# “Improving face verification rate using Near Infrared and Visible image fusion based on Differential Evolution”

A Dissertation Report

Submitted

**By**


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**Baljit S. Saini**

**(Asst. Prof., UID- 15359)**


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# PAC FORM

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3. Application of Artificial Bee Colony in Pattern Recognition

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**PAC Remarks:**

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## ABSTRACT

Face verification is the process of verifying the individual's identity against his current face image with his reference image available in the database. In face verification systems identifying an individual in presence of factors like illumination, pose etc. creates performance degradation. NIR images have shown great resistance to these factors. Within this report we have discussed the implementation of two image fusion schemes using Near Infrared and Visible images. First scheme presents fusion at wavelet domain level, where Differential Evolution (DE), a population based optimization algorithm is used for optimization of wavelet coefficients. Second scheme is employing feature extraction and fusion of these features using DE. In both schemes match scores are calculated and results from both schemes are plotted using FAR vs FRR graph for comparison purpose. Execution time taken by these schemes are also compared.

**ACKNOWLEDGEMENT**

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## DECLARATION

I hereby declare that dissertation work entitled **"Improving face verification rate using Near Infrared and Visible image fusion based on Differential Evolution"** is my own work conducted under the supervision of **Baljit S. Saini**.

I further declare that to best of my knowledge this dissertation-II does not contain any of my work, which has been submitted for the award of any degree either in this university or any other institute.

Date: ____________

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# CERTIFICATE

This is to certify that **Rajesh Thakur** has completed M-Tech dissertation implementation work titled "**Improving face verification rate using Near Infrared and Visible image fusion based on Differential Evolution**" under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the dissertation proposal has ever been submitted for any other degree or diploma.

The dissertation proposal is fit for the submission and the partial fulfilment of the conditions for the award of M-tech Computer Science & Engg.

Date: ____________

Signature of Advisor
Name: Baljit S. Saini
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# INTRODUCTION

## 1.1 Pattern Recognition

Pattern recognition is used to find the patterns and regularities in any given data space. Pattern recognition is built with labeled training data (supervised learning) and unlabeled data using some algorithms to find patterns (unsupervised learning) which are unknown. The combination of labeled and unlabeled data is known as semi-supervised learning. Feature extraction is used for dimensionality reduction which transforms the data under process to set of features. Feature selection, is the process of creating a subset of relevant features. There are some features which are redundant and don't have information up to the level of those currently selected ones and also there are some features which have no useful information to the context.

### 1.1.1 Image Analysis

It comprise of methods which perform statistics and measurements based on the gray-level intensities of the image pixels. Its functions are to determine the image quality is good enough for the inspection task or not. An image can also be analyzed to understand its content and to decide which type of tools to be used to handle further proceedings. Image analysis also provide measurements functions that can perform checks like presence or absence of verification.

### 1.1.2 Digital Image Processing

DIP is basically used to improve the quality of image and information gathered from analyzing the image. It can be done by removing noise, highlighting features of interest, and separating the object of interest from the background. Various steps associated with DIP in context to face verification,

- **Image decomposition** – It refers to doing a multi-scale decomposition of image. Many techniques like Laplacian pyramid or Wavelet transform can be implemented for image decomposition.

- **Image Fusion -** It is the process where two or more images are fused together to generate a new and improved image with better features, by mixing the images of same scene gathered by using sensors or cameras. There different levels at which fusion can be done like at feature level or pixel level. For better results any global optimization approaches can be used here e.g. PSO, DE, GA, and ACO.

- **Image filtering** – Here localized filters can be used to modify the value of every pixel in image depending on the value of their neighborhood pixels. This process depicts extraction of useful features from the images. Filters like Gabor Filter or Log Gabor Filter are example.

- **Dimension Reduction** – This is the feature selection process from the extracted features from image filtering and to further reduce the dimension. Here methods like PCA, LDA, or KDDA can be implemented.

### 1.1.3 Face Recognition

Since more than a decade time companies and researchers in biometrics, pattern recognition and computer vision have given major attention on face recognition process for authenticating individuals. Sensor technology have increased the use of person's face as widely used feature for successful identification in security applications. Some terms under face recognition are,

- Face identification - It is one-to-many process in which image under query is compared with available images in database to determine identity.

- Face verification - It is an authentication process in which one-to-one match of face image under query is done against "to be identified as" face image. To evaluate the verification performance, false acceptance rate (FAR) vs. false rejection rate (FRR) is plotted, called receiver operating characteristics (ROC) curve or detection error trade-off (DET) used to measure the performance of identification system. For a verification to be good enough, it should balance these two rates related to operational requirements.

- False acceptance rate (FAR) – It is the probability that the verification system wrongly matches the input image to a template image in the database.

- False rejection rate (FRR) - It is the probability that the verification system is deviated from the true match between the input pattern and a matching template in the database. It calculates the percent of genuine face images which are wrongly rejected.

There are many issues with face verification method including

- Various illumination conditions
- Pose and face expression
- Occlusion due to accessories
- Hair
- Aging

Fusion of images taken from different sources like image sensors, cameras etc. can eliminate the above given hurdles for proper verification. An example of this is use of visible and infrared (NIR or thermal) images. NIR which utilizes an in between light spectrum range of infrared and visible light throw some counter effects on illumination variations with preservation of useful attributes of face like structure and appearance. It makes face recognition possible on images taken in odd illumination environments.

## 1.2 Optimization problem

Many optimization problems concern with the choice of a best set from the give solution space to achieve some criteria. They are generally divided into two classes one with where solutions are represented with real-valued variables, and the other where solutions are represented with discrete variables. Discrete variables optimization problems. For a problem, P = (S, f) , ‘S’ is search space or solution space with each element a candidate solution and ‘f’ is an objective function to be minimized, we are looking for an object from a finite or possibly countably infinite set. To solve these optimization problems many algorithms are represented as complete or approximate algorithms. For complete algorithms it is possible for all finite size model of a problem to find an optimal solution in expected time. For NP-hard problems, there is no polynomial time algorithm, taking that P is not equal to NP. Therefore, complete methods may need computation time to be exponential in nature for the worst-case. It makes computation time unacceptable [1]. Approximate methods don’t give guarantee of optimal solutions instead give solutions in much less time which are good enough to be accepted.

