Face Recognition using Truncated Transform Domain Feature Extraction

Rangan Kodandaram, Shashank Mallikarjun, Manikantan Krishnamuthan, and Ramachandran Sivan
Department of Electronics and Communication Engineering, M.S. Ramaiah Institute of Technology, India

Abstract: *Face Recognition (FR) under varying pose is challenging and exacting pose invariant features is an effective approach to solve this problem. In this paper, we propose a novel Truncated Transform Domain Feature Extractor (TTDFE) to improve the performance of the FR system. TTDFE involves a unique combination of Symlet-4 DWT, 2D-DCT, followed by a novel truncation process. The truncation process extracts higher amplitude coefficients from the Discrete Cosine Transform (DCT) matrix. An optimal Truncation Point (TP) is estimated, which is inspired by a relationship developed between the image dimensions and the positions of DCT amplitude peaks. TTDFE is used for efficient feature extraction and a Binary Particle Swarm Optimization (BPSO) based feature selection algorithm is used to search the feature space for the optimal feature subset. Experimental results, obtained by applying the proposed algorithm on 5 benchmark face databases with large pose variations, namely Facial Recognition Technology (FERET), University of Manchester Institute of Science and Technology (UMIST), Foundation for Education of Ignatius (FEI), Pointing' 04 Head Pose image Database (PHPD) and Indian Face Database (IFD), show that the proposed system outperforms other FR systems. A significant increase in the Recognition Rate (RR) and a substantial reduction in the number of features selected are observed.*

Keywords: *FR, feature extraction, discrete wavelet transform, DCT, feature selection, BPSO.*

Received January 28, 2013; accepted September 18, 2013; published online June 26, 2014

1. Introduction

Face Recognition (FR) has emerged as an extensively studied topic over the last few years, having repercussions on fields such as pattern recognition, signal processing and computer vision. FR is at the heart of human-computer interaction and is indispensable in other applications such as security (Identity authentication), indexing of image and video databases, etc., the various approaches to FR have been discussed in [32, 37]. FR under varying pose is a challenging task and has been discussed in [1, 20]. FR under varying facial expression has been discussed in [25]. It is imperative that a good FR system has to handle pose and expression variation extremely well in order to be viable. The ability of an FR system to perform accurately on new, unseen examples after training on a finite data set and to generalize from experience is the focus. Hence, the system is trained with a definite number of images from each class.

A basic block diagram of an FR system is as shown in Figure 1. The pre-processing stage is meant to improve the quality of the image and lays the ground for efficient feature extraction. A feature extraction methodology plays a major role in the recognition process and a good extraction methodology selects the best Discriminant features which are not sensitive to variations in pose, scale and facial expressions. Feature selection involves conversion of extracted features into a feature subset. Its purpose is to eliminate the irrelevant features and reduce computational complexity without compromising the classification accuracy. During the testing stage, similarity of the image under test is measured with the trained images and hence the image is matched. Feature selection is performed using a suitable feature selection algorithm and the similarity measurement is done by using a suitable classifier.

The rest of the paper is organized as follows. Section 2 discusses the problem definition and contributions, section 3 deals with the preliminary information, section 4 deals with the proposed Truncated Transform Domain Feature Extractor (TTDFE), section 5 deals with feature selection based on Binary Particle Swarm Optimization (BPSO), section 6 deals with Euclidean classifier and section 7 discusses the proposed FR system and experimental results. Conclusions are discussed in section 8.

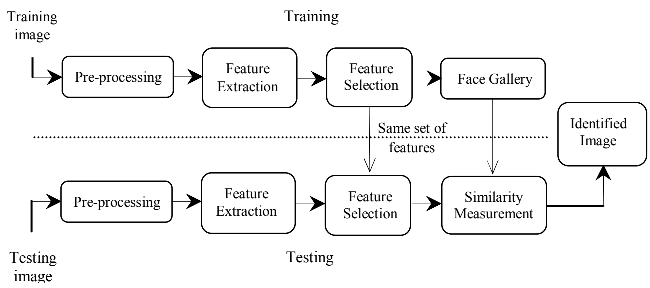


Figure 1. Basic block diagram of an FR system.

2. Problem Definition and Contributions

Feature extraction aims at extracting only the most significant and distinctive features from the feature set to satisfy an objective with the least possible features selected. The objective in this case is FR and the purpose of extracting the right features is to satisfy engineering constraints in software/hardware complexity. The problems with current computer based 2D-FR systems are:

- Iinability to extract the most important features needed for recognition.
- Handling variations in pose, expression and occlusion.

In this paper, a robust FR system is proposed with the aim of minimizing problems due to pose variations and variations due to facial expressions and occlusions. The features invariant to pose, expression and occlusion are extracted using a novel extraction algorithm consisting of Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT) and a truncation process.

The conventional usage of DWT for feature extraction in FR includes only [cA] sub-band The [cA] sub-band however, lacks the information regarding the horizontal features like the eyes, lips, etc. We propose to use Symlet-4 DWT to accommodate the deficiency of the [cA] sub-band alone. By creating a sequence of extractors in the order of DWT and DCT, we take advantage of the frequency characteristics of the image. A novel truncation process on the DCT matrix significantly reduces the number of required features. Following the DCT truncation process, a swarm intelligent optimization algorithm called BPSO results in a 50% reduction in the number of selected features. Thus the proposed DWT + DCT + Truncation + BPSO extraction methodology results in a highly optimized face-feature gallery. Thereby using even a simple Euclidean classifier, a significant improvement in facial Recognition Rate (RR) is observed.

