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Fingerprint Matching Based on Dimension Reduced DCT Feature Vectors

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Abstract
In this work a Discrete Cosine Transform (DCT)-based feature dimensionality reduced approach for fingerprint matching is proposed. The DCT is applied on a small region around the core point of fingerprint image. The performance of our proposed method is evaluated on a small database of Bologna University and two large databases of FVC2000. A dimensionally reduced feature vector is formed using only approximately 19%, 7%, and 6% DCT coefficients for the three databases from Bologna University and FVC2000, respectively. We compared the results of our proposed method with the discrete wavelet transform (DWT) method, the rotated wavelet filters (RWFs) method, and a combination of DWT+RWF and DWT+(HL+LH) subbands of RWF. The proposed method reduces the false acceptance rate from approximately 18% to 4% on DB1 (Database of Bologna University), approximately 29% to 16% on DB2 (FVC2000), and approximately 26% to 17% on DB3 (FVC2000) over the DWT based feature extraction method.

Keywords
Biometric, Discrete Cosine Transform, Fingerprint Identification, Similarity Measure

1. Introduction

In real life, identity authentication is a general task that has many efficient applications, such as transaction authentication (i.e., for telephone banking or remote credit card purchases). Further advances in the field of security focus on biometric solution in order to get rid of Personal Identification Number (PIN) codes and cards, which can be stolen or lost. This is because biometric speech, face, fingerprints and ear prints cannot be stolen or lost. Fingerprint Identification is very essential for authenticating data integrity and security.

Fingerprints are graphical flow-like ridges found on human fingers [1]. They are used as one of the most popular biometrics due to their uniqueness and invariance with age. A number of automatic fingerprint matching techniques [2-5] have been proposed in the literature of fingerprint identification. Most of them are based on minutiae matching according to the common hypothesis that the individuality of fingerprints can be faithfully captured by minutiae and their spatial distributions [1]. The

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minutiae points of fingerprint image are the ridge ending and ridge bifurcation. To extract the genuine minutiae features the image quality should be good.

Another approach used for matching are the texture features of a fingerprint image. In this approach the texture features are extracted using the Gabor filter and wavelet transform [4,6-10]. The Gabor filter based approach gives better performance than wavelet transform based approach. Feature redundancy is more in Gabor filter based approach as Gabor basis functions are non-orthogonal. The wavelet based approach is computationally efficient as wavelet basis functions are orthogonal. However it reduces the accuracy as it captures features that are oriented at the vertical, horizontal and diagonal directions. Tachaphetpiboon and Amornraksa [11] proposed a discrete cosine transform (DCT)-based approach for fingerprint matching.

A key issue in Fingerprint Identification is designing a compact signature that contains significant information. Hence, we introduced a DCT based feature dimensionality reduced approach for fingerprint matching that gives better results than the DWT method, the rotated wavelet filters (RWF) method, and a combination of DWT+RWF and DWT+(HL+LH) subbands of the RWF based feature extraction method [12].

We have proposed a DCT based feature dimensionality reduced approach for fingerprint matching. We applied DCT to a small area around the core point of the fingerprint image. The performance of proposed method is evaluated on a small database (DB1) of Bologna University and two large databases (DB2 and DB3) of FVC2000. We only used approximately 19%, 7%, and 6% DCT coefficients of the DB1, DB2, and DB3 databases for feature extraction. The results of the proposed method are then compared with the Gabor filter, DWT, DWT+RWF, and the DWT+(HL+LH) subbands of the RWF based method. The proposed method reduces the false acceptance rate from approximately 18% to 4% on DB1, approximately 29% to 16% on DB2, and approximately 26% to 17% on DB3.

The rest of the paper is organized as follows: Section 2 elaborates on our proposed feature dimensionality reduced approach. Section 3 illustrates the experimental results. Conclusions are given in Section 4.

2. Proposed Approach

Fig. 1 shows the system architecture of our proposed fingerprint matching system that uses DCT. It consists of the functional blocks fingerprint image database, fingerprint image localization and DCT computation, estimation of the region of interest, feature computation, feature database, distance computation, and matching.

