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FINGERPRINTS PREPROCESSING USING WALSH FUNCTIONS

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Abstract: *Minutiae classification and fingerprint classification in fingerprint evaluating process are very important. Fingerprint image contains about 150 minutiae's. When we compare two fingerprint images, we compare latent and non latent fingerprint and we try to find 12 minutiae's placed on the same position on latent and non latent fingerprint images. After fingerprint image pre-processing we can perform classification or we can try to find minutiae. In this paper we describe the process of minutiae classification for comparison purposes. For that purpose we use Walsh function and Walsh transforms. Paper describes minutiae classification which is relatively new in recognition systems and gives contribution for development of practical fingerprint recognition systems. Paper also gives contribution in the theoretical part due to the fact that Walsh functions were not implemented in fingerprint pre-processing systems so far. The new symbolic database model for fingerprint storage gives multifunctional foundations for future research.*

Keywords: *Fingerprint, minutiae, Walsh transform, classification.*

1. INTRODUCTION

Positive person recognition and verification are important in our fast-moving, modern society with the infrastructure of airline travel and broadband networks. Conventional identification methods such as driver's license, passport, ATM cards and PIN codes do not meet the demands of this wide-scale connectivity. Automated biometrics in general, and automated fingerprint authentication in particular, provide efficient solutions to these modern identification problems. Fingerprints have been used for many centuries as a means of identifying people. The fingerprints of individual are unique and are stay unchanged during the life time. In the past fingerprint recognition was performed manually by professional experts. But this task has become more difficult and time consuming, particularly in the case where a very large number of fingerprints are involved [7].

Experimental researches of pictures in the field of fingerprints mostly deal with recognition and identification of fingerprints pictures [9, 10, 15]. Using fingerprints in biometric detection process in civil or police application is of great importance. Fingerprint images which have been used in recognition process contain too many data. In order to ensure faster fingerprint recognition process we try to classify minutiae in one of four predefined classes. In that way fingerprint recognition process becomes more reliable and faster. The chronological approach to fingerprint minutiae extraction is more or less the state of the art. It is simply bottom up process. Not much attention is given to modelling the image formation process or to modelling the object that is imaged. One aspect of modelling a fingerprint is modelling the minutiae.

2. MINUTIAE

Experimental researches of pictures in field of fingerprints mostly deal with the recognition and identification of fingerprints pictures as has been already mentioned. This approach has very good rate of accuracy, but in practice we haven't found a system which operates in that way. A reason for that lies in speed of fingerprint pictures retrieval in the database [4]. Specification and structure of a fingerprint is very well known and described, but in practice these results aren't still used at a satisfactory level. One can find several different types of minutiae's classification structures, consisting from three up to ten classes [12]. The major problem within the fingerprint classification system is in unique fingerprint development process; the extraction of fingerprints may cause serious problems. If we take, for the basic database classification purposes, a structure based on three classes, it can happen that the final result is not at the satisfactory level because classes are too big and contain too many data. On the other side databases based on ten classes will be still large, but the data distribution within these classes inside the database may not be equal. So we will present and use a partial solution of the classification system problem. We can say that not much work has been carried out in minutiae classification field and on the other hand a lot has been done in fingerprints classification and minutiae findings [14].

The problem of fingerprint identification is in fact problem of detecting whether some part of presenting fingerprint pictures belongs to the set of fingerprint pictures which we want to find. The problem is system stability; we can partly tolerate incorrect detection of fingerprint picture because a fake fingerprint will not pass through recognition process, until incorrect recognition is very serious problem [13].

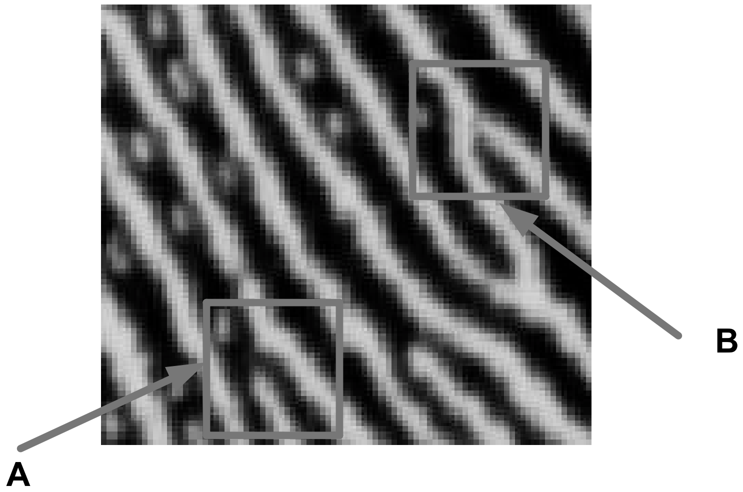

Figure 1. Ridge endings A (ridge bifurcation) B (ridge ending)