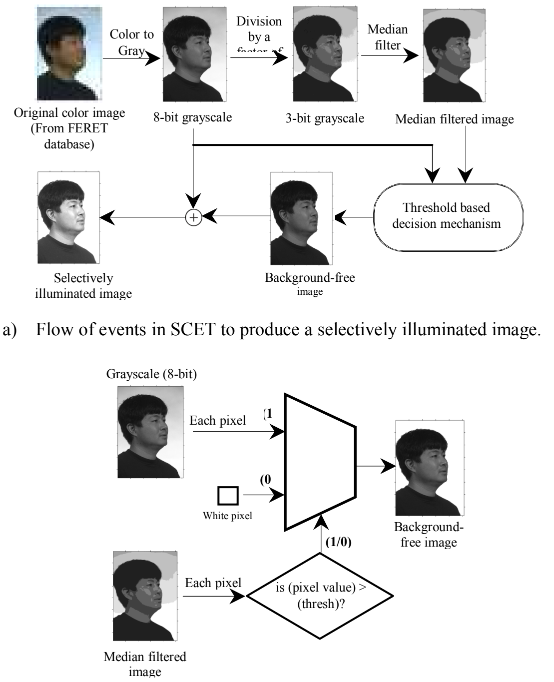
3. Related Work

The approaches to solve the FR problem have been diverse and numerous. FR using Modular Eigen spaces [2] is an extension of Eigen faces [33] technique and uses the concept of detection of Eigen eyes, Eigen faces, Eigen noses and Eigen mouths for improving recognition. Fisher faces technique [4] provided better results even under large variation in expression and lighting condition. Laplacianfaces [35] is an appearance based method that provided better representation and lower error rates compared to eigenfaces and fisher faces. The Principle Component Aanalysis (PCA) is a classic feature extraction and data representation technique. 2D-PCA [17] was developed based on 2D image matrices rather than 1D vector. Independent Component Analysis (ICA) [23] is a holistic approach for extracting facial independent components. Recently, the transform based approach is gaining popularity mainly because of its low computational complexity and promising recognition. [21, 30, 36] discuss various transform domain approaches. A wavelet based approach has been discussed in [5]. [16, 28] have discussed DCT as the feature extraction methodology and recognition is performed directly on the compressed image. Combined transform domain extraction concepts are being developed as shown in [6] which uses a combination of different transforms to obtain feature subset. [14, 24] are excellent references for the above mentioned concepts. More recently, optimization algorithms such as genetic algorithm [18] (aims at solving multi-criteria problem of feature subset selection) and BPSO [8] have succeeded in optimal feature selection. With this background, we set out in trying to create an improved and efficient FR system.

4. A Novel TTDFE

Before performing feature extraction, few image pre-processing techniques need to be employed to enhance the quality of the image. The sizes of images used are large with considerable redundancy, thereby causing unnecessary computational burden. Image re-sizing is therefore necessary and is done through bi-cubic interpolation in this FR model. The various image down-sampling techniques are discussed in [3].

Here, we propose a novel Selective Contrast Enhancement Technique (SCET), which selectively illuminates the non-background part of the image and minimizes the effect of the background as shown in Figure 2-a.



a) Flow of events in SCET to produce a selectively illuminated image.

b) Threshold based decision mechanism to obtain background free image.

Figure 2. IIlustration of SCET.

The original color image is converted to an 8 bit gray scale image, which is further converted into a 3 bit gray scale image.

A median filter of size *n*=5 (the value *n*=5 signifies that each pixel in the output image has a median value of 5×5 neighbouring pixels in the input image) is then applied on the 3 bit gray scale image. The median filter forces points with distinct gray levels to be like their neighbours. Isolated clusters of images which are lighter or darker with respect to their neighbours are forced to median intensity. Later, image background areas with low gray scale variation are addressed on a region based approach. Regions above a specified threshold are selected as shown in Figure 2-b to obtain a background free image. This background free image is then added to the 8 bit gray scale image to obtain a selectively illuminated image with suppressed background.

Wavelets provide spatial and frequency representations of the image simultaneously and hence are excellent feature extractors. A wavelet based approach helps us to focus on the space sub bands that contain the most relevant information to better represent the original image and assist in classifying different images, a flow of events in SCET to produce a selectively illuminated image, b Threshold based decision mechanism to obtain background free image.

Wavelets have hence found their way into FR as discussed in [5]. A large variety of Wavelets exist based on the selection of Wavelet families. The conventional usage of DWT as a feature extraction methodology in FR includes only [cA] sub-band, which contains the approximate coefficients. The [cA] sub b and lacks the information regarding the high frequency horizontal features like the eyes, lips, etc., we propose to use Symlet-4 DWT to accommodate this deficiency.

DCT is a popular transformation technique and is used in image processing because of its energy compaction property. DCT has been used in FR systems as discussed in [16, 28] and was found to generate good RRs.

A technique called Truncated Transform Domain Feature Extraction (TTDFE) is proposed which works efficiently on pose-variant images and the extracted features are found to be a minimized set resulting in improved RRs. This uses a combination of DWT, DCT and a truncation process. Symlet-4 DWT coefficients extract the spatial content of the image. DCT is used due to its energy compaction property. The truncation process proposed here results in a drastic reduction in the number of selected features. It was observed that if the number of selected features is limited to, or truncated up to the mid-point between the first and second peaks in the DCT plot as shown in the final part of Figure 3, the RR obtained was found to be maximum. Hence, what the 'truncation' process means, is that we need to select only those DCT coefficients up to the mid-point between the first and second DCT peaks.