2.1 Fingerprint Image Database

We used three databases, DB1, DB2, and DB3, to evaluate the performance of our proposed method. DB1 is the fingerprint database available at Bologna University Cesena-Italy. It consists of 140 fingerprint images from 20 people with 7 impressions from each person. The images are 256×256 in size. DB2 is the FVC2000 db1_a, which is a database that consists of 800 fingerprint images. The images are 300×300 in size. DB3 is the FVC2000 db2_a, which is a database that consists of 800 fingerprint images from 100 people with 8 impressions from each person. The images are 364×256 in size.

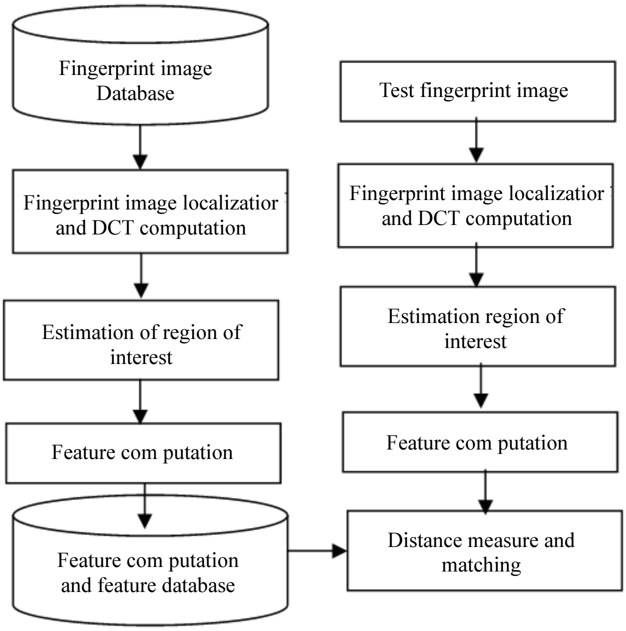
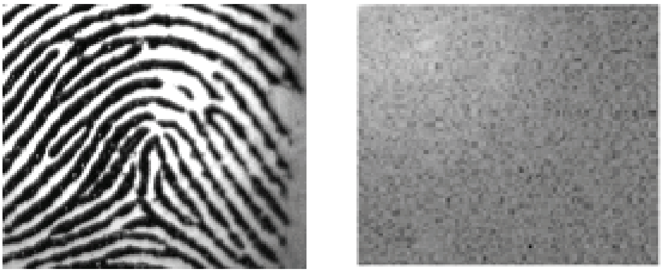


Fig. 1. System architecture of proposed method.

For the DB2 and DB3 databases it is not possible to extract a sufficient area around core point because these images are captured by small sized, low cost optical and capacitive sensors, respectively. For the DB2 database a 300×300 sized image is used for feature extraction by discarding 15 pixels from top-bottom and 15 pixels from left-right of the image, which carries the background information. For the DB2 database a 304×216 sized image is used for feature extraction by discarding 25 pixels from top-bottom and 10 pixels from left-right of the image, which carries the background information.

2.2 Fingerprint Image Localization and DCT Computation

The fingerprint image is localized around the core point, which is 128×128 in size [4,13]. We implemented our proposed method on the localized fingerprint that is 128×128 in size. The DCT is then applied to the localized fingerprint image. Fig. 2 shows the localized image and DCT of the localized image, respectively.



(a) (b)

Fig. 2. (a) Localized fingerprint image of size 128×128. (b) Discrete cosine transform of Fig. 1(a).

2.3 Estimation of the Region of Interest

Instead of using the 128×128 discrete cosine transformed fingerprint image for feature extraction, a small portion of the DCT transformed fingerprint image is used called the region of interest. The top right corner of the transformed image is brighter than the the top left, bottom right, and bottom left corners, as shown in Fig. 2(b). Pixels in the brighter region have a significant intensity value. Hence, the maximum energy is concentrated in the brighter region. Fig. 2(b) shows that most of the energy is concentrated at the top right corner, as compared to the rest regions of the DCT transformed image. We used the top right corner for computing the feature vector because the pixel values in the rest of the corners of the transformed image have an insignificant intensity value. The appropriate area at the top right corner of the transformed image is selected for feature vector computation, which is called the region of interest. The region of interest is computed by analyzing the five square portions at the top right corner of the transformed image in terms of FAR and GAR. These five square portions are 88×88, 64×64, 56×56, 48×48, and 40×40, respectively, as shown in Fig. 3. Our analysis of the five square portions, in terms of GAR and FAR, shows that the square portion that is 56×56 in size provides better performance on Bologna University's database.

