Automated Fingerprint Identification System based on Sectorized Complex Walsh Plane

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ABSTRACT
Most of the current security and attendance systems are shifting towards automated biometric systems, the most popular biometrics being fingerprints. In Automated Fingerprint Identification Systems (AFIS), the fingerprint of an individual needs to be identified with that stored in the database. In this paper, a method which deals with fingerprint identification in the transform domain is considered and the main focus is on the reduction of the processing time. First, the mean of rows (or columns) of the fingerprint image is computed, this converts a two dimensional image signal into one dimension. The one-dimensional Walsh transform of the row (or column) vector is generated and is distributed in a complex plane which is subjected to sectorization to generate the feature vector. The feature vector of a given test image is compared to those present in the database. The scores from row and column transform methods are fused using OR and MAX functions. The results with accuracy of more than 73% (for 16 sectors) and high computational speed show that the method can be used in fingerprint identification in application with requirements of less processing time.

General Terms
Biometrics, Image Processing

Keywords
Fingerprint identification; Walsh transform; row and column mean vector; sectorization; complex plane.

1. INTRODUCTION
Conventionally, verified users have gained access to secure information systems, buildings, or equipment through multiple means: PINs, passwords, smart cards, and so on. However, these security methods have significant vulnerabilities: they can be lost, stolen, or forgotten. In recent years, there has been an increasing use of biometrics, which refers to personal biological or behavioural characteristics used for verification or identification[1]. Biometrics refers to authentication techniques that rely on measurable physiological and individual characteristics that can be automatically verified.. Automatic fingerprint recognition technology has now rapidly grown beyond forensic applications into civilian applications. In fact, fingerprint-based biometric systems are so popular that they have almost become the synonym for biometric systems [2].

Biometrics has three broad uses –

- Verification, i.e. confirming another identifier such as a password, PIN or photograph
- Identification, providing a discrete identifier (or identifiers) that are independent of what the individual knows/remembers (e.g. a password) or what the individual carries (e.g. an identity document or card)
- Screening, enabling surveillance and sorting of groups of people (e.g. . finding a person in a crowd or selecting travellers for detailed examination of passports).

The AFIS are minutiae-based, image-based or textured-based systems [5][6][9][12]. In the first type, the minutiae [11], generally ridge-endings, ridge-bifurcations etc are extracted which form the feature vector (set of features). In these systems the size of feature vector is very small as only the type and location of the minutiae is to be stored. But these types of systems have large requirements of pre-processing of image which include image denoising and enhancement [4]. Image-based representations, constituted by raw pixel intensity information, are prevalent among the recognition systems using optical matching and correlation-based matching. However, the utility of the systems using such representation schemes may be limited due to factors such as brightness variations, image quality variations, scars, and large global distortions present in the fingerprint image. Furthermore, an image-based representation requires a considerable amount of storage.

In this paper, a texture-based fingerprint matching method is explained in which features of a fingerprint are extracted in transform domain[7][8]. The Walsh transform of a fingerprint generates a pattern of sequency distribution described in detail in section 2. The sectorization of complex plane representation of Walsh transform coefficients of the fingerprint image is computed and features are generated for each sector. This method has the advantage over both the above methods; in that it has smaller size of feature vector as well it doesn't need any pre-processing. The added advantage of this method is that the computation time is reduced processing time.

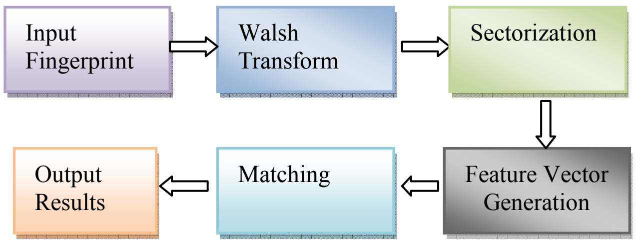

Fig 1: Flow diagram of Fingerprint Matching Method

Figure 1 explains the flow of the method used in this paper. The input fingerprint is transformed into sequency domain using Walsh transform. After sectorization feature vectors are generated and they are matched with those of stored fingerprints. Matching gives the output which is the best match.

The rest of the paper is structured as follows. Section 2 describes the Walsh transform technique. Section 3 explains the proposed sectorization method. Section 4 explains how two methods based on row-mean vector and column-mean vector have been fused to obtain better accuracy. The experimental results are given in section 5. Finally, conclusions are given in section 6.

2. WALSH FUNCTIONS AND TRANSFORM

In this paper we have used Walsh transform which is a powerful tool of linear system analysis for discrete signals [3]. Images are discrete functions of two dimensions, when acquired by digital acquisition devices. Hence Walsh transform can be aptly used on images to generate coefficients in frequency domain. The Figure 2 shows the Walsh functions for N=8.