The chronology of events in the proposed TTDFE is presented in Figure 3. The selectively illuminated image is converted into a 1D array using raster scan technique and DWT is applied with Symlet-4 as the wavelet.

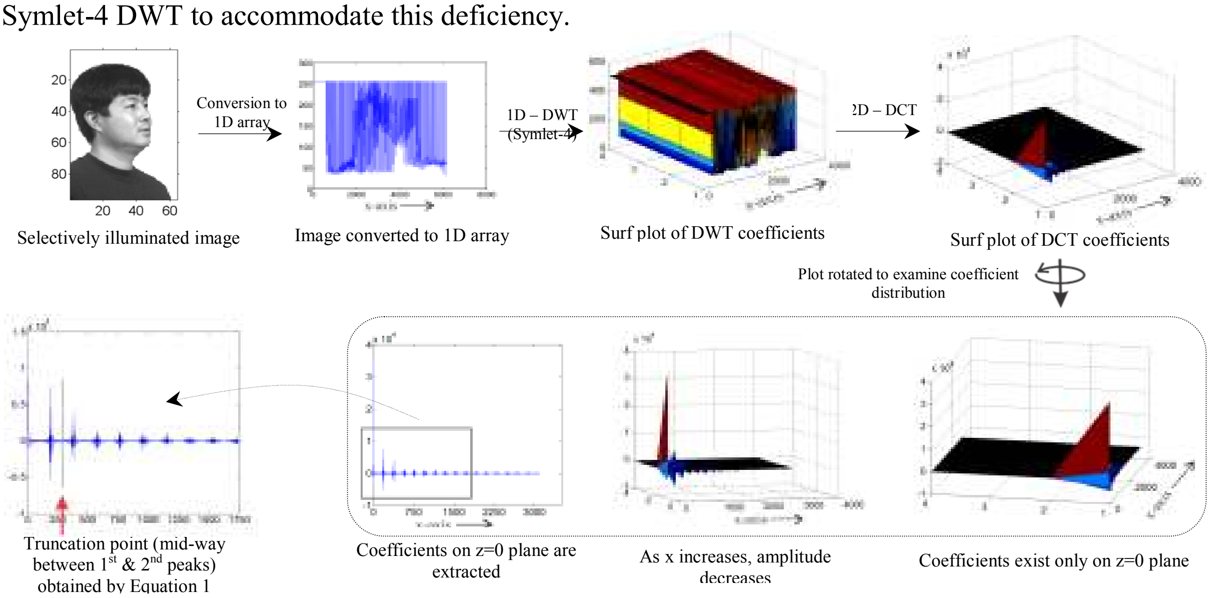


Figure 3. Flow of events in the proposed TTDFE.

4.1. Constants 'a' and 'b'

The truncation point, i.e., mid-point between the first and second DCT peaks, can easily be identified practically in the DCT plot. This Truncation Point (TP) can also be calculated theoretically by a relationship which was obtained during experimentation. For any general image of size $P \times Q$ (Note: 'P' is the no. of pixels in the mage along y-axis, 'Q' is the no. of pixels along x-axis), the DCT TP is calculated as:

$$TP = 1.5 * (P * a + Q * b) \tag{1}$$

Where, constants 'a' and 'b' are determined as follows:

Experimentally, it was found that a linear relationship exists between the image dimensions and the position of the first DCT magnitude peak (after $x=0$), as given by Equation 2:

$$(P * a + Q * b) = R \tag{2}$$

Where, 'R' is the position of the first DCT peak. Consider two images with different dimensions, for example, consider an University of Manchester Institute of Science and Technology (UMIST) image of size 112×92 and another image from Foundation for

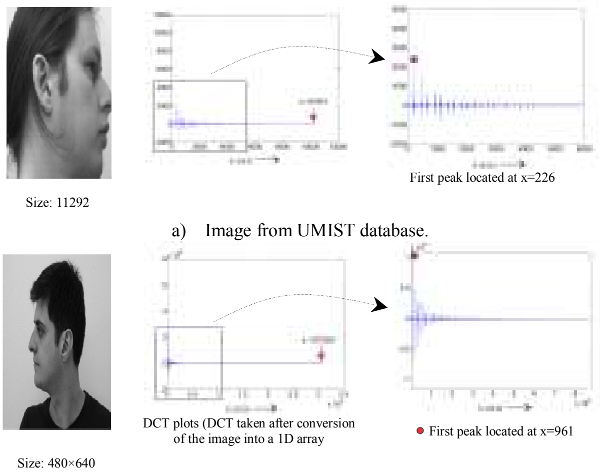
Education of Ignatius (FEI) database of size 480×640 Figure 4. Applying Equation 2 to both these images, the constants '*a*' and '*b*' can be determined.

$$112*a+92*b=226 \quad (3)$$

$$480*a+640*b=961 \quad (4)$$

The first DCT peak values appear at *x*=226 for UMIST image and at *x*=961 for FEI image as shown in Figure. 4. Solving for '*a*' and '*b*', we have:

$$a = 2.04316805 \approx 2.04,\ b = -0.030813953 \approx -0.03$$



a) Image from UMIST database.

b) Image from FEI database.

Figure 4. Flow of events in the calculation of linear constants 'a' and 'b.'

The successive peaks in the DCT plot are seen to be periodic and hence the second peak's position is obtained by multiplying the first peak's x-position by 2. This holds good for all further peaks. Also, the values of the constants 'a' and 'b' remain the same for any image. The position of the first peaks for different images as calculated theoretically by Equation 2 and the experimentally observed values are shown in Table1. Clearly the theoretical and experimental values show excellent compliance.