Similarly, we extracted a square portion that is 72×72 in size with 7.11% DCT coefficients for the FVC2000 db1_a and a 64×72 sized square portion with 6.13% DCT coefficients for the FVC2000 db2_a database, as a region of interest.

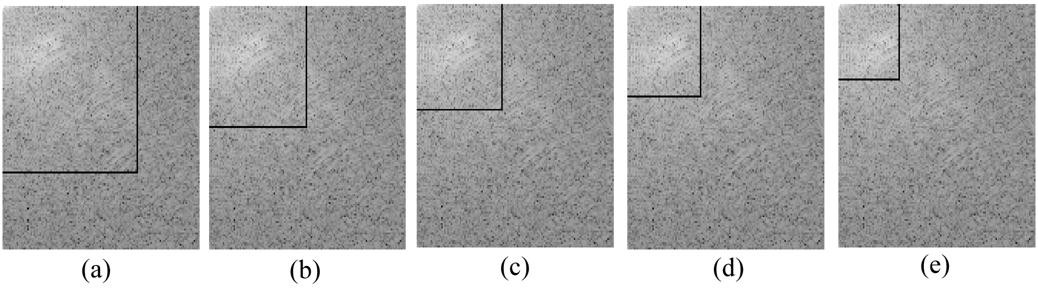


Fig. 3. Square portions of size (a) 88×88, (b) 64×64, (c) 56×56, (d) 48×48, and (e) 40×40.

2.4 Feature Computation and Feature Database

The features of database images and test fingerprint images are extracted by dividing the region of interest in 8×8 non-overlapping blocks. The standard deviation feature of each 8×8 block is computed to form a feature vector using Eq. (1). The features of the database images are computed and stored to form a feature database.

$$S = \sqrt{\frac{1}{N \times N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \left(b(i, j) - M\right)^2} \tag{1}$$

where $b(i, j)$ represents the pixel values of block, $N \times N$ is the size of block, S is the standard deviation of block and $M = \frac{1}{N \times N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} b(i, j)$. A dimension reduced feature vector is achieved by selecting a small area at the top right corner of the transformed image, which is called the region of interest. A dimension reduced feature vector is possible only because of the energy compaction property of DCT. The maximum energy at the top right corner of the transformed image proves the energy compaction property of DCT. The feature vector dimension of the existing Gabor filter based feature extraction method is 512 for the DB1 database. The feature vector dimension with the proposed DCT based feature extraction method is 49. A dimension of the feature vector is reduced by factor approximately 11 over the existing Gabor filter based method.

2.5 Distance Measure and Matching

The distance between the test images and database images are calculated to find the similarity between the test image and database images. The similarity is computed using a city block distance [14]. The P and Q are the features of the database image and test image, respectively. N is the length of the feature vector. The city block distance is given by Eq. (2). The distance of the test image is computed with the database images. Then, distances are arranged in ascending order. The value that is slightly greater than the mean of the top seven distances is considered to be the threshold.

$$d = \sum_{j=1}^{N} \left| P_j - Q_j \right| \tag{2}$$

3. Experimental Results

The performance of the proposed approach is measured in terms of GAR, FAR, FRR, and ROC and computational complexity in terms $O(n)$. The results of the proposed method are compared with DWT, DWT+RWF [12], and the Gabor filter based method. All of the results are conducted using MATLAB 7 on a Pentium IV machine.