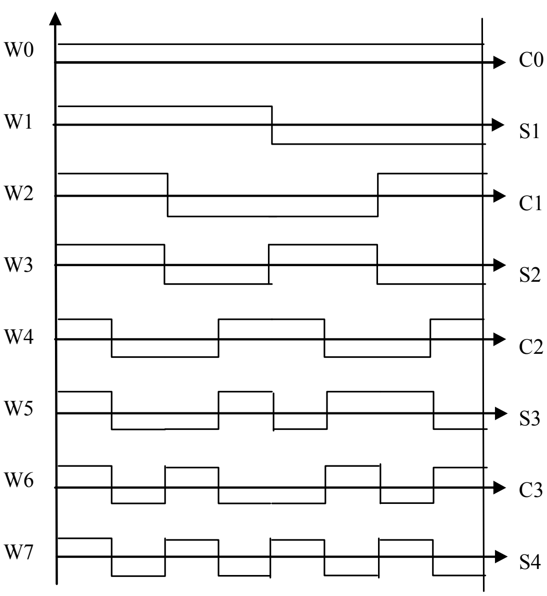

Fig 2: Walsh Functions

$$W = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & j & j & j & -j & -j & -j & -j \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & j & -j & -j & j & j & -j & -j \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -j & -j & j & -j & j & j & -j \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -j & j & -j & j & -j & j & -j \end{pmatrix} \qquad (1)$$

Here C_0 represents the coefficient of the DC component and S_n and C_n represent the sal and the cal (analogous to sine and cosine) coefficients of the n^{th} sequency (analogous to frequency) component. The Walsh functions[10] are generated by Walsh generator as shown in the Figure 5. First a DC signal C_0 is generated. This function (base function) is then used for the generation of all other Walsh functions. The odd signal S_1 is generated by time compressing C_0 (by half), shifting it (by time equal to that of compressed signal), inverting it and then adding time compressed and shfted signal as shown in Figure 3. The even signals C_1 is generated by time compressing S_1 (by half), shifting it (by time equal to that of compressed signal), inverting it and then adding time compressed and inverted signal as shown in Figure 4. The other even and odd functions are generated by the same procedure as mentioned above except that the base signal is its previous even or odd function respectively as shown in Figure 5.

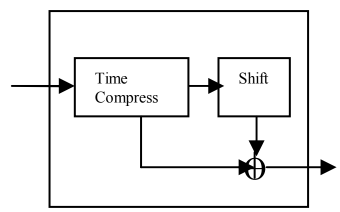

Fig 3: Time Compress and Shift (TCS) Module

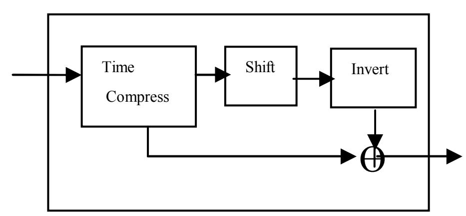

Fig 4: Time Compress, Shift and Invert (TCSI) Module

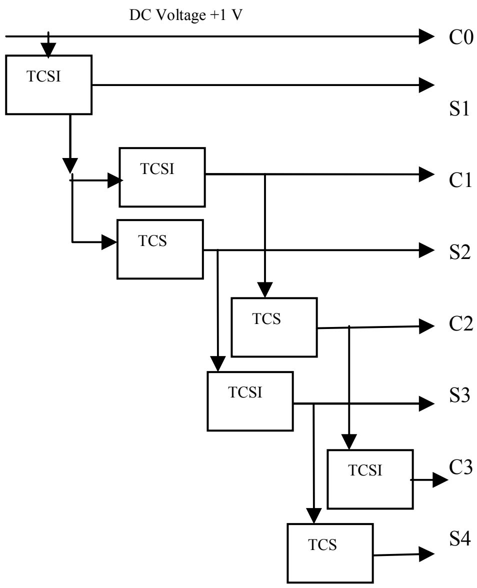

Fig 5: Walsh Generator

The Walsh transform can then be represented by a matrix as shown in equation (1) which is generated by sampling the Walsh functions at the middle of the smallest time interval. The samples of the sal functions are multiplied by j to convert them into imaginary part of the complex Walsh Transform. The Walsh transform F(u) of a one dimensional discrete signal f(x) is calculated by (2).

$$F(u) = W f' \qquad (2)$$

where f' is the column representation of row vector form of discrete signal f(x). The first value in F(u) represents the DC component, and the next ones the higher sequency components. Now, since images are two dimensional the Walsh transform of an image is generated by two step method. First transform of each row vector is calculated and then the transform of each column vector of the output of first step is calculated to get the final Walsh transformed image.

