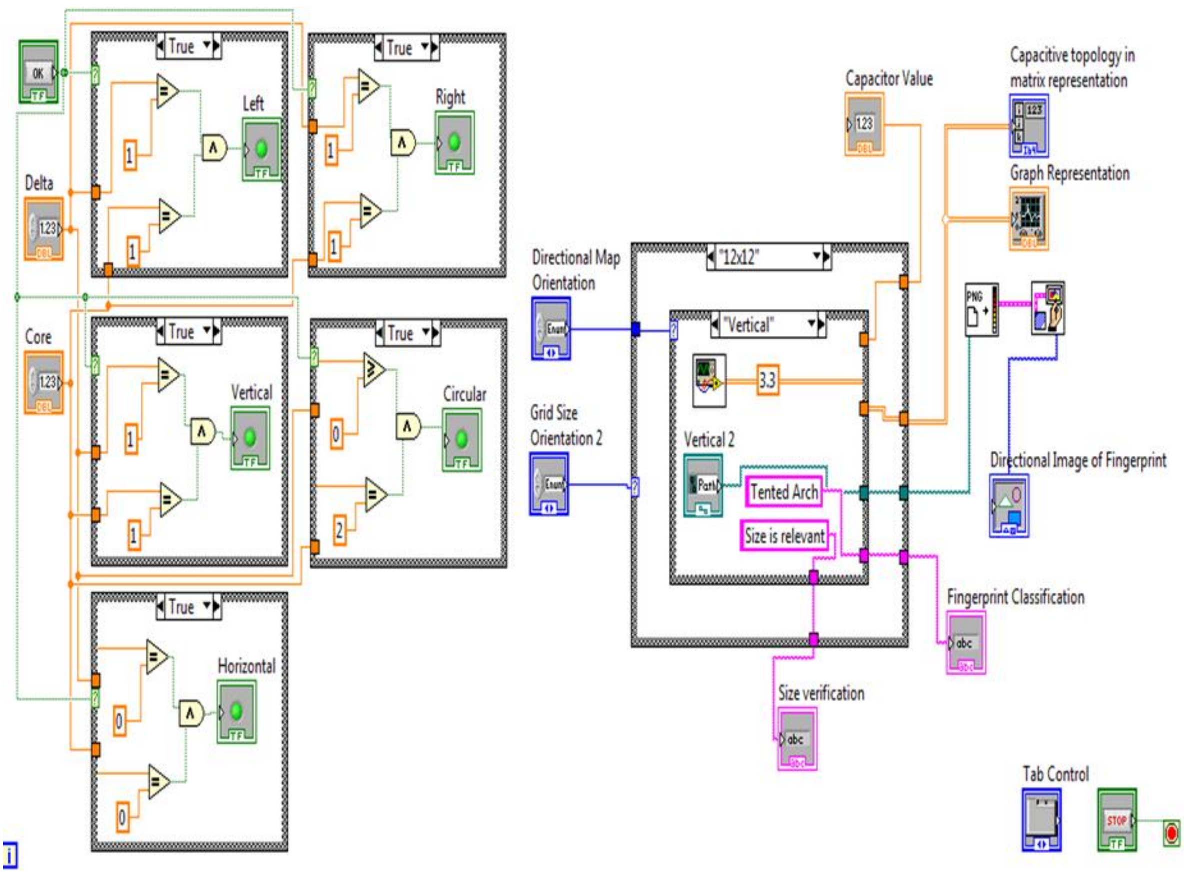


Figure 4. Fingerprint classifications block diagram using LabVIEW

III. RESULTS AND DISCUSSION

The block diagram of the graphical user interface modelled using LabVIEW is shown in Figure 4. The block diagram was divided into two functions.

The first function is to obtain indicators for each directional map orientation based on cores and deltas selected by the user. The second function is to obtain the capacitance, graph and matrix representation, fingerprint classification and the most relevant size of an array. The classification process for this work is targeted to achieve the smallest capacitor size array arrangement for MEMS fingerprint sensor design. Three sizes of capacitance array are taken into consideration; 16 x 16, 12 x 12 and 8 x 8 grid sizes. From the design of the block diagram, the user could determine parameters of singular points or directional map orientation for fingerprint recognition.

Figure 5 shows the fingerprint classification result with 16 x 16 grid sizes, the number of core and delta selected by the user is 2 and 2, respectively. When the OK button is pressed, the indicator will show the type of directional map orientation that the user can select, the indicator light for the circular type orientation lights up. Therefore, user is allowed to choose the orientation of the circular type only. Then, the software will represent the singular points and directional map orientation in the form of a matrix. The software will produce a result that includes graphical representations, directional map images, the capacitor value and fingerprint classification.

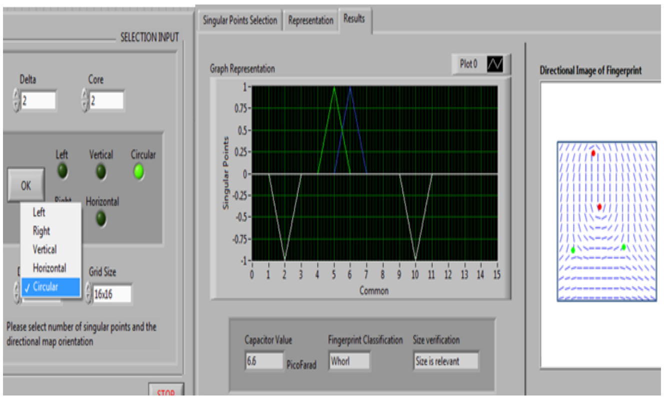


Figure 5. The selection input and result windows for 16 x 16 grid size

Figure 6 shows the fingerprint classification result with 12 x 12 grid sizes, the number of core and delta selected by the user is 1 and 1, respectively. As shown in Figure 6, the directional map image shows the size of the capacitor and the size of 12 x 12 grid are smaller than the size of a 16 x 16 grid.