3.1 Performance Measure Based on GAR, FAR, and FRR

The performance of the proposed method is evaluated in terms of GAR, FAR and FRR. All of the DCT coefficients are not used for feature extraction, because most of DCT coefficients have a negligible magnitude. DCT coefficients having a negligible magnitude are discarded. The top right corner of the transformed image shows the DCT coefficients that have a significant magnitude. Hence, the performance of a different percentage of DCT coefficients in the top right corner of the transformed image are evaluated to find the optimum percentage of DCT coefficients. GAR, FAR, and FRR are the parameters used to evaluate the performance of the different percentage of DCT coefficients. Table 1 shows the comparison of the percentage DCT coefficients used for feature extraction. The optimum percentage of DCT coefficients consist of a small area at the top right corner of a transformed image with a fewer number of DCT coefficients. Reduced feature dimensionality is achieved by using DCT coefficients with a significant magnitude for feature extraction. Approximately, 19%, 7%, and 6% of the DCT coefficients with square portions of size 56×56, 72×72, and 64×72 provided a better performance on the DB1, DB2, and DB3 databases, respectively. Hence, these square portions of 56×56, 72×72, and 64×72 are considered to be a region of interest for the DCT based feature extraction method.

Approximately, 19%, 7%, and 6% of the DCT coefficients are the optimum percentage of the DCT coefficients. The FRR, FAR, and GAR are given in Eqs. (3), (4), and (5), respectively.

$$FRR = \frac{\text{True claims rejected}}{\text{Total true claims}} \times 100 \tag{3}$$

$$FAR = \frac{\text{Imposter claims accepted}}{\text{Total imposter claims}} \times 100 \tag{4}$$

$$GAR = (1 - FRR) \times 100 \tag{5}$$

Table 1. Comparison of % DCT coefficients used for feature extraction in terms of average GAR, FAR and FRR on DB1, DB2 and DB3

Database	Percentage DCT coefficients	GAR (%)	FAR (%)	FRR (%)
DB1	47.27	94.08	3.131	5.91
	25.00	94.38	3.93	5.61
	19.14	**94.18**	**3.94**	**5.81**
	14.06	94.28	6.09	5.71
	9.77	94.18	8.15	5.81
DB2	10.62	90.04	12.33	9.95
	8.78	90.29	12.35	9.70
	7.11	**90.35**	**12.91**	**9.64**
	5.60	90.39	15.00	9.60
	4.30	90.53	20.10	9.46
DB3	8.42	91.42	10.10	8.57
	7.82	91.76	10.47	8.23
	6.13	**92.14**	**11.44**	**7.85**
	5.36	91.75	11.31	8.25
	4.60	90.64	11.27	9.35

Table 2. Comparison of DCT based proposed feature extraction method, DWT, DWT+RWF, and DWT+(HL+LH) subbands of RWF based method in terms of GAR, FAR, and FRR

Database	Method	GAR (%)	FAR (%)	FRR (%)
DB1	Proposed DCT based method(19.14% DCT coefficients)	**94.18**	**3.94**	**5.81**
	DWT	92.14	25.20	7.85
	DWT+RWF	96.22	25.17	3.77
	DWT+(HL+LH) subbands of RWF	95.10	18.03	4.89
DB2	Proposed DCT based method (7.11% DCT coefficients)	**92.46**	**16.56**	**7.53**
	DWT	89.79	34.45	10.20
	DWT+RWF	88.85	30.01	11.14
	DWT+(HL+LH) subbands of RWF	90.04	29.29	9.95
DB3	Proposed DCT based method (6.13% DCT coefficients)	**95.32**	**17.47**	**4.67**
	DWT	89.45	31.03	10.54
	DWT+RWF	90.89	27.85	9.10
	DWT+(HL+LH) subbands of RWF	90.26	26.36	9.73

Table 2 shows the comparison of the proposed method with the DWT, DWT+RWF, DWT+(HL+LH) subbands of the RWF based method in terms of GAR, FAR, and FRR. The results in Table 2 show that the proposed method performs better than the DWT, DWT+RWF, DWT+(HL+LH) subbands of the RWF based method. Our proposed method gives 94.18% GAR and 3.94% FAR on DB1, 92.46% GAR and 16.56% FAR on DB2, and 95.32% GAR and 17.47% FAR on DB3.