Approximate methods can be constructive methods and local search methods. In constructive algorithms, solutions are generated from nothing by accumulating to an initially empty partial solution components, till completion of solution. These methods provide solutions quickly but mostly return solutions of low quality if checked against local search algorithms. In local search algorithms, initially a solution is provided at start and then try to replace the current solution with a better solution iteratively in a proper defined neighborhood of that solution [1].

### 1.3 Soft Computing

Soft computing is different from traditional computing or hard computing such that it is resistive to partial truth, approximation, imprecision, and uncertainty. Soft computing is evolved from the model of human mind like the ability to solve problems defined in indistinct terms or solving problems without use of predefined solution steps. Various methodologies has been developed under soft computing like Support Vector Machines (SVM), Fuzzy Logic (FL), and Evolutionary Computation (EC) etc.

For optimization issues in image processing EC methodology shows good response.

#### 1.3.1 Evolutionary Computation

EC involves continuous optimization and combinatorial optimization problems Algorithms under EC are considered to be global optimization methods with a metaheuristic or stochastic optimization behavior and are mostly applied for problems where no initial parameters or solutions are provided and also are in context to expensive optimization. . Evolutionary algorithms have resemblance of Darwin's Natural Selection theory of evolution, where a population is continuously improved by selectively leaving the worse and breeding new children from the better.

#### 1.3.2 Metaheuristics

Global optimization deals with the global optimization of a function or a set of functions according to some criteria. It focuses on achieving the maximum or minimum over all input values in global space. There are two types of algorithmic approaches to find above defined goal of optimization – Heuristic and Metaheuristic.

Heuristics algorithms are basic approximate algorithms that search the solution space to find a good solution. Heuristics are divided into: constructive and local search algorithms. The former finds a solution by assembling together components, of solution, added one after another until completion of a solution and the latter one start from an available solution and modify some of its components to improve overall solution.

Metaheuristics are those algorithms that use heuristics in a more common framework. Metaheuristics are concepts of upper level where search spaces are explored by different strategies. These strategies must be adapted in a way that there should be dynamic balance between the exploitation of search experience called intensification and the exploration of search space called diversification. This balance is required on one side to quickly identify regions in the search space with high quality solutions and on the other side not to waste too much time in regions of the search space which are either already explored or don't provide high quality solutions.[1]

Metaheuristic algorithms can be classified and described in many ways. They can be classified according to the associated characteristics with them and also depending on the required results needed from them.

There are different classifications for metaheuristics approaches like:

- Single solution approach which tries to modify and improve solution of only single candidate
- Population-based approaches which manage and intensify multiple candidate solutions, generally by using characteristics associated with population for guiding the search. It includes EA's and swarm intelligence.

Metaheuristic optimization algorithms can be further divided into Evolutionary Algorithms e.g. Genetic Algorithm (GA), Differential Evolution (DE) and Swarm-based algorithms like Bat Algorithm, Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO).

### 1.3.3 Some Metaheuristic Algorithms Explained

**Particle Swarm Optimization**

PSO is a stochastic, population based optimization method to find solution to an optimization problem in search space. The PSO algorithm was first described by Kennedy and Eberhartin in 1995. The inspiration behind its implementation came from the social and co-operative behavior of various species like birds, fish, termites, ants and even human beings. The main objective of PSO is to optimize a given fitness function.

Initialization of PSO is done using particle population which is spread over the search space. All particles refer to some point in that N-dimension search space. The ith particle is denoted as,

$$X_i = \{x_1, x_2 \dots x_N\}$$

On every iteration, two best values pbest and gbest are associated with each particle. *pbest* denotes the best position associated with the best fitness value of particle 'i' obtained so far and is represented as

$$pbest_i = \{pbest_{i1}, pbest_{i2}, \dots pbest_{iN}\}$$

with fitness function denoted as $f(pbest_i)$ and the overall best position in swarm is denoted by . The velocity or rate of change of position for particle 'i' is represented as

$$V_i = \{v_1, v_2, \dots v_{iN}\}$$

The velocities of particle are updated according to the following equations:

$$V_{id}^{new} = w * V_{id}^{old} + C1 * rand_1() * (p_{bestid} - x_{id}^{old}) + C2 * rand_2() * (g_{bestid} - x_{id}^{old})$$

$$x_{id}^{new} = x_{id}^{old} + v_{id}^{new}$$

Where $id$ = 1, 2… N and $w$ is the weight of inertia for particle. Optimized inertia weights provides a equivalence between global and local explorations, and results in fewer iterations on an average to find near optimal results. C1 and C2 are the acceleration constants used to pull each particle towards pbest and gbest. Low values of C1 and C2 allow the particle to roam far from target regions, while high values result in abrupt movements towards or past the target regions. $rand_1()$ and $rand_2()$ are random numbers between (0, 1).

$V_{id}^{new}$ and $V_{id}^{old}$ are the current and updated particle velocity and $x_{id}^{old}$ and $x_{id}^{new}$ are the current and updated particle positions respectively.