Alternatively, the 2-D Walsh transform can be calculated by equation (3) where W and W′ (transpose of Walsh matrix) are same, W being symmetric.

$$F(u,v) = (W f(x,y) W') / N \qquad (3)$$

This two step method is very computation intensive and hence in this paper we have used a method to reduce the processing time. The Walsh transform is computed on two sets of vector: one is a row vector generated by calculating the mean of each column of the image matrix and the other is the column vector generated by calculating the mean of each row of the image matrix as shown in the Figure 6.

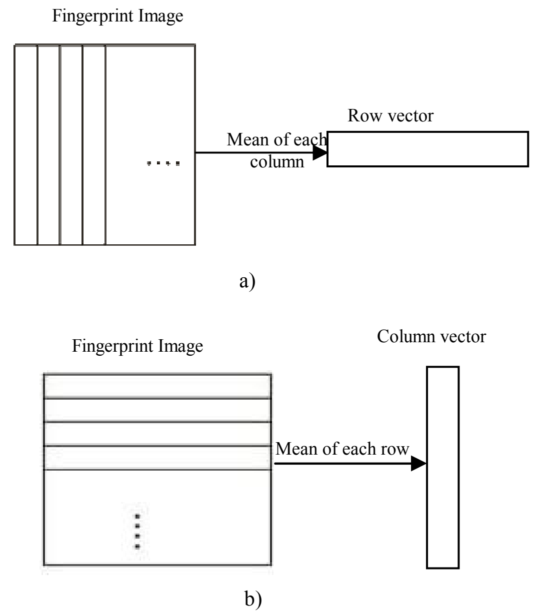

Fig 6: a) Mean of columns b) Mean of rows of the fingerprint image

The Walsh transform of the row-mean vector is calculated by taking its transpose and that of the column-mean vector is calculated directly [13]. This method takes less processing time as row-mean and column-mean vectors are 1-D vectors and Walsh transform of 2 1-D vectors each of size N need 2NlogN additions whereas that of one 2-D vector (entire image) will need $2N^2\log N$ additions. Hence there is improvement in the processing time by 1/N for this method, though the accuracy is compromised to some extent.

The cal and the sal components of the same sequency are grouped together and are considered to be in the four quadrants of 2-D complex co-ordinate plane as shown in Figure 7. This complex plane is now sectorized into different numbers of sectors.

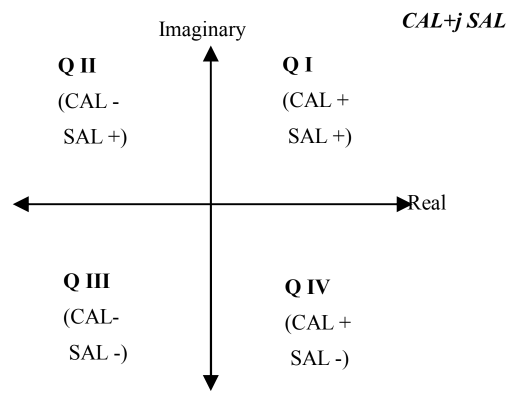

Fig 7: Complex Walsh Plane

3. SECTORIZATION

The complex plane consisting of same-sequency (sal, cal) components is now sectorized into 4, 8 and 12 radial sectors[14]. A feature vector is generated for each sector, which is the mean value of all the transform coefficients in that sector. This value is unique for each fingerprint as the sequency distribution of each fingerprint is unique in different sectors[15][16]. As compared to all or those transform coefficients which contain major part of signal energy feature vectors generated using sectorization are much less in number and hence the reduction in processing time and complexity. The division of the complex 2D plane into various sectors is based on the criteria as shown in the tables (Tables 1, 2, 3 and 4). Here, first the complex plane is divided into 4 sectors, the division being same as those of the quadrants of a plane as shown in Figure 7. For more number of sectors i.e. 8 and 12, the 4-sector plane is considered as the basic entity and the criteria shown in the respective tables are applied for sectorization.

Table 1. Four Sectors

Sectors	Locations
I	Top right quadrant (QI)
II	Top left quadrant (QII)
III	Bottom left quadrant (QIII)
IV	Bottom right quadrant (QIV)

Table 2. Eight Sectors

Sectors	Criteria
I, IV, VI and VII	If x < y
II, III, V and VIII	If x >= y

Table 3. Twelve Sectors

Sectors	Criteria
I, VI, VII and XII	If x < ytan(π/6)
II, V, VIII and XI	If x>= ytan(π /6)) and (x <ytan(π /3)
III, IV, IX and X	If x>= ytan(π /3)

Table 4. Sixteen Sectors

Sectors	Criteria
I, VIII, IX and XVI	If x < ytan(π/8)
II, VII, X and XV	If x>= ytan(π /8)) and (x <ytan(π /4)
III, VI, XI and XIV	If x>= ytan(π /4)) and (x <ytan(3π /8)
IV, V, XII, XIII	If x>= ytan(3π /8)

The sectors generated are radial and the mean values of the transform coefficients in each sector are calculated as in equation (4), where Mk is the mean and N is the number of coefficients in a sector, which form the features. The DC component, separate means of the sal and cal component and the last sequency component together form the feature vector, and hence the number of features is 2S+2, where S is the number of sectors.

$$M_k = \frac{1}{N} \sum_{i=1}^{N} W_i \tag{4}$$

The sectorization of both row mean transform and column mean transform vectors is performed and feature vectors for both are generated.