Fingerprint expertise is doing by compare of latent fingerprint with fingerprint of familiar person, or to compare identical ridge lines of latent and known fingerprints image. When we said that the two fingerprints pictures are identical that means that they have identical basic ridge shapes, same class and same anatomic characteristic called minutiae [15]. If two fingerprints belong to the same category and have a sufficient of minutiae details that are identical, then it can be concluded confidently that they are from the same finger. Figure 1 presents minutia ending and minutiae bifurcation. In order to determine that two fingerprints are form the same finger, four factors must be evaluated: a. general pattern configuration agreement which means that two fingerprints must be on the same pattern configuration, b. qualitative concordance which requires that the corresponding minutia details must be identical, c. quantitative factor which specifies that at least a certain numbers (minimum 12 according the Croatian Police) of corresponding minutia details must be found, and d. relationship of minutia details which specifies the corresponding minutia details must be interrelated. Some of basic characteristic of minutia are (present on figure 2):

1. Pre-defined classes of minutiae: minutiae termination, minutiae bifurcation, minutiae spur, minutiae dot, minutiae lake, minutiae crossover.
2. minutiae orientation,
3. minutiae frequency, and
4. minutiae coordinates.

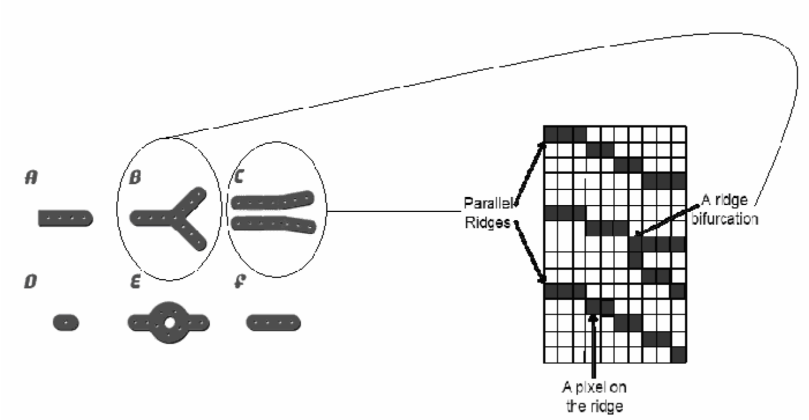

Figure 2. Minutia classes and minutiae example (B represents ridge bifurcation; C represents parallel ridges)

The analysis of the static and dynamic pictures with digital techniques uses the manipulation multidimensional signals which are implemented using large numbers of operations on large amount of data. Because these processes require significant hardware resources and large time of computation, many efforts have been performed in order to find effective problem solution. Combination of Walsh functions together with fast computing plays an important role in the field of picture analysis research. Walsh functions are very simple and adaptable functions and can be transformed to other transform techniques (like Fourier, Hadamar etc.), and are the right choice in the field of digital techniques for pictures processing.

For minutiae extraction we have used a mathematical tool which can be easily implemented (hardware implementation). Direct implementation of software in hardware components requires Boolean operator level of software. For that reason we have chosen Walsh functions as the best mathematical tool for minutiae extraction. Walsh functions are excellent choice because they can produce two values as on output: +/- 1, and function description is not so complex.

3. FINGERPRINT

Large volumes of fingerprints are collected and stored everyday in a wide range of applications, including forensics, access control, and driver license registration. Automatic identity recognition based on fingerprints requires that the input fingerprint is matched with some picture(s) from a large number of fingerprints stored in a database. To reduce the search time and computational complexity, it is desirable to classify these fingerprints in an accurate and consistent manner such that the input fingerprint needs to be matched only with a subset of the fingerprints in the database. Fingerprint classification is a technique used to assign a fingerprint into one of the several pre-specified types already established in the literature which can provide an indexing mechanism. An input fingerprint is first matched to one of the pre-specified types and then it is compared to a subset of the database corresponding to that fingerprint type. To increase the search efficiency, the fingerprint classification algorithm can classify a fingerprint into more than one class. Classification of fingerprints is also very attractive for indexing where fingerprints are not partitioned in non-overlapping classes, but each fingerprint is characterized with a numerical vector summarizing its main features. In this paper, we have concentrated on an exclusive fingerprint classification and we have classified fingerprints into five distinct classes, namely, whorl (W), right loop (R), left loop (L), arch (A), and tented arch (T). The five classes are chosen based on the classes identified by the National Institute of Standards and Technology (NIST) to benchmark automatic fingerprint classification algorithms. The natural proportion of occurrence of these five major classes of fingerprints is 0:3252, 0:3648, 0:1703, 0:0616, and 0:0779 for whorl, right loop, left loop, arch, and tented arch, respectively.