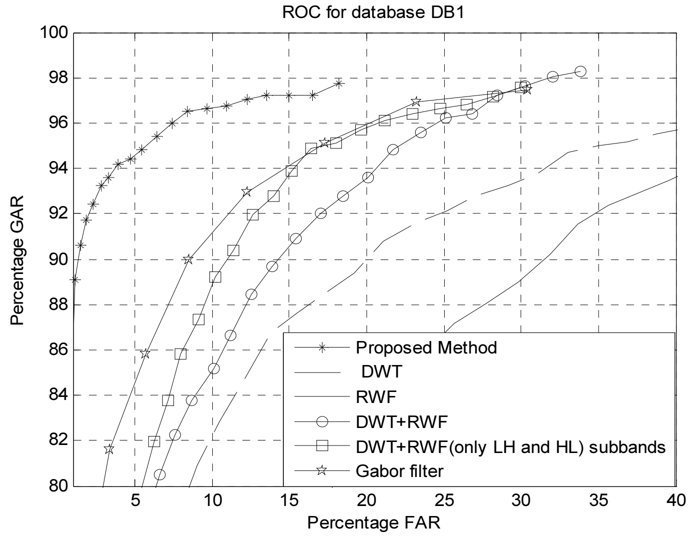


Fig. 4. Comparison of proposed feature extraction method, DWT, RWF, DWT+RWF, DWT+(HL+LH) subbands of RWF and Gabor filter based method in terms of ROC on DB1 database.

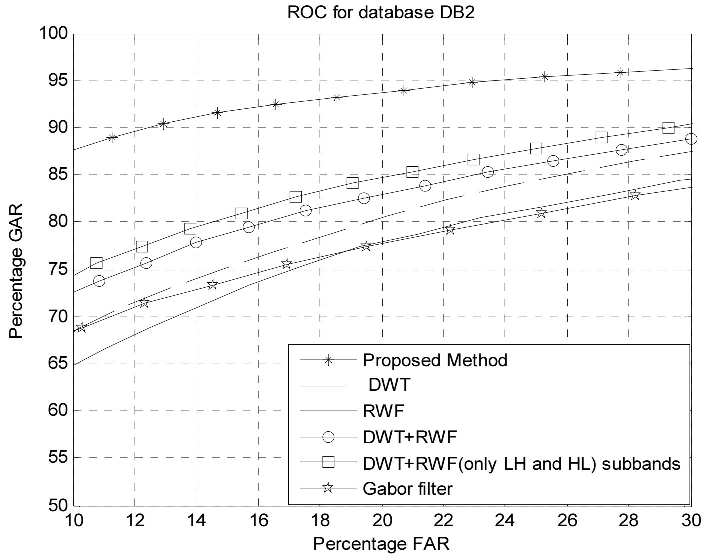


Fig. 5. Comparison of proposed feature extraction method, DWT, RWF, DWT+RWF, DWT+(HL+LH) subbands of RWF and Gabor filter based method in terms of ROC on DB2 database.

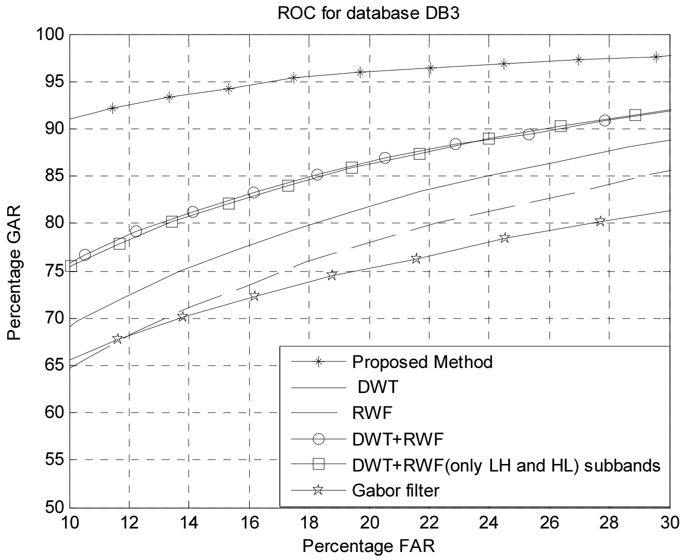


Fig. 6. Comparison of proposed feature extraction method, DWT, RWF, DWT+RWF, DWT+(HL+LH) subbands of RWF and Gabor filter based method in terms of ROC on DB3 database.