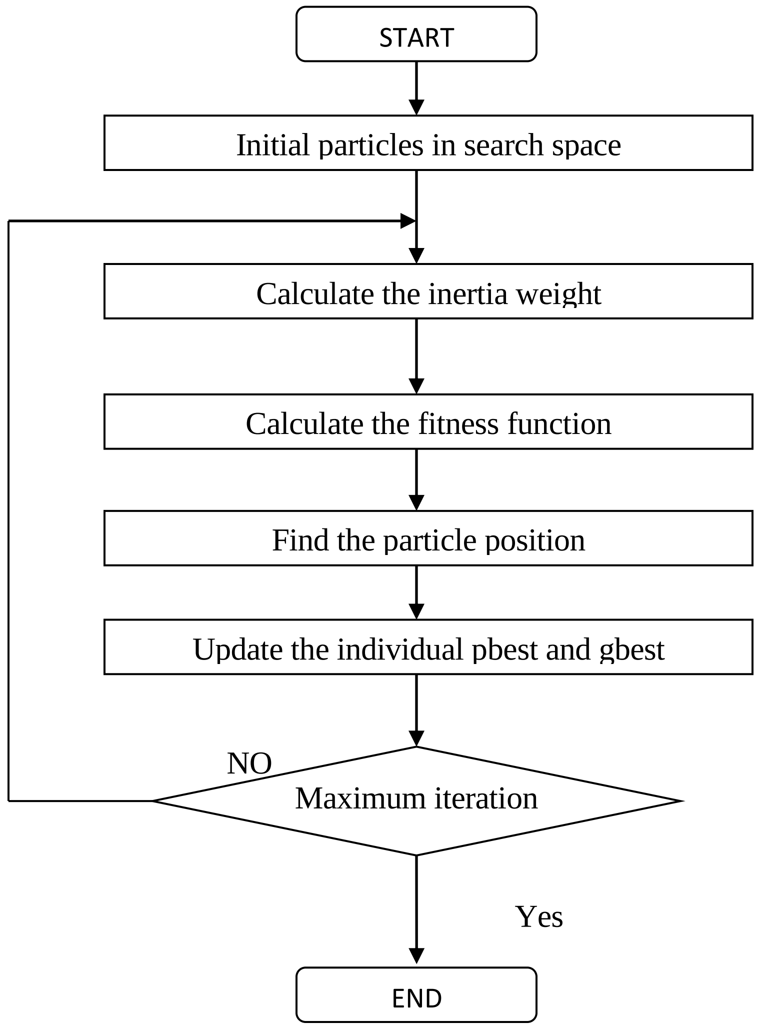


Figure. 1 PSO Flow Chart

**Differential Evolution**

DE is a population-based search technique for global optimization. It is a stochastic and population-based optimization technique. DE was introduced by Storn and Price in 1995 [1]. The DE algorithm fully corresponds to a typical EA like Genetic Algorithm (GA) and composed of steps like reproduction, mutation, recombination, and selection. Its difference from traditional EA's lies in its generation phase for generating new solutions as candidates and a greedy approach for selection from them. Differential evolution is capable of handling non-differentiable, nonlinear and multimodal objective functions and is fairly fast in doing so.

The DE algorithm started evolving very competitively more than a decade ago. Two journal articles [2], [4] were presented by R. Storn and K. V. Price in 1995, providing enough detailing of DE algorithm. Almost after a year DE algorithm's power to solve optimization problems was demonstrated at the International Conference on Evolutionary Computation (ICEC) in 1996 [3].

**Steps involved in Differential Evolution:**

**1. Initialization:**

Population will be initialized between $X_{lower}$ and $X_{upper}$ as,

$$
\begin{array}{l}
for\ i = 1 : NP \\
\{ \\
\quad for\ \ j = 1 : D \\
\quad X_{j,i,G} = X_{lower} + (X_{upper} - X_{lower}) * rand(0,1) \\
\}
\end{array}
$$

**2. Mutation:**

In mutation step the search space is expanded and for a given target vector $x_{i,G}$ any three random vectors $X_{r1,G}, X_{r2,G}, X_{r3,G}$ are selected where $i \neq r1 \neq r2 \neq r3$. Now the difference of two vectors is added to the third vector to form a Mutant vector or Donor vector. There are

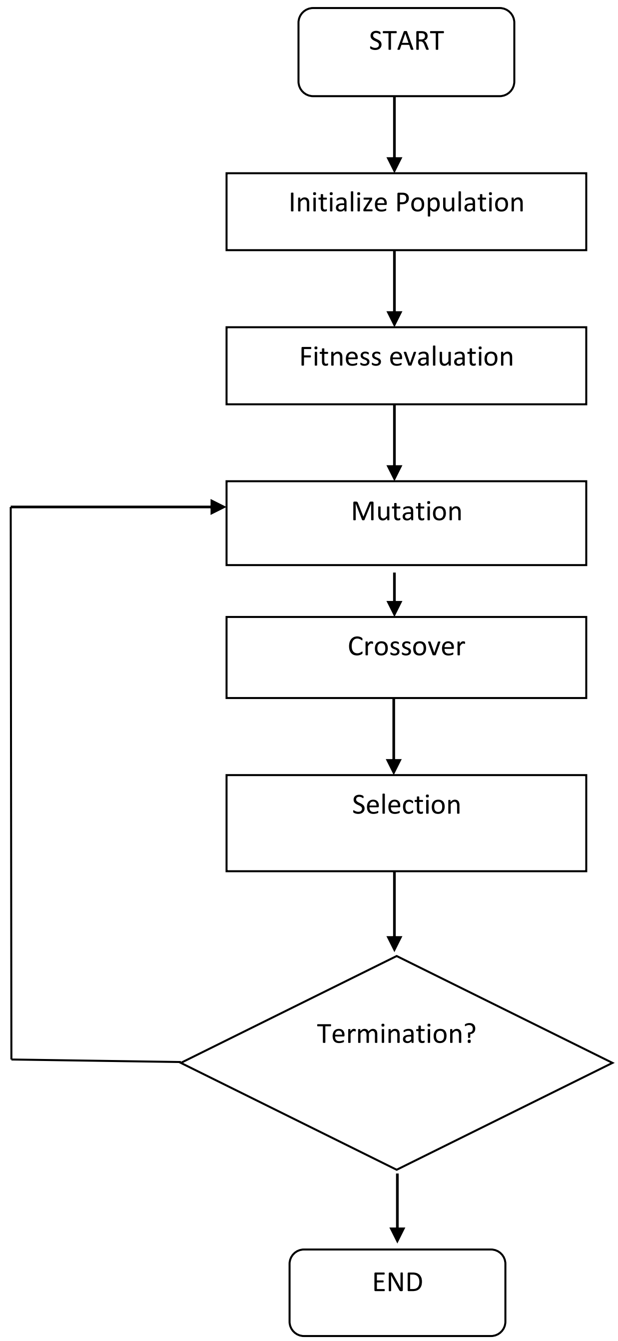


Figure 2. Differential Evolution Flow Chart

different mutation strategies, e.g. "DE/rand/1" mutation strategy is given by,

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G})$$

Here ' $F$ ' is scaling factor with values between (0, 2).

**3. Crossover:**

It is used to increase the diversity of perturbed vectors. It carries useful solutions from previous generation. Trial vector $u_{i,G+1}$ is generated from the elements of the target vector $x_{i,G}$ and mutant or donor vector $V_{i,G+1}$

$$u_{j,i,G+1} = \begin{cases} v_{j,i,G+1} & if\ (rand(j) \leq CR) or\ \ j = rnbr(i) \\ x_{j,i,G} & if\ (rand(j) > CR)\ and\ j \neq rnbr(i) \end{cases}$$ , where $j = 1, 2 \ldots D$

Here $rand(j)$ is a uniform random number generator with a range [0, 1]. *CR* is the crossover constant between [0, 1] and is user defined. Also $rnbr(i)$ is a random number between 1 to D to make sure that trial vector $u_{i,G+1}$ includes minimum of one parameter from $V_{i,G+1}$.