Major problem in fingerprint classification process are depicted in previous chapter, and we can say that minutiae classification and fingerprint classification are based upon the same principle.

4. WALSH FUNCTIONS

Traditional Fourier series and transforms have been used to represent large classes of functions by superpositioning sine and cosine function. Walsh functions have been used for analyzing various natural events. Much of information is belong to such events in the form of signals which are function of time. The Walsh functions form an ordered set of rectangular waveforms taking only two amplitude values +1 and –1, [5], [6]. We are using Walsh functions rather then the other ones because we have been used Walsh function in previous research and for that purpose we develop system for fingerprint classification based on Walsh function. We can't positively say that the Walsh functions better then those other functions which have been used in digital image processing, but in every case they personate novelty. Complete definition of Walsh functions required two arguments: a time period t and an ordering number n related to frequency. The function is written:

$$WAL(n,t),\ \mathrm{n} = 0,1,...,\mathrm{N}\text{-}1. \qquad (1)$$

where t is time period (usually normalised to the time base as t/T) and n is ordering number related to frequency.

If the expression for the discrete Walsh function which have N=2p terms stated in terms of continued product like1

$$WAL(n_{p-1},n_{p-2},..n_0;t_{p-1},t_{p-2},...t_0)=\prod_{r=0}^{p-1}(-1)^{n_{p-1-r}(t_r+t_{r+1})} \qquad (2)$$

where n and t are the arguments of the function expressed in binary notation.

[1] In this expression *n* and *t* are the arguments of the function expressed in binary notation.

4.1. TWO-DIMENSIONAL TRANSFORMATION

When we deal whit image processing the sampled image is available as an N x N array of discrete values. The two-dimensional Walsh of two-dimensional array xi,j of N2 values is given by [4], [10]

$$X_{m,n} = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} x_{i,j} WAL(m,j) \qquad (9)$$

And the inverse transformation by

$$x_{i,j} = \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} X_{m,n} WAL(n,i) WAL(m,j) \qquad (10)$$

Process of transformation may be carried out in two steps, first transformation for the variable i

$$X_{m,j} = \sum_{i=0}^{N-1} x_{i,j} WAL(n,i) \qquad (11)$$

and after that for variable j

$$X_{m,n} = \sum_{j=0}^{N-1} x_{m,j} WAL(m,j) \qquad (12)$$

For our work we used two dimensional Walsh transform described in [3],[4].

5. MINUTIAE EXTRACTION ALGORITHM

Minutiae extraction algorithm is very complex set of processes which usually takes the following stages [2]:

- Orientation field estimation,
- Ridge extracting, and
- Minutiae extraction and post processing.

The overall scheme of this algorithm is depicted in Figure 2. On the input image the local ridge orientation is estimated and a region of interest is located [11]. After that, the ridges are extracted from the input image, refined, and thinned in order to obtain eight connected single pixel wide ridges [8], which are depicted in Figure 3. And finally, minutiae is extracted from the thinned ridges and refined using some heuristic. For the purpose of this paper we have developed an application for minutiae extraction based on Walsh functions which is depicted on figure 4. In the first step we transform fingerprint image into a 64x64 square matrix (we used this form because we decided to follow 8x8 arrays in 8 multiplications). Then we use Walsh transforms on this array in order to detect the major points (these points have value more then 0,75 in absolute expression[2]) which are in fact minutiae. After that, we have extracted minutiae and put them in the array to repeat the whole process, and perform minutiae classification.