4. FUSION

The features obtained from the test image are compared with those obtained from the stored fingerprint in the database, for which the Euclidian distances and absolute distances between the two are calculated and the results matched. The minimum distance gives the best match. The results obtained from both the methods (row mean transform and column mean transform) are then fused together by using OR function to calculate the accuracy in terms of the first position matching and MAX function in terms of total number of matches obtained in the first 7 matches (there are total 8 samples of each fingerprint and one of those is taken as test image). Larger is the number of sectors better is the accuracy obtained in fingerprint identification.

5. EXPERIMENTAL RESULTS

The fingerprint image database used in this experiment consists of 168 fingerprint images of 500 dpi and size 256×256 pixels including 8 images per finger from 21 individuals. The set of fingerprints are obtained with rotational (+/- 15^o) and shift (horizontal and vertical) variations. The algorithm compared the feature vectors of the test image with those in database and the first 7 matched were recorded. Two measures to indicate the performance of the system have been considered. The average number of matches in the first 7 matches gives a good indication of accuracy. The second measure evaluated was whether the first match belonged to the same fingerprint or not. The results shown in Table 5 and 6 are of randomly selected 3 samples of each fingerprint and it has been observed that for 8 sectors the results more accurate than for 4 or 12 sectors as shown in Figure 8 and 9. We have applied the proposed technique on the database images and results in each category show that our method can satisfactorily identify the fingerprint images with the advantage of reduced computational time. Matching done using absolute distance vis-à-vis Euclidean distance show that the results are almost similar for both, whereas absolute distance method helps in further reduction in computation time as number of multiplications are eliminated. The accuracy rate observed is 73% for 16 sectors with processing time reduced by as much as 1/256 of that of full image methods.

Table 5. Average Number of Matches

Sectors	Using Euclidean distance	Using absolute distance
4	2.05	1.825
8	2.29	2.05
12	2.16	2.00
16	2.635	2.54

Table 6. Percentage Accuracy

Sectors	Using Euclidean distance	Using absolute distance
4	58.73 %	60.32%
8	66.67 %	66.67%
12	63.50 %	63.50%
16	73.02%	72.03%

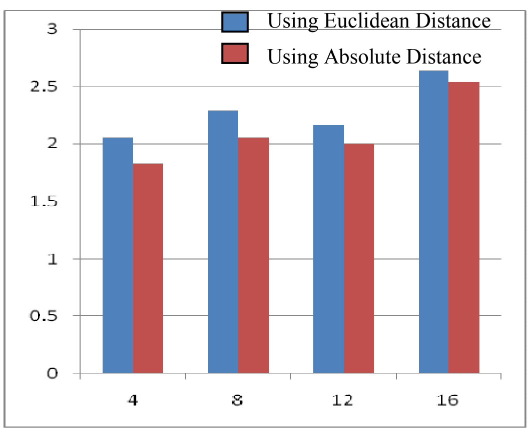

Fig 8: Average number of matches in the first 8 matches for different sectors

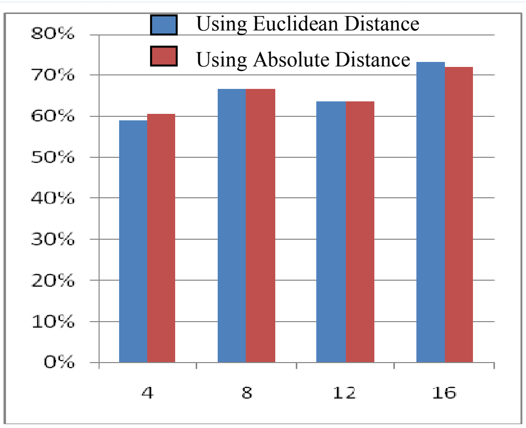

Fig 9: Accuracy obtained for different sectors

6. CONCLUSION

In this paper, a fast and unique method for fingerprint identification is described. Walsh Transform is applied to the row and column means of fingerprint image. Sectorization of the complex plane in which the Walsh coefficients are projected generates the feature vector and matching is done using the same. This method is computationally very simple and fast as it is based on 1-D transform rather than 2-D transform. It is also considerably independent of shift and rotation of fingerprint images. Experimental results show that our proposed simple yet effective method can be used for fingerprint identification where high speed processing is given priority over accuracy.

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