**4. Selection:**

Here the trial vector $u_{i,G+1}$ is compared against the target vector $x_{i,G}$ using survival of the fittest principle .The trial vector $u_{i,G+1}$ is compared with the target vector $x_{i,G}$ and the one with a better fitness value is included to the next generation.

There are many variants for DE. To classify the variants, following notation is used [2]:

$$DE / x / y / z\ ,$$

Where,

$x$ : denotes the vector to be mutated, *'rand'* for population vector chosen randomly or *'best'* for the vector with best fitness function value.

$y$ : denotes the number of vectors used for differentiation.

$z$ : tells which crossover scheme is used, *'bin'* for a binomial scheme or *'exp'* for an exponential crossover.

The convergence rate and accuracy of DE can be enhanced with implementation of different mutation and selection strategies. Some of those strategies are,

*1. DE/best/1/exp*

*2. DE/rand/1/exp*

*3. DE/rand-to-best/1/exp*

*4. DE/best/2/exp*

*5. DE/rand/2/exp*

*6. DE/best/1/bin*

*7. DE/rand/1/bin*

*8. DE/rand-to-best/1/bin*

*9. DE/best/2/bin*

*10. DE/rand/2/bin*

**Advantages of DE**

- DE is more simple and unambiguous to implement compared to other EA's.
- DE has been found more on performance side in comparison to other approaches tested on uni-modal, multi-modal, separable and non-separable problems.
- The control parameters in DE are less (*Cr*, *F*, and *NP* in classical DE).
- DE has less space complexity as compared to other widely used real parameter optimizers.

## 1.4 Wavelet Transformation

Wavelet transforms are used for signal decomposition, where higher levels of it corresponds to more scaled resolution. Wavelet transform has two main subtypes named continuous transform and discrete transform.

### 1.4.1 Continuous Wavelet Transform

This type of wavelet transform is carried out by imposing inner product of the image matrix to the signal and the wavelet functions. Wavelet coefficient using continuous transform can be calculated as,

$$W_f(a,b)=(f,\Psi_{a,b})=\int f(x)\Psi_{a,b}(x)dx$$

Wavelet coefficients tells the information stored in the signal at a particular level. To recover the original signal inverse transform can applied as following,

$$f(x)=\frac{1}{C_w}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W_f(a,b)\Psi_{a,b}(x)db\frac{da}{a^2}$$

Continuous wavelet requires signal and wavelet function to be in closed type, making it unfeasible to apply in real scenarios.

### 1.4.2 Discrete Wavelet Transform

A wavelet transformation of an image in regard to Discrete Wavelet Transform (or DWT can be said as an orthogonal function applied to limited group of data. DWT uses discrete set of the wavelet scales and translations with some set of rules. Here the signal is continuous itself, discrete word refers to the sets of decomposition at multiple levels and the different factors involved it in.

Suppose a scale $J$ is given, the signal is represented as follows in terms of wavelet coefficient,

$$f(x)=\sum_k c_{Jk}\Phi_{Jk}(x)+\sum_{j=1}^{J}\sum_k d_{jk}\Psi_{jk}(x)$$

The DWT is a process defined in term of bank of filters. Every level of image decomposition involves splitting of signal into HF and LF components. The LF components may be decomposed until a desired resolution is achieved.

If there are several levels of image decomposition involved then this task is referred as multiresolution decomposition. In context of computation power, for optimized usage of wavelet decomposition in image fusion task single level decomposition is considered enough, but also rely on the ratio of the resolutions of images under process.

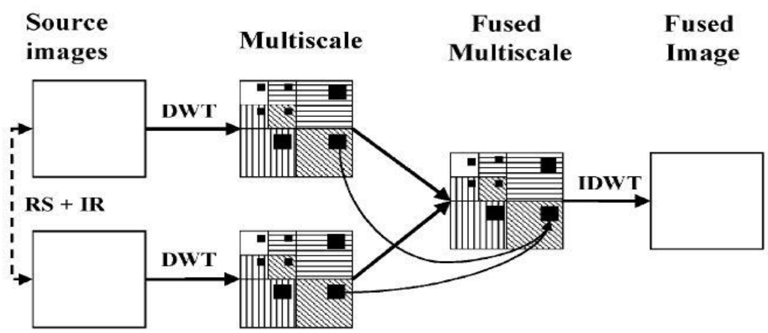


Figure 3- Basic framework for Image Fusion using Wavelet Transform

Image fusion tasks can employ wavelet transform for following reasons:

- Being a multi-scale or multiresolution approach it is good choice to perform with different image resolutions. Image fusion process requires multi-scale information.
- Image decomposition in DWT with several coefficients allows keeping the image information intact.
- These coefficients retrieved from images can be merged to obtain newer coefficients.
- After merging coefficients, final resulting image is obtained by applying IDWT, where detail of merged coefficients is already saved.

### 1.5 Gabor Filter

Feature extraction of an image is widely done using Gabor filter. It is multi-channel filtering process selects parts of essential signals from original image and discards others including the noise signals. They are shown to acquire optimized localized details in spatial and frequency domain. They are represented as sinusoidal plane of specific frequency and orientation which is modulated by a Gaussian envelope.

Below is the equational representation of Gabor filter:

$$g(x, y) = s(x, y)w(x, y),$$

here $s(x, y)$ represents complex sinusoidal also called as carrier, and $w(x, y)$ represents a 2-D Gaussian-shaped function also called as envelope.

## 1.6 Scope of Study

The scope of study involves an optimized image verification system with an input as -infrared and visible images. The approach will be to fuse those images using a metaheuristic algorithm (such as DE) to get an optimized fused image. The research work is aimed to implement two face verification schemes with comparison between using FAR vs FRR graph. Literature surveys point that different implementations for face recognition have suffered with illumination and facial expression as hurdles to achieve a good accuracy rate. Use of Near infrared images with visible images overcome these type of drawbacks while preserving details of the images after fusion.

The scope of scheme one includes image decomposition using Wavelet Transform while applying DE for optimized wavelet coefficients selection. While the second scheme employs Gabor Filter for feature extraction individually for both images and then applying DE on those extracted features.