Table 1. Comparison of the first peak position of DCT plot as calculated using Equation 2. with the corresponding value obtained experimentally for various test images.

Image Source	Image Size in Pixels	Location of First Peak (using Equation 2)	Location of First Peak (Experimental)
FERET	384×256	'776	779
UMIST	112×92	226	226
FEI	480×640	960	961
PHPD	288×384	576	576
IFD	480×640	960	961

The conclusion is that the DCT truncation point, given by Equation 1, can be determined just by a knowledge of the image dimensions and no experimentation needs to be done.

5. Feature Selection based on BPSO

Feature selection is the technique of selecting a subset of relevant features for building robust learning models. By removing most irrelevant and redundant features from the data, feature selection helps improve the performance of FR systems by improving generalization capability, minimizing redundancy and speeding up the learning process. Hence, feature selection forms an integral part of an FR system.

Evolutionary algorithms perform well because they do not make any assumption about the underlying fitness landscape. PSO [9, 19] is an algorithm based on the swarm intelligence and behaviour of flock of birds searching for food. This algorithm is used to optimize the solution set by iterative operations on the given solution space. The tendency of a particle to move towards a better solution is the behaviour that guides the PSO algorithm.

BPSO [8] is inspired by PSO algorithm. The BPSO algorithm searches for the most representative feature subset through the feature space provided by the extraction methodology.

6. Euclidean Classifier

Classification involves identifying which of a set of categories a new observation belongs, on the basis of training set of data containing observations. Here, we use Euclidean as the classifier. Euclidean classifier calculates the distance between two corresponding points. This technique is used to measure the similarity between the features of the test image with the feature gallery obtained during the training process. The N-dimensional distance between them is calculated using Equation 5, where p_i is one of the feature vectors, q_i is the feature vector of the test image and *N* is the number of features extracted. The feature vector which gives the least euclidean distance is the matched image.

$$E = \sqrt{\sum_{i=1}^{N} (p_i - q_i)^2} \quad (5)$$

7. Discussion of the Proposed FR System and Experimental Results

The block diagram of the proposed FR system is as shown in Figure 5. RR is used as the performance metric. If a total of *S* images are successfully recognized from a total of *T* testing images, then RR is defined as the ratio *S/T*.

To demonstrate the robustness and practicality of the proposed FR system, experiments are conducted on different databases with pose, occlusion and facial expression variations. The databases are chosen carefully such that they are the most effective in addressing the specified variations. Five benchmark databases are hence selected and are essential to prove the consistency of the proposed FR system.

Three experiments were conducted on the basis of the nature of database under test. Experiment-1 deals with the pose variation, Experiment-2 with pose occlusion variation and Experiment-3 with pose expression variation. Comparison of TTDFE with other extraction methodologies like DWT, DCT and Truncated-DCT (TDCT) is performed (Note: TDCT is DCT+ Truncation, i.e., DWT not used). The experiments were conducted on a PC with Intel core i7 2.4 GHz processor with 8 GB RAM using MATLAB [26]. The DCT truncation points for different databases as calculated by Equation 1 are shown in Table 2. The database details used in the following experiments are given in Table 3.

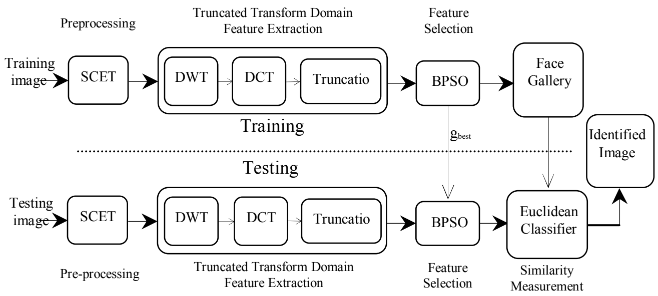


Figure 5. Block diagram of the proposed FR system

Table 2**.** Image dimensions (in pixels) and truncation points.

Database	Original Image Size	Image Size after Resizing	DCT TP (using Equation 1)
FERET	384×256	96×64	291
UMIST	112×92	56×46	169
FEI	480×640	60×80	180
PHPD	288×384	72×96	216
IFD	480×640	60×80	180

Table 3. Database details for experimentation.

Database	FERET	UMIST	FEI	PHPD	IFD
Total No. of Subjects	35	20	35	15	20
No. of Images in each Subject	20	19	10	39	11

7.1. Experiment 1- Pose Variation

In order to demonstrate the robustness of the proposed FR system to variations in pose, three databases are chosen as described below.

7.1.1. Experiment-1a: Facial Recognition Technology (FERET) Face Database

The color FERET database [10] has color images with a homogeneous background which have pose variation with a slight variation in illumination for each image. For experimentation, 35 subjects with 20 images per subject under different poses are selected Figure 6-a. Eight images are selected randomly from each subject and are used to train the system. The remaining 12 images are used for testing. It is seen that the proposed TTDFE produces an average RR of 89.21% with 181 features. The TP as given by Equation 1 clearly indicates that the point is midway between the first and second DCT peaks.