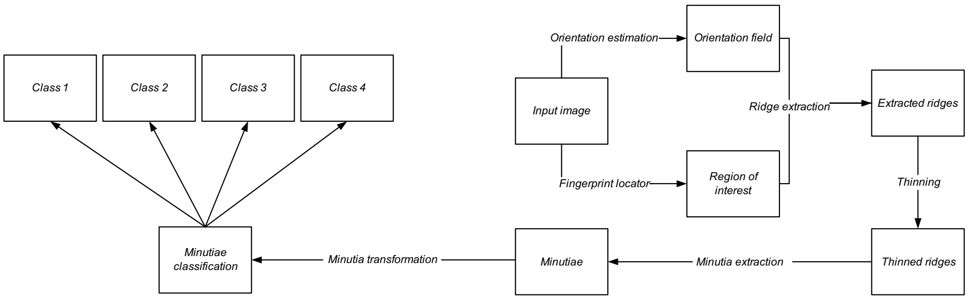

Figure 3. Flowchart of the minutiae extraction and classification algorithm

It is important to notice that we don't make any changes on input fingerprint image. We have used an original picture, and performed all processing operations on that input. For that purpose we used minutiae detection algorithm described in IIS'04.

For experimental purpose we developed minutiae database with four classes. First class is minutiae bifurcation, second is minutiae lake, third is parallel ridge and last is minutiae termination. Each of these classes possesses 50 pictures generated by computer and rotated in four positions. In that way we get 200 minutiae in four positions (0O, 45O, 90O, 135O) which means 800 pictures. Every picture is saved in bitmap format and has between 13 KB and 25 KB.

The post processing step further refines the extracted minutiae. Walsh transforms are mathematically tool which is very simplified for practical approach in the field of digital image processing, because it uses just basic arithmetic operations. Every fingerprint image differs from another, so two-dimensional Walsh transform have given as a result different numerical values for every image [3].

5.1. CLASSIFICATION AND RESULTS

In the classification process we put two-dimensional minutiae picture into Walsh transform application and get the classification result (Figure 4). As can be seen, minutiae pictures have been classified in four classes. Major problem in the classification process represents the fact that ridge bifurcation class and parallel ridge class are covered in one part, minutia lake class and minutia termination class have been covered in one part and parallel ridge class and minutia lake class and minutiae termination class have been covered in one part too. So, as we can see, only ridge bifurcation class has not been covered with minutia lake class and minutia termination class. The experimental results show that minutia classes can be used in the field of fingerprint processing. The results also show that the class

[2] The value of minutiae points we get in experimental way. We used values form 0 to 5 in absolute expression. Valuse more then 1 giving us to many minutiae points, but valuse less then 0,5 are give to few minutiae points.

parallel ridge must be thrown out from class types because it is mostly covered with other classes.