3.2 Performance Measure Based on ROC

The performance of the proposed method is evaluated in terms of the receiver operating curve. The receiver operating curve is the plot of FAR versus GAR at various threshold values. Figs. 4–6 show the comparison of the proposed method with the DWT, DWT+RWF, DWT+(HL+LH) subbands of the RWF and the Gabor filter based method in terms of ROC on the DB1, DB2, and DB3 databases, respectively. The topmost curves in these three figures show the outstanding performance of our proposed method over the existing feature extraction methods.

3.3 Performance Measurement Based on Computational Complexity

Computational complexity is measured in terms of the time complexity of the algorithm. Time complexity is measured by the number of elementary operations carried out during the execution of the algorithm. The worst-case time complexity can be described using the big *O* notation. Table 3 shows the comparison of time complexity and length of the feature vector for the DCT, the DWT, and the Gabor filter [8]. The length of the feature plays a key role while computing the matching time required for the query image and database image. The smaller the length of the feature vector, the less matching time required for the query image and database image. Hence, reducing the length of the feature vector reduces the time complexity. Our proposed feature extraction method gives the reduced feature vector length by using the optimum percentage of DCT coefficients for feature extraction. Table 3 shows that the length of the feature vector of the proposed method is less, as compared to the existing feature extraction methods. DCT can be implemented using the standard fast Fourier transform (FFT) algorithm. DCT requires $O(N\log_2 N)$ real operations unlike the Discrete Fourier transform [15]. The computational time complexity of DCT for a one-dimensional signal of length N is $O(N\log_2 N)$.

Table 3. Time Complexity for the DCT, DWT, and Gabor filter

Database	Method	Time complexity $O(N)$	Length of feature vector
DB1	DCT	$O(N \log_2 N)$	49
	DWT	$O(N)$	20
	Gabor filter	$O(M^2 N^2)$	512
DB2	DCT	$O(N \log_2 N)$	81
	DWT	$O(N)$	20
	Gabor filter	$O(M^2 N^2)$	2312
DB3	DCT	$O(N \log_2 N)$	72
	DWT	$O(N)$	20
	Gabor filter	$O(M^2 N^2)$	2400

The complexity of the Gabor filter response is $O(M^2 N^2)$ when the Gabor filter mask of size $M \times M$ is applied on image of size $N \times N$. DWT gives the orthogonal features, which reduces computational complexity. Hence, the DWT is faster than DCT and the Gabor filter. Guo and Burrus [16] proposed the fast approximate Fourier transform via a wavelet transform algorithm to reduce the complexity of the FFT algorithm. Hence, DCT can be implemented with the fast approximate Fourier transform via a wavelet transform algorithm to approximately obtain the same computational complexity of the DWT.

Table 3 shows that the time computational complexity, in terms of $O(N)$, for the proposed real valued feature extraction methods is less, as compared to the existing feature extraction methods. Also, Table 3 shows that the proposed real valued feature extraction method reduces the length of the feature vector by the factors of approximately 11, 29, and 33 for the DB1, DB2, and DB3 databases, respectively, over the existing Gabor filter based feature extraction method.

4. Conclusions

We have proposed a novel feature dimensionality reduced approach for fingerprint matching based on real valued DCT. We have shown that the DCT can be efficiently used to extract the informative and discriminative features from the small region of a fingerprint image. The results of our proposed method outperform the existing feature extraction methods. Our comparative analysis shows that our proposed feature dimensionality reduced approach gives the compact feature vector better performance over the DWT, RWF, DWT+RWF, DWT+(HL+LH) sub bands of RWF and the Gabor filter based method in terms of recognition rate and ROC. Hence, our extensive performance analysis on a small database of Bologna University and two large databases of FVC2000 (db1_a and db2_a) show that our method has an enhanced performance over existing feature extraction methods.

The computational complexity of our proposed DCT based feature extraction method is more as compared to DWT. However, DCT can be computed with approximately the same computational complexity of DWT using the Guo and Burrus [16] algorithm. Hence, DCT based approach is faster than the Gabor filter based approach, which requires a set of filters oriented at different angles and frequencies. Our proposed method reduces the dimensions of the feature vector by a factor of approximately 48 over the Gabor filter based feature extraction method. The key advantage of our proposed feature dimensionality reduced approach is that it requires real valued operations.

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