We study the variation of RR and number of features with change in the position of TP. The factor 1.5 in Equation 1 is replaced with a variable '*k*'. Hence, Equation 6 gives us different TPs as we vary *k*.

$$TP = k * (P * a + Q * b) \tag{6}$$

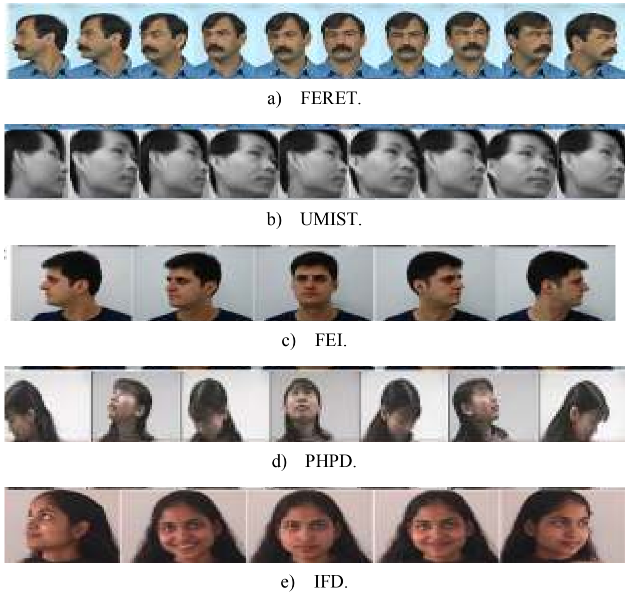


Figure 6. Sample images from databases under test.

When *k*=1.5, TP corresponds to the midpoint between the first and second DCT peaks; second peak corresponds to *k*=2 and so on. As *k* increases, the size of the truncated coefficient vector increases. We now observe the variation of RR with k. The value of k is varied from 1.5 to 20 in steps of 0.5 and the corresponding RR is plotted Figure 7. From the graph, it is evident that RR is maximum for *k*=1.5 and remains around the maximum value till *k*=4. Beyond *k*=4, RR drops off, owing to the increase in feature vector size and the arrival of redundant features leading to false recognition.

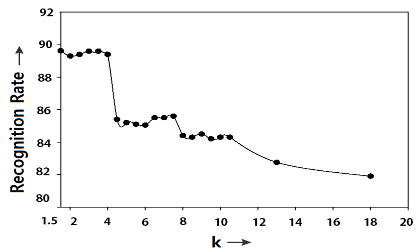


Figure 7. Variation of RR with k for FERET database; k=1.5 produces the best RR.

The idea which TTDFE proposes, is applying a consistent approach in obtaining an optimum TP by having the knowledge of image dimensions alone. It is experimentally established in section 4 that there is a periodicity in the DCT coefficient plot for all databases. This periodicity is the cornerstone in developing a consistent method for the procurement of the truncation point. *k*=1.5 provides the best RR, utilizes the minimum number of features, and provides an understandably consistent and universal approach to determine the TP for any database. Hence, the selection of the TP according to Equation 1 is justified.

The RR calculation was averaged out for 100 trials and for varying train-to-test image ratios to indicate the role of the training set. The system is able to recognise a person better if it is trained extensively. The results, including the training and testing times, are tabulated in Table 4.

Table 4. Effect of train-to-test ratio on RR and computation times for FERET database.

Tr:Tes Ratio	Avg. RR (%)	Avg. Testing Time per Image (10^{-3}s)	Avg. Training Time(s)
1:19	41.68	15.89	2.16
2:18	57.93	15.99	2.71
4:16	75.78	16.14	3.82
6:14	84.69	16.35	4.93
8:12	89.21	16.53	6.03
10:10	92.56	16.71	7.14
12:8	94.88	16.88	8.24
14:6	96.88	17.06	9.35
16:4	97.98	17.23	10.46
18:2	99.23	17.42	11.57
19:1	99.60	17.59	12.15

7.1.2. Experiment-1b: UMIST Face Database

UMIST database [31] has gray scale images which are highly pose variant but are of same illumination and are cropped, i.e., only the facial part is visible with a small amount of background as seen from Figure 6-b. Even for such extreme pose variance and with very little training (train to test ratio of 2:17), the proposed TTDFE algorithm gives an RR of 83.05% with only 107 features.

7.1.3. Experiment-1c: The FEI Face Database

FEI database [11] has color images which are similar to those of FERET but are more scaled. Also, pose varies from extreme left to extreme right. Figure 6-c which shows the images of a particular subject. A very good RR of 94.36% with 113 features is obtained for a train to test ratio of 4:6, which reiterates the robustness of TTDFE algorithm even for severe pose variation.

7.2. Experiment 2: Pose-Occlusion Variation

In order to study recognition of face images with pose and occlusion variations, pointing' 04 Head Pose Image Database (PHPD) [15] database is chosen. The horizontal angles of the images vary from extreme left to extreme right with 3 different head lift angles in each subject (-60^0, 0^0, $+60^0$). Sample images are shown in Figure 6-d. Thus, this is a more challenging database to study the effect of pose and occlusion variance on FR. For experimentation, 39 images per subject comprising all angles are chosen and an RR of 93.13% with just 107 features is obtained for a train to test ratio of 8:31.

7.3. Experiment 3: Pose-Expression Variation

In the above databases, images exhibit pose variance but not expression (FERET images exhibit slight expression variation). But, Indian Face Database (IFD) [34], as seen in images from Figure 6-e, contains images with pose and expression variations. The ability of TTDFE algorithm to neutralize the effects of expression variation along with pose variation is justified from the RR obtained for IFD database. An RR of 85.36% with 114 features is obtained for a train-to-test ratio of 3:8 establishing that TTDFE handles expression variations very well too, along with pose variation.