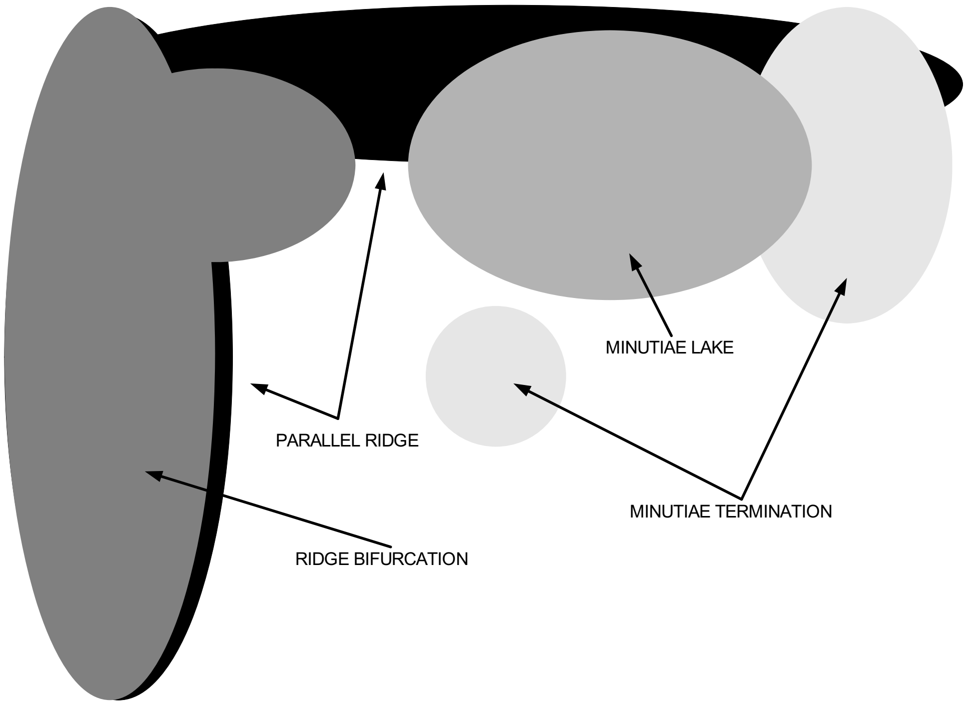

Figure 4. Classification result in minutiae classification process

6. FINGERPRINTS CLASSIFICATION SCHEME

The proposed fingerprint classification scheme is based on direct implementation of Walsh functions. Uniqueness of this classification scheme is the number of pre-defined classes. Because the classification scheme must satisfy only the conditions which fingerprint image must satisfy too, for classification process we need only three classes. Detection scheme and classification are based on uniqueness of Walsh transform for every feature. For every fingerprint class we build a set of features which are compared with Walsh transformed image to enable the classification. To avoid influence of spectral compression which appears in most fingerprint images, we have used simplified tests. These tests give only small number of Walsh coefficients which contain significant values. For significant coefficients for fingerprint images with Walsh transform we have used $\geq |0{,}85|$ (experimentaly given). For fingerprint classification process we have used values of sumarized rows and colums. After that it is possible to develop clasification template for every fingerptint class (shown in Figure 5.)

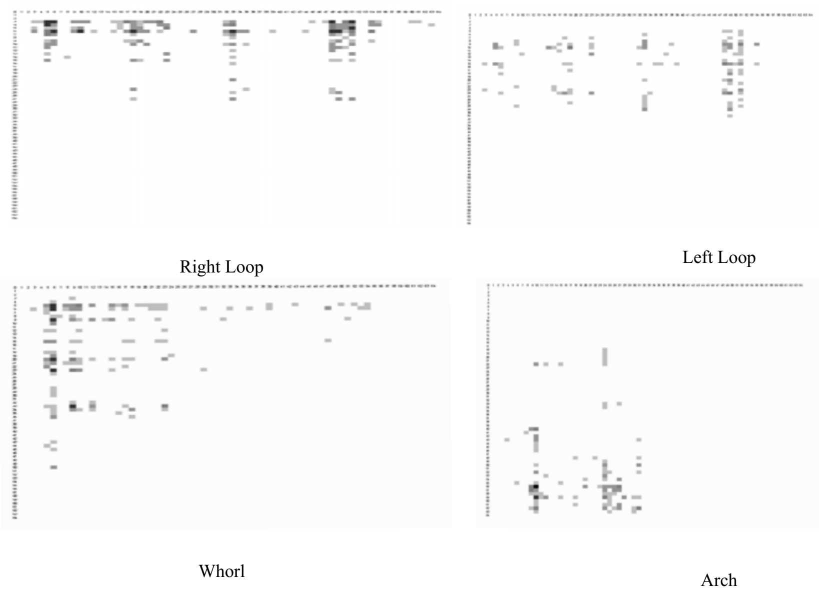

Figure 5. Four fingerprint templates develop wit Walsh transform

As we can see in Figure 5. right loop class and left loop class cover one another. So it is logical to observe these two classes like one. Lost of one class has no influence on final result because we can use negative classification and try to find the fingerprint candidate for these class.

6.1. CLASSIFICATION AND RESULTS

For testing depicted classification scheme we used three databases. In the first test every from 504 test fingerprint images from the database was compared with some in advance defined fingerprint classes. Comparison was correct if tested picture belongs to the requested class. Results are shown in table 1. (left). Proportion testing shows next results: arch-arch (80,92 %) is statistically less significant then loop-loop (92,09 %; $Z=3,3$ $p<0,001$), also arch-arch is statistically less significant then whorl-whorl (88,73 %; $Z=1,8$ $p<0,05$), there is no statistical significance between loop-loop and whorl-whorl ($Z=1,1$ n.s.). In the second test we have used two databases (test database + learning database). We have used 1512 fingerprint images and we compared it with the ones of classes. Comparison was correct if tested picture belonged to the requested class. Results are shown in table 1 (right). Proportion testing shows next results: there is no significant differences between loop-loop (91,88 %) and arch-arch (94,00 %, $Z=1,37$ n.s.), there is no significant differences between loop-loop and whorl-whorl (94,01%, $Z=1,18$ n.s.), and there is no significant differences between arch-arch and whorl-whorl ($Z=0,01$ n.s.). In the last test we have used only learning database and comparison results were more then 95 %. Analyses of given results lead us to the next conclusion: the best results were given by testing a learning database. When we test fingerprint database (images are not in learning database) some deviation, especially in class arch, exists. This is because images from class arch are overlapped with some other classes.