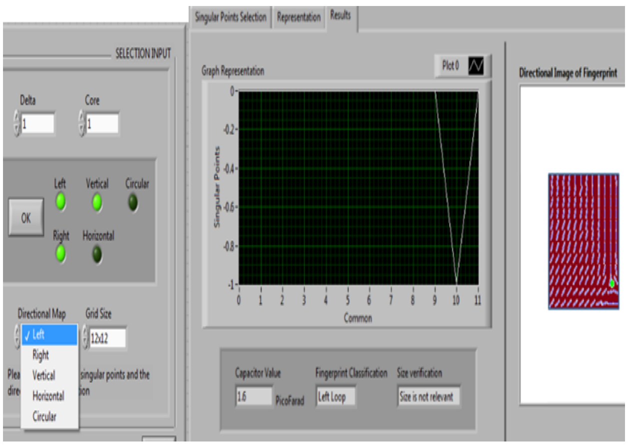


Figure 6. The selection input and result windows for 12 x 12 grid size

Figure 7 shows the fingerprint classification result with 8 x 8 grid sizes, the number of core and delta are selected by the user is 1 and 1, respectively. The directional map image shows the size of the capacitor array for 8 x 8 grid size is smaller than the size of the profile-directed map grid 16 x 16 and 12 x 12 grid.

The results are summarized for each size as shown in Table 2. For 16 x 16 size grid, the verification of sizes is relevant because the singular points are detected. As for size 12 x 12, only the classification for the tented arch and the plain arch is relevant. Other classifications were not relevant because not all singular points for this classification are detected. Finally, for the size of 8 x 8, the only plain arch classification is relevant because there was no singular point detected.

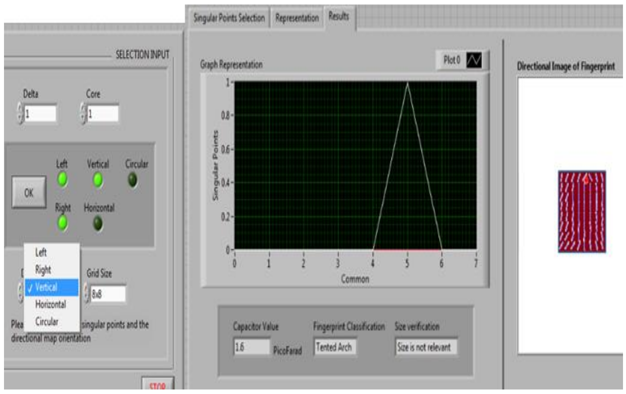


Figure 7. The selection input and result windows for 8 x 8 grid size

Table 2. Fingerprint classification results

Size	Classification	Amount of singular points	Amount of singular points detected	Size verification
16 x 16	Tented arch	2	2	Relevant
16 x 16	Left loop	2	2	Relevant
16 x 16	Right loop	2	2	Relevant
16 x 16	Plain arch	0	0	Relevant
16 x 16	Whorl	4	4	Relevant
12 x 12	Tented arch	2	2	Relevant
12 x 12	Left loop	2	1	Not relevant
12 x 12	Right loop	2	1	Not relevant
12 x 12	Plain Arch	0	0	Relevant
12 x 12	Whorl	4	3	Not relevant
8 x 8	Tented arch	2	1	Not relevant
8 x 8	Left loop	2	0	Not relevant
8 x 8	Right loop	2	0	Not relevant
8 x 8	Plain arch	0	0	Relevant
8 x 8	Whorl	4	2	Not relevant

The capacitance values obtained from the classification process range from 6.6 pF to 1.5 pF. The largest value of 6.6 pF was shown by 16 x 16 grid size of whorl type fingerprint. While, the smallest value of 1.5 pF was shown by plain arch type fingerprint for capacitive arrangement of 16 x 16 grid size, 12 x 12 grid size and 8 x 8 grid size. The other type of fingerprint classification shown an average of 3.3 pF of capacitance value. The different grid sizes will give different performances of the MEMS capacitive based sensor. This is due to the static capacitance value the determines the minimum resolution of the device. The capacitive arrangement below the value caused the fingerprint detection inaccurate and failed to detect more fingerprint classifications.

IV. CONCLUSION

The study of micro capacitive MEMS array group arrangement design has been done to obtain the most relevant window size. In obtaining the most optimal fingerprint images, the capacitor plays an important role in fingerprint recognition or classification. By using the LabVIEW software, it is found that the array size and structure need to be considered in fingerprint recognition. The size of capacitive arrays plays an important part in classifying or obtaining a fingerprint image. Basically, the larger the size of array, the more feature will be obtained, but less optimized. Meanwhile, the smaller the size of the array, the lesser the fingerprint feature will be obtained. Furthermore, based on the results from the LabVIEW, the arrangement for a smaller sized capacitive arrangement was used but the image obtained was not relevant as a reference or classified according to predefined classes. A larger capacitive arrangement is more relevant. As a conclusion, this work will assist the MEMS designer for the fingerprint sensor to optimize the grid size of a capacitive array.

V. ACKNOWLEDGEMENT

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