The metaheuristic algorithms like DE depends on formulation of fitness function which provides an optimum vector selection. DE involves mutation, crossover and selection which provide greedy approach for finding an optimized solution vector. DE evaluates population on the basis of fitness function value of each population member. The results are also be compared on the basis of match score level.

The database of required images for experimental purpose contains vast range NIR and VI images acquired over a period of time under different illumination condition. It helps to increase the precision level of the acquired result.

# Chapter 2
# Review of Literature

**V. Aslantas and R. Kurban (2010)** have presented the fusion of multi-focus images with GA and DE and also a comparison between both schemes. There proposed framework was to decompose the images which were defocused, into blocks, and after that select the blocks whose sharpness weightage are higher and calculated from a criterion function .After that fused images were put to test using GA an DE fitness functions separately. Performance check was done using fused and reference images. Performed experiments have shown that the DE scheme overcomes other methods like GA, Wavelet and Laplacian pyramid.

**J. Vesterstrøm and R. Thomsen (2004)** in their study they have compared the performances of different DE, PSO and EA's based on their applicability to numerical optimization. They have done intensive comparison based on 32 benchmark problems. The experimental results show that DE has outperformed other algorithms in most of the problems in context to convergence and finding the optimal solution in almost every iteration.

**I. De Falco et al. [2008]** have approached to solve the satellite image registration problem with the use of metaheuristic algorithm DE. Image registration process has tasks like feature detection and matching, transform model estimation and image resampling and transformation. In affine transformation method, the problem of choosing best two images to be registered out of many transformations was taken. They have implemented DE with affine transformation and Mutual Information maximization for image registration. This method was then compared to 5 different tools available for image registration. The results show that DE has edged in performance over all other tools.

**T.Bhadra et al. [2012]** in this paper they have defined a meta-classification scheme based on support vector machines in conjunction with DE for parameter optimization process. A DE fitness function is made by them keeping in check 3 classifier constraints, accuracy, sensitivity and specificity. The proposed meta-classifier $SVM_{meta}$ with DE as optimizing agent has outperformed other methods tested using 3 different dataset. The results show that use of fitness function has improved the overall classifier performance.

**S.Das and A.Konar [2009]** has proposed in their research work an evolution-fuzzy clustering method to automatically group pixels of an image into different homogenous areas. They have used an improved version of DE to find the number of naturally forming clusters in image and also to tune cluster centers. The have tested the proposed method and two other clustering techniques on an image database comprised of different grayscale images and remote sensing satellite images. The comparison show that their proposed AFDE outperformed the fuzzy variable string genetic algorithm (FVGA) and fuzzy c-means (FCM).They have implied that by doing some changes in the parameters of the DE more efficient results can be achieved.

**S. Das and P.N. Suganthan [2011]** has described the concepts of DE, different variants of DE available, application to different optimization problems. The paper summarizes the advantages of DE which can be exploited by integrating it into any system requiring to solve optimization problem. They have also mentioned a pool of future scope for DE.

**M.M.Ali et al. [2005]** in their tested five different stochastic global optimization algorithms to a collection of selected 50 continuous global optimization problems. The algorithm's merit was calculated on the basis of general applicability, efficiency, trustworthiness and ease of use. The test suggest that although DE was dominated by other four algorithms but it consistently improved its estimate of global optimum.

**S.Singh et al. [2004]** in their paper suggested two approaches to overcome the insensitivity of the IR images caused by eyeglasses and that of visible images to the illuminations. They suggested and compared two approaches first of image fusion of IR and visible images in wavelet domain and second was of feature based fusion in eigenspace domain. They have used GA for optimization operation here. They used Equinox face dataset. There experiment results have shown that wavelet domain fusion of images have more improvements in face recognition.

**W. Hizem et al. [2009**] in their research work designed an image capturing mechanism for both NIR and visible images to create a face database from it. Their aim was to study the sensitivity of visible images to illumination and insensitivity of NIR images to the same. First they compared NIR and visible images with algorithms like local based (LDA), global based (EGM) and LDAG with different protocols defined for the image sets. Here the performance of NIR images have been better than visible images alone. Second they performed score level fusion with these algorithms using image set defined by a protocol. This experiment have shown that the fusion of two different algorithms every time improves the performance without regard of type of images.

**R.Singh et al. [2008**] have presented a technique to fuse long wave infrared (LWIR) and visible face images using 2v-GSVM which performs classification of images at different levels of granularity and image resolutions and then to fuse them. Then they have used 2D log polar Gabor transform and local binary pattern feature extraction algorithms which are used on those images to extract global and local facial features. After that they proposed match score fusion algorithm implemented with DSm. They merged these fusion schemes then tested them on face databases named Notre Dame and Equinox. Results have shown the superiority of merged approach over individual approaches.

**W.Hizem and Y.Ni, Dorizzi [2008]** have designed a system to capture NIR and visible images simultaneously. They have designed it in a way that it can be integrated to their mobile platform VINSI. They have referred to the illumination problem related to the image verification. They developed a landmark (e.g. eyes, nose and mouth) detection algorithm for these type of face images. This algorithm has been tested on NIR images taken from different sensors. The results prove that this methods can be used on different types of infrared images with good results.

**R. Raghavendra et al. (2011**) has proposed a face verification framework using NIR and visible images based on two versions of PSO (real valued and binary).The IRVI image database was used comprised if various NIR and visible images taken over period of time and under non-controlled illumination conditions. First those NIR and visible images are separately decomposed to sub-band level. Then two PSO schemes are used for image fusion and global optimization using a fitness function for feature selection from the fused image. The test was performed using match score fusion and feature level fusion score with a reference image. The first scheme using real PSO have shown better EER percentage as compared to tests implemented on binary PSO and also on individual NIR and visible images.

# Chapter 3
# Present Work

In this chapter, we have presented the problem of our research work, its objectives and methodology that we used for our purposed research work and also an introduction about the tool used for implementation purpose. Here section 3.1 discuss about the base on which overall research work built upon that is the problem formulation. Section 3.2 discuss the objectives that we have tried to complete through our implementation work. Section 3.3 discuss the methodology we have used for our research work. Section 3.4 discuss about the tool that we used for implementation.