Table 1. Comparison result for first (testing) database (left) and second (testing & learning) database (right)

True class	Tested class		
	Arch	Loop	Whorl
Arch	**80,92**	2,88	4,93
Loop	7,63	**92,09**	6,34
Whorl	11,45	5,04	**88,73**
Total	100	100	100

True class	Tested class		
	Arch	Loop	Whorl
Arch	**91,88**	1,02	2,00
Loop	2,54	**94,00**	3,99
Whorl	5,58	4,98	**94,01**
Total	100	100	100

7. THE DATABASE

Databases which store pictures of fingerprints are very complex and contain large amount of data which make them hard to explore. This problem can be solved by implementing symbols within the database which represent pictures of fingerprints. Database building starts with the process of class definition. For the purposes of our work, we have chosen five classes of fingerprint image: whorl, arch, tented arch, left loop and right loop. In that way we get the optimum number of classes with relatively good distribution between them. So our developed database consists of extracted minutiae fingerprint pictures placed in one out of five pre-defined classes. A big problem in the database development process is the amount of data. Fingerprint pictures must contain information about minutia (number and types) and class of the fingerprint. So, database contains from minimum 15 to maximum 300 records (minutiae) per fingerprint. In Croatian law 12 minutia's represents the minimum number for positive person identification, one data is type of minutiae and other data is fingerprint class. For example, database which contains pictures of ten fingers belonging to one person will contain at least 150 and maximum 3000 records. In order to describe the types of minutiae, Walsh transform is used. Walsh transform can give us only five types of minutiae, so that is the reason for developing a database in five minutiae base concept. Minutia types in database are: *(|) for dot; (/) for bifurcation; (\) for termination; (-) for spur; and (X) for crossover*. As you can see on figure 3 and figure 4, Walsh transforms give the graphical output (based on maximum absolute values in array). We used that output and transformed it into predefined minutiae class, based on a symbolic form. Final result is a symbolic database form for fingerprint image consisting only of predefined symbols.

7.1. DATABASE RETRIEVAL

Data retrieval from the database has three steps. In the first step we must transform latent fingerprint into digital form and perform the pre-processing in order to detect appropriate class and minutiae. In the second step we must detect minutiae's types. In the final step the retrieved data is compared to fingerprint class, minimum of 12 minutiae and their types. Final result is a fingerprint picture which must contain true fingerprint class, precisely 12 minutiae in the same fingerprint position and for every minutiae the same type. In that way we get numerous data about fingerprints, and the retrieval process is quicker because we are looking for the fingerprint class and after that we try to locate and compare minutiae in a symbolic way. If a latent fingerprint exists in the database (fingerprint which hasn't been classified yet), the retrieval process will mark only the types of minutiae which are placed in the same array position.

8. CONCLUSION

Minutiae classification finds classification features, called minutiae, from the input fingerprint images. A minutiae extraction algorithm should be reliable as well as computationally efficient. A poor fingerprint image can be either rejected or enhanced prior to the minutiae extraction. A good minutiae extraction algorithm should be able to tolerate, to a limited extent, the corrupted ridge structures and degrade gracefully with the image quality. The developed minutiae extraction algorithm based on Walsh transforms is fast and reliable in minutiae extraction process.

Major problem which we tried to solve is the minutiae classification without human help. Our solution is based on the implementation of Walsh functions in the image pre-processing phase. In that way the input picture is transformed into a symbolic fingerprint form which is stored in binary form. The results of Walsh transforms application form give us very good base for the future exploration. Using Walsh functions for minutiae classification and implementing them directly within hardware led us to the conclusion that the general system characteristic (for fingerprint minutiae extraction) could be significantly improved. Developed and described model for fingerprint classification has very good performances. Yielded results give us the base to expand our research in improvement minutiae classification process. The retrieval process in symbolic fingerprints database is much easier and quicker than the graphical way of searching. Future exploration will be directed towards employing agents in the process of image pre-processing and data retrieval and building a multimodal biometric system based upon these results.

This paper shows that Walsh transforms can be used in the field of fingerprint minutiae classification, which was not done before. This paper also gives a basic template for developing an integral model for fingerprints recognition system based on Walsh functions.

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