7.4. Comparative Study

In this section, three experiments are conducted and in each the advantage of TTDFE over other methods is highlighted. The use of BPSO in selecting the most optimum set of features is also emphasized. The first experiment shows how dimensionality gradually reduces after each stage of TTDFE and also shows how BPSO selects the most desirable features if DCT is preceding it. The second experiment is a comparison wherein TTDFE is compared with the basic DWT, DCT and TDCT techniques. This clearly shows how TTDFE+ BPSO helps in combating the curse of dimensionality much better than the other basic extractors. In the third, TTDFE is compared with other state of the art feature extraction techniques to show the improved performance of TTDFE.

7.4.1. Dimensionality Reduction in TTDFE

The overall dimensionality reduction caused at each stage of TTDFE for all five databases is shown in Figure 8. After feature extraction using TTDFE, BPSO is used to obtain an optimized feature subset. Although, the feature vector size is considerably small after the proposed truncation, BPSO is applied to further select the most optimum features. 'Features after BPSO' Figure 8 clearly shows the advantage of TTDFE + BPSO in achieving an optimized feature vector.

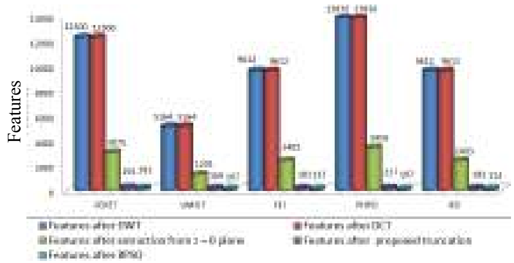


Figure 8. Dimensionality reduction at different stages in TTDFE showing the significant reduction in number of feature increases**.**

7.4.2. Comparison of TTDFE with DWT, DCT and TDCT Extraction Methods

In the previous subsection, Figure 8 showed the feature reduction after each stage only in TTDFE. Another useful comparison would be to compare TTDFE with DWT, DCT and TDCT along with BPSO with respect to RR and features. This comparison highlights the real advantage of TTDFE + BPSO. RR and feature comparison is given in Table 5. While calculating both RR and number of features, the experimental results were averaged over 100 trials.

Table 5. RR (%) comparisons for databases under test with single transform extractors; TTDFE is seen to produce the best results (Note: NOF-No. of features)

Database	DWT+BPSO		DCT+BPSO		TDCT+BPSO		TTDFE+BPSO	
	RR	NOF	RR	NOF	RR	NOF	RR	NOF
FERET (8:12)	79.9	2020	80.6	3198	84.56	205	89.21	181
UMIST (2:17)	82.03	935	82.05	1402	82.76	140	83.05	107
FEI (4:6)	88.43	1621	88.52	2519	92.89	145	94.36	113
PHPD (8:31)	87.25	2257	86.66	3591	88.61	167	93.13	107
IFD (3:8)	78	1631	79.62	2522	82.16	145	85.36	114

DWT helps in extracting essential features (horizontal features like eyes, lips, etc.,). But, RR is low in the case of DWT+BPSO as there is considerable redundancy because of the large number of features. The case is similar with DCT+BPSO. The advantage of DCT's compaction property is not exploited if we don't truncate the coefficient vector and this is reflected in the low RR obtained. It is seen that truncation increases RR and significantly reduces the number of features (TDCT+BPSO). But, TTDFE stands out among the extraction methodologies being compared, providing the best RR using the minimum number of features. Combining DWT's excellent feature extraction property, DCT's energy compaction property and the careful selection of TP has resulted in the development of a unique extraction methodology which significantly outperforms existing techniques.

7.4.3. Comparison with other FR Systems

To demonstrate the robustness of the proposed FR system, a comparison is made with various standard FR systems. The comparison is made by using the RR as the metric. Table 6 compares TTDFE with other techniques for FERET database. Table 7 compares TTDFE with other approaches for UMIST database. It is seen that the proposed FR system with TTDFE as the feature extraction methodology clearly outperforms other FR systems.

Table 6. Comparison with other FR systems for FERET database with 8:12 Training-Testing ratio.

Extraction Methodology	Avg RR(%)
Spectrum - based feature extraction [6]	80.23
IMUM + DWT [13]	86.45
DWT Thresholding + Laplacian-Gradient Masking [27]	85.07
Circular Sector DCT (Thresh=30, Rad= 50) [12]	83.54
Proposed TTDFE	89.21

Table 7. Comparison with other FR systems for UMIST database (Note: PCA-Principal Component Analysis; HOG- Histogram of Oriented Gradients; FLDA- Fisher Linear Discriminant Analysis.)

Extraction Methodology	RR(%)
2D - HOG/2D - PCA (5 Training Images) [22]	90.35
FLDA (1 Training Image) [29]	61.39
DWT Thresholding + Laplacian-Gradient Masking (5 Training Images) [27]	94.42
Asteroid shaped DCT Extraction (6 Training Images) [7]	95.04
Proposed TTDFE (5 Training Image)	95.76

7.5. Reason for Improved Performance with TTDFE

In order to justify that TTDFE results in better RR than DWT, DCT and TDCT, the following experiment was conducted. FERET database is chosen and the FR system is trained with four images from each of the 35 subjects. Testing is done with an image (not present in the training set) from the 3rd subject. Euclidean distance is computed between the feature vectors of the test image and each of the 140 training images. A graph of Euclidean distance versus the number of the training image is plotted. Figure 9 for the four extraction methodologies, namely, DWT, DCT, TDCT, TTDFE. The graph clearly shows that inter-subject Euclidean distance is maximum, while intra-subject Euclidean distance is minimum with TTDFE**,** making recognition easier and hence results in better RR, thus justifying its advantage over the other three.