## 3.1 Problem Formulation

In biometrics systems, image verification has been used for verifying identity of a person based on their current face image and image stored in database. There are many frameworks used over decade to build image verification systems using various image processing components. But there are always issue like illumination, age, accessories etc. which come in play and impacting the desired rate of face verification. Image fusion have shown great resistance to these type of issues, especially with Near infrared images (NIR) and Visible images (VI).After that there is issue of getting optimized set of features from the images, which can be merged and generate a fused image of only best possible features. There are several optimization algorithms which can be employed here. There is also a problem of achieving good results with low computation power, as image processing systems demand high computation power for processing the verification schemes. Finally face verification systems require to achieve better values for false acceptance (FAR) and false rejection rate (FRR) in order to prove their usability.

Our work has been focused on achieving a better FAR and FRR values for the novel schemes which we have implemented and also low computation time between those schemes.

### 3.2 Objectives

Our main objective for this thesis work is to implement two novel face verification schemes using Differential Evolution (DE) as the optimization algorithm at feature level. Other than that the proposed research work aims at covering the following research objectives:

Use NIR and VI as face image dataset for fusion process.

Implementing DE algorithm to optimize the feature selection process.

Plot the FAR vs FRR graph for both schemes to check superiority among them.

Compare the CPU time taken by both schemes.

### 3.3 Research Methodology

Research methodology refers to solving a problem in systematic way. It is targeted to provide the planned work to be done in order to complete the research. It is required for a researcher to understand the research methodology along with research techniques.

- Initially we have to acquire a database of images from two sources viz. NIR and Visible which are taken under different illumination condition and also are taken over a period of time. For this purpose CASIA NIR-VIS 2.0 Face Database is used.
- Our proposed face verification schemes requires extraction of features to reconstruct a new image. For this purpose we have used Wavelet Transform and Gabor Filter at both schemes respectively.
- Fusion process will be applied using DE so that to get only those vectors out of the fused image which are of high interest. It is done using Rosenbrock Saddle test function. Rosenbrock is a kind of optimization problem in which objective functions are inexpensive to compute.
- After getting the feature vectors of interest from above optimization process, a new image is constructed.
- Resulting image is compared to reference images from the image database. Here we have calculated the match score from this comparison.
- The resulting scores are then plotted using FAR vs FRR graph.

### 3.4 Proposed Schemes

We have proposed two novel image verification schemes and compared their FAR and FRR values to check the superiority.

### 3.4.1 Image verification scheme-I

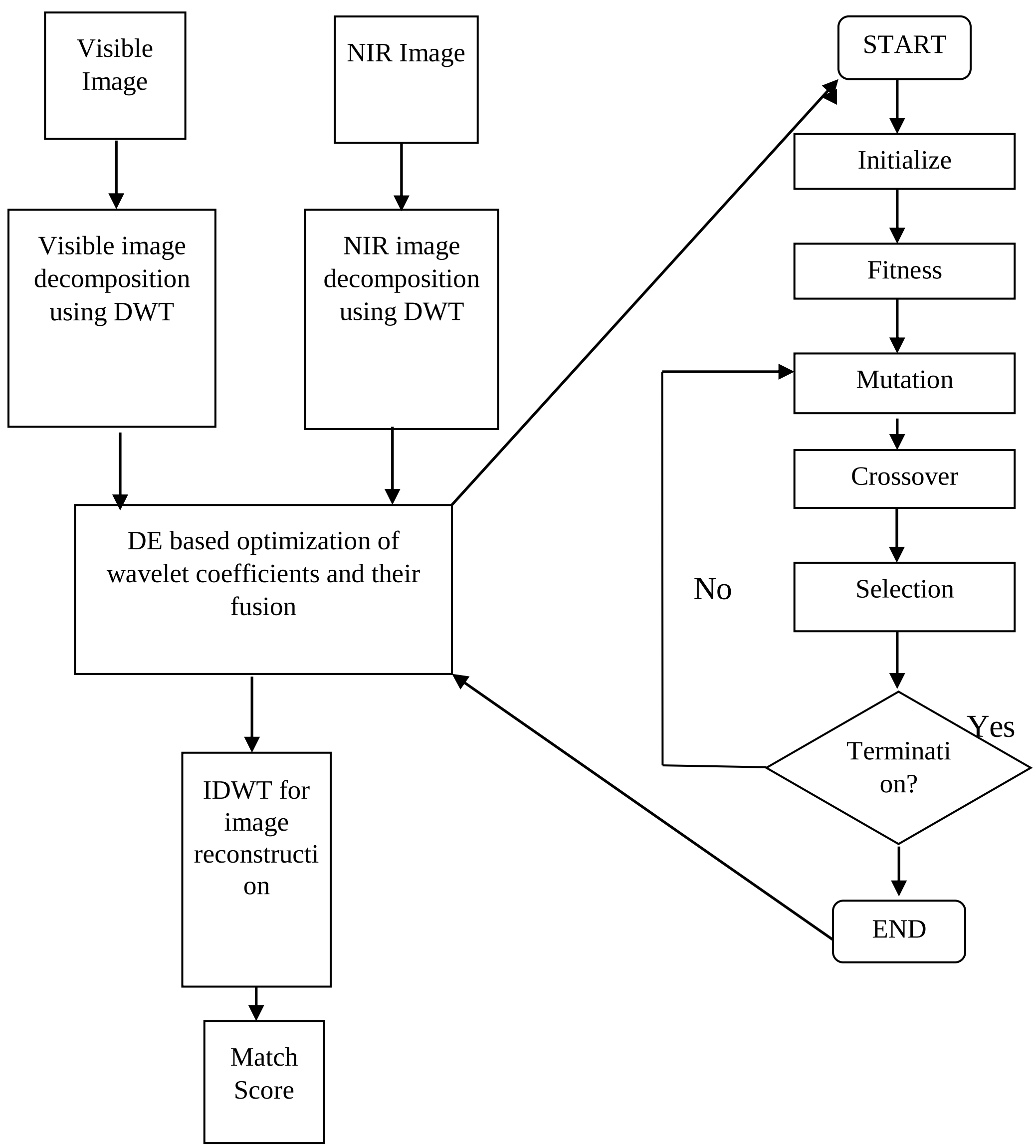


Figure 4 - Image verification scheme-1

The image fusion scheme-1 is comprised of following steps:

NIR and Visible images are given as input to 1-Level discrete wavelet transform (DWT) for multi-scale decomposition of those images individually.

After decomposing images into different sub-bands, respective wavelet coefficients of both images are tested with a fitness function (Rosenbrock saddle test function) with DE. The qualifying solutions are used to generate newly fused image in next step. The fitness function here is used to check if either the fused multi-spectral images have reached optimal fitness or number of iterations are completed. Here DE specific steps like mutation, crossover and greedy selection are employed to find optimal solutions (wavelet coefficients).

Now inverse discrete wavelet transform (IDWT) is performed to obtain a single fused image from the optimal solutions derived from previous step.

Lastly we shall map the obtained image against reference images to get a match score. FAR and FRR values are calculated and plotted. Also the CPU time taken by the scheme is also calculated.

### 3.4.2 Image verification scheme-II

This scheme for image verification is based on feature level fusion where features from NIR and Visible images are extracted using Gabor filter and features are optimized using DE. The steps shall be as follow:

- Initially both NIR and Visible images shall be processed for feature extraction. Here we have used Gabor Filter.
- Here we shall be employing feature level fusion of both NIR and Visible image features selected in last step.
- Now we shall be using DE for optimized selection of the features.
- Finally the image constructed from the features obtained from above step is compared to the reference images and a match score is generated.
- FAR and FRR values are plotted on graph and CPU time taken by scheme is also calculated.

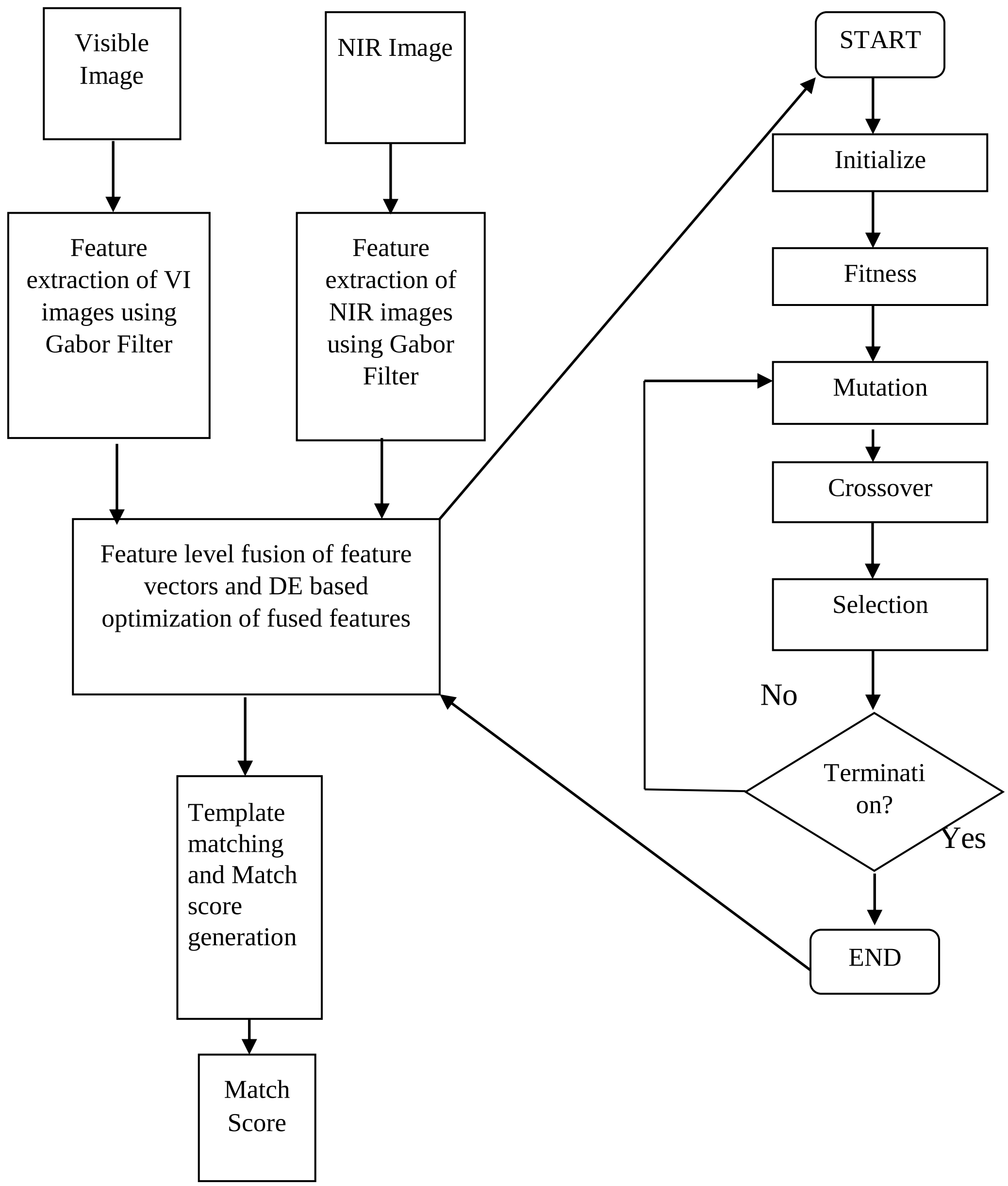


Figure 5 - Image verification scheme-II

### 3.5 Tools used

Requirements for image processing related tasks require higher computation resources. MATLAB is one of the most important tool for image related processing. MATLAB helps in understanding the concept of programming very easily and can simulate the results very easily. It uses very high level language for the numerical computation and visualization. It can be used to analyze the images, run algorithms and create applications easily. Simplicity is another aspect of this tool which makes any novice comfortable for it to use. So we have used MATLAB R2014a as tool to implement proposed image verification schemes.

MATLAB has following advantages over other languages:

- Matrix formulation is done on the basis of data element. Matrix generation is done in rows and column basis. The Mathematical function required for the different operation on MATLAB is given by built in functions to MATLAB environment.
- For the generation of two arrays for single operation that is for addition needs only single command instead of using looping condition.
- We can plot the different graph on the basis of results we get in numeric form. It's so easy to change the colours, size, scales gesture and many more of the graph on the need for differentiation the methods
- Functionality of this tool is greatly experienced by the user; it is only possible with the help of toolbox used. It provides all kind of tools which is specified for different function. It gives more accurate results according to it.