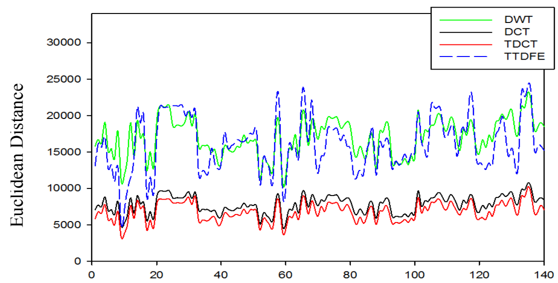


Figure 9. Euclidean distance comparison for FERET database under varying extraction methodologies (Test image is from the 3rd subject); maximum inter-subject variation in TTDFE as compared to other feature extractors is observed

8. Conclusions

A novel approach for a flexible FR system is proposed which uses DWT + DCT + Truncation TTDFE for feature extraction and a BPSO based feature selection. TTDFE has played a key role in efficient feature extraction, which is the main contributor for the high RRs being obtained. DCT not only helps DWT in enhancing the RR, but also aids BPSO in achieving a significant reduction in the number of features. A successful attempt has been made to equally handle all image variations (Pose, expression, and occlusion). The proposed method exhibits extremely good performance under varying poses with variations in facial expressions and facial details (FERET, UMIST, FEI, PHPD and IFD). The experimental results indicate that the proposed method has performed well under severe pose variations with top RR having reached 89.21% for FERET database (considering all 13 poses). The proposed DCT TP was proven to be the most optimum, resulting in average RRs of 83.05%, 94.36%, 93.13% and 85.36% for UMIST, FEI, PHPD and IFD databases respectively for the specified train-to-test ratios. On a PC with Intel core i7-2760QM (2.4 GHz) machine with 8GB of RAM, TTDFE costs an average testing time of 16.53 ms per image (FERET database) using MATLAB (R). This may still be a limitation of TTDFE for real time applications. Hence, a future research issue could be to develop fast computation methods for TTDFE.

References

[1] Abate F., Michele N., Daniel R., and Gabriele S., "2D and 3D Face Recognition: A Survey," *Pattern Recognition Letters*, vol. 28, no. 14, pp. 1885-1906, 2007..

[2] Alex P., Baback M., and Thad S., "View-based and Modular Eigenspaces for Face Recognition," *in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, Seattle, pp. 84-91, 1994.

[3] Anthony P., Robert K., and Donald T., "Comparing of Interpolation Methods for Image Resampling," *IEEE Transactions on Medical Imaging*, vol. 2, no. 1, pp. 31-39, 1983.

[4] Belhumeur N., Hespanha P., and Kriegman J., "Eigenfaces vs. Fisherfaces: Recognition using Class Specific Linear Projection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 19, no. 7, pp. 711-720, 1997.

[5] Dai Q. and Yan H., "Wavelets and Face Recognition," available at: http://cdn.intechopen.com/pdfs-wm/195.pdf, last visited 2007.

[6] Deepa M., Keerthi R., Meghana N., and Manikantan K., "Face Recognition using Spectrum-based Feature Extraction," *Applied Soft Computing Journal*, vol. 12, no. 9, pp. 2913-2923, 2012.

[7] Divya R., Anvesha R., Manikantan K., and Ramachandran S., "Asteroid Shaped DCT Feature Extraction For Enhanced Face Recognition," *in Proceedings of the CUBE International Information Technology Conference*, Maharashtra, India, pp. 95-101, 2012.

[8] Eberhart C. and Kennedy J., "A Discrete Binary Version of the Particle Swarm Algorithm," *in Proceedings of IEEE International Conference on Systems, Man, and Cybernetics*, Orlando, pp.4101-4108, 1997.

[9] Eberhart C. and Kennedy J., "A New Optimizer using Particles Swarm Theory," *in Proceedings of the 6th International Symposium on Micro Machine and Human Science*, Nagoya, pp. 39-43, 1995.

[10] Facial Recognition Technology Database., available at: http://www.itl.nist.gov/iad/humanid/ferer/feretmaster.html, last visited 2014.

[11] FEIFaceDatabase., available at: http://fei.edu.br/~cet/facedatabase.html, last visited 2014.

[12] Gagan R., Hardik S., Manikantan K., and Ramachandran S., "Circular Sector DCT based Feature Extraction for Enhanced Face Recognition using Histogram based Dynamic Gamma Intensity Correction," *in Proceedings of CUBE International Information Technology Conference*, Maharashtra, India, pp. 74-81, 2012.

[13] Gautham Y., Sankhadeep S., Manikantan K., and Ramachandran S., "DWT Feature Extraction based Face Recognition using Intensity Mapped Unsharp Masking and Laplacian of Gaussian Filtering with Scalar Multiplier," *in Proceedings of the 2nd International Conference on Communication Computing and Security*, pp. 475-484, 2012.

[14] Gonzalez, Rafael C., and Woods E., *Digital Image Processing*, Pierson Prentice Hall, 2007.

[15] Gourier N., Hall D., and Crowley L., "Estimating Face Orientation from Robust Detection of Salient Facial Structures," *in Proceedings of International Workshop on Visual Observation of Deictic Guestures*, Cambridge, UK, pp. 1-9, 2004.

[16] Hafed M. and Levine D., "Face Recognition using Discrete Cosine Transform," *International Journal of Computer Vision*, vol. 43, no. 3, pp. 167-188, 2001.

[17] Huang G., Ramesh M., Berg T., and Learned-Mill E., "Labeled Faces in the Wild: A Database for Studying Face Recognition in Unconstrained Environments," available at: http://visw.cs.umass.edu/~vidit/IndianFaceDataase/, last visited 2014.

[18] Jian Y., David Z., Alejandro F., and Jing-yu Y., "Two-Dimentional PCA: A New Approach to Appearance-based Face Representation and Recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 26, no. 1, pp. 131-137, 2004.

[19] Jihoon Y. and Vasant H., "Feature Subset Selection using A Genetic Algorithm," *IEEE Intelligent Systems and their Applications*, vol. 13, no. 2, pp. 44-49, 1998.

[20] Kennedy J. and Eberhart C., "Particle Swarm Optimization," *in Proceedings of IEEE International Conference on Neural Networks*, Perth, pp. 1942-1948, 1995.

[21] Kevin B., Kyong C., and Patrick F., "A Survey of Approaches and Challenges in 3D and Multi-modal 3D+2D Face Recognition," *Computer Vision and Image Understanding,* vol. 101, no. 1, pp. 1-15, 2005.

[22] Marcos F., Josep R., Virginia E., and Jaun O., "An Efficient Face Verification Method in a Transformed Domain," *Pattern Recognition Letters*, vol. 28, no. 7, pp. 854-858, 2007.

[23] Marian A., Salah A., and Islam Y., "Efficient Web-based Facial Recognition System Employing 2DHOG," available at: http://arxiv.org/pdf/1202.2449.pdf, last visited 2012.

[24] Marian B., Javier M., and Terrence S., "Face Recognition by Independent Component Analysis," *IEEE Transactions on Neural Networks*, vol. 13, no. 6, pp. 1450-1464, 2002.

[25] Mark N. and Alberto A., *Feature Extraction and Image Processing*, Elsevier, 2008.

[26] Marryam M., Muhammad S., Mudassar R., and Jamal S., "Analysis of Face Recognition Under Varying Facial Expression: A Survey," *the International Arab Journal of Information Technology*, vol. 10, no. 4, pp. 378-388, 2013.

[27] Mathworks., available at: http://www.mathworks.in/products/matlab/, last visited 2014.

[28] Naveen M., Raghunandana R., Manikantan K., and Ramachandran S., "Face Recognition using DWT Thresholding based Feature Extraction With Laplacian-Gradient Masking As a Pre-Processing Technique" *in Proceedings of the CUBE International Information Technology Conference,* Maharashtra, India, pp. 82-89, 2012.

[29] Podilchuk C. and Zhang X., "Face Recognition using DCT-based Feature Vectors," *in Proceedings of IEEE International Conference on Acoustics, Speech and Signal Processing*, Atlanta, pp. 2144-2147, 1996.

[30] Quan-xue G., Lei Z., and David Z., "Face Recognition using FLDA with Single Training Image per Person," *Applied Mathematics and Computation*, vol. 205, no. 2, pp. 475-484, 2008.

[31] Ramadan M. and Abdel-Kader F., "Face Recognition using Particle Swarm Optimization-based Selected Features," *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 2, no. 2, pp. 51-66, 2009.

[32] The Sheffield (previously UMIST- University of Manchester Institute of science and Technology) Face Database., available at: http://www.sheffield.ac.uk/eee/research/iel/research/face, last visited 2014.

[33] Tolba S., El-baz H., and El-harby A., "Face Recognition: A Literature Review," *International Journal of Signal Processing,* vol. 2, no. 2, pp. 399-458, 2006.

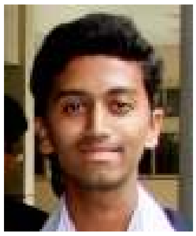
[34] Turk A. and Alex P., "Face Recognition using Eigenfaces," *in Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, Maui, pp. 586-591, 1991.

[35] Vidit J. and Amitabha M., "The Indian Face Database: http:// vis-www.cs.umass.edu/ ~vidit/ IndianFaceDatabase/, last visited 2014.

[36] Xiaofei H., Shuicheng Y., Yuxiao H., Partha N., and Hong-Jiang Z., "Face Recognition using Laplacianfaces," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 27, no. 3, pp. 328-340, 2005.

[37] Zana Y., Cesar-Jr, Feris R., and Turk M., "Local Approach for Face Verification in Polar Frequency Domain," *Image and Vision Computing*, vol. 24, no. 8, pp. 904-913, 2006.

Rangan Kodandaram is pursuing BE degree (final year) in electronics and communication at MS Ramaiah Institute of Technology, India. His research interests include image processing, computer vision, business analytics and optimization. Currently, he is working on a project involving Computer Vision for Robotic Application.



Shashank Mallikarjun is pursuing BE degree (final year) in electronics and communication engineering at MS Ramaiah Institute of Technology, India. His research interests are machine learning, artificial intelligence, computer vision, digital design, and image processing. Currently, he is working on a project involving Computer Vision for Robotic Applications.

Manikantan Krishnamuthan holds a doctoral degree in pattern recognition and is currently an Associate Professor in the Department of electronics and communication engineering at M.S. Ramaiah Institute of Technology, India. His research interests include pattern recognition; image processing and FPGA based designs.

Ramachandran Sivan is currently a Professor in the Department of Electronics and Communication Engineering at S. J. B. Institute of Technology, India. He obtained his MTech and PhD from IIT, Kanpur and Madras respectively. His research interests include developing algorithms, architectures and implementations on FPGA/ASICs for video processing, DSP applications, reconfigurable computing, and open loop control systems. He is the recipient of the Best Design Award at VLSI Design 2000, International Conference held at Calcutta, India and the Best Paper Award at WMSCI 2006, Orlando, Florida, USA. He has also written a book on Digital VLSI Systems Design, published by Springer Verlag, Netherlands (www.springer.com).