There are also disadvantages:

- As we all know MATLAB is very huge software, it needs large amount of memory which makes our system to slow for working.
- It can take much CPU time from windows because there are many processes running under it.

Inputs into MATLAB can be done through different ways:

1 Enter an explicit list of elements.

2 Load matrices from external data files.

3 Generate matrices using built-in functions.

4 Create matrices with your own functions in M-files.

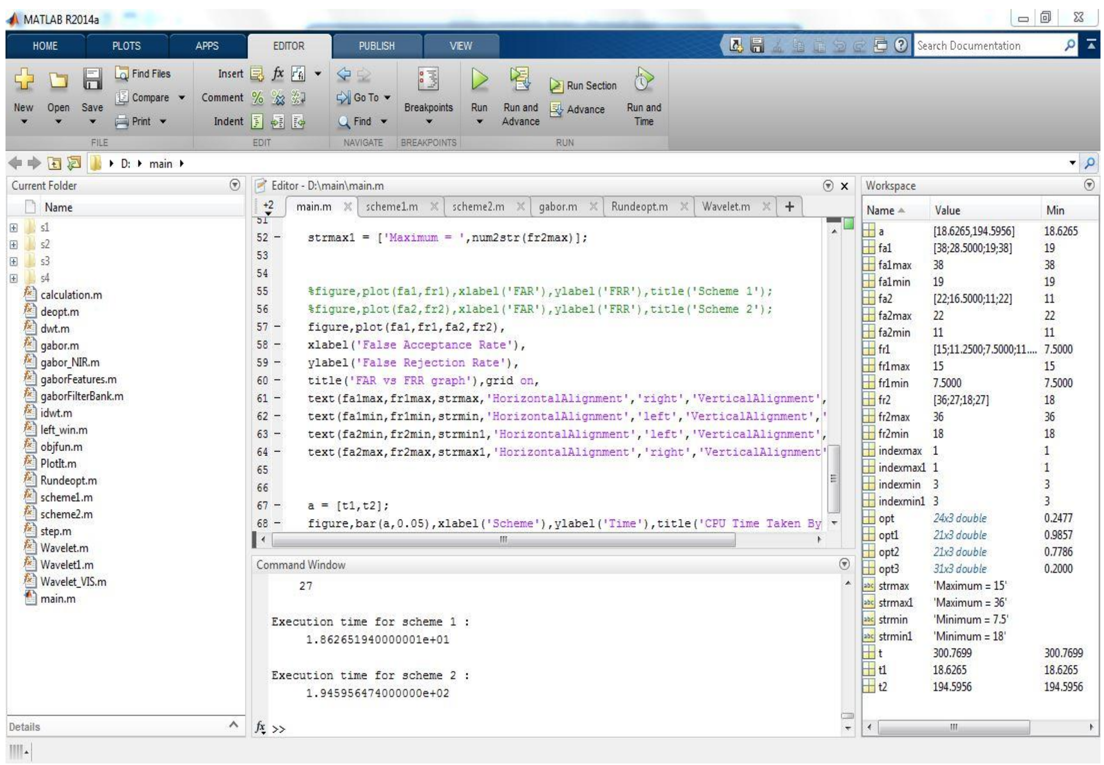


Figure 6 - MATLAB GUI environment

# Chapter 4
# Results and Discussion

## 4.1 About Dataset Used

From our proposed schemes it is clear that we need face image dataset containing both NIR and Visible images. Till now there are very few face image databases available globally free of cost to use and creating one is also costly and time consuming task. Out of those limited database available we have chosen CASIA NIR-VIS 2.0 Face Database. This database has four set NIR and VI images, containing thousands of those images with 725 test subjects. The age of test subjects are spanning from children to old people. The images are taken over a period of time (2007-2010), under different illumination conditions and different with facial expressions. Many test subjects are also wearing spectacles making the image database richer for experimental purpose.

The NIR-VIS 2.0 database includes the following contents:

- The raw images, including the VIS images in JPEG format and the NIR images in BMP format. Their resolutions are both 640x480.
- The eye coordinates of the VIS, NIR images. They are automatically labelled by an eye detector, and several error coordinates are corrected manually.
- Cropped versions of the raw VIS, NIR images. The resolution is 128x128, and the process is done based on the eye coordinates.

Figure 7- Visible (1$^{st}$ row) and NIR (2$^{nd}$ row) images of dataset

We have used only cropped versions of the face images with resolution 128x128. We have chosen this resolution because higher resolutions need higher computation resources and CPU time.

### 4.2 Experimental setup

DE requires its various parameters to be in optimal setting to achieve good set of optimized population. Various parameters and there values which we have used in DE algorithm are,

- Number of population members, I_NP = 30
- Crossover probability constant, F_CR = 1
- Objective function parameters, I_D = 2
- Number of iterations, I_itermax = 200
- Scaling factor or Stepsize weight, F_weight= 0.85
- Since there are many variants of DE available we have used two of its basic variants using variable I_strategy = 1 or 2, where,
    1. *DE/rand/1*, the classical version of DE.
    2. *DE/local-to-best/1*, used by quite a number of scientists. Attempts a balance between robustness and fast convergence.

```
if (I_strategy == 1)                              % DE/rand/1
  FM_ui = FM_pm3 + F_weight*(FM_pm1 - FM_pm2);    % differential variation
  FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;      % crossover
  FM_origin = FM_pm3;
elseif (I_strategy == 2)                          % DE/local-to-best/1
  FM_ui = FM_popold + F_weight*(FM_bm-FM_popold) + F_weight*(FM_pm1 - FM_pm2);
  FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;
  FM_origin = FM_popold;
```

Figure 8- DE strategies

To check the fitness values of the population members we have used Rosenbrock Saddle test function which provides good minimum value with less computation cost,

```
%---Rosenbrock saddle------------------------------------------------
F_cost = 100*(FVr_temp(2)-FVr_temp(1)^2)^2+(1-FVr_temp(1))^2;
```

Figure 9- Rosenbrock Saddle Test Function

Due to limited computation resource we have used only one test subject per execution phase. The NIR and VIS face images of the test subject are given as input to both schemes. For Scheme-I we have used only 1-Level of decomposition using Wavelet transform. As higher level of image decomposition requires more computation power resulting in hours or even days of time for complete execution.

### 4.3 Results

Below given experimental results are based on two test subjects face images from CASIA database. We have generated results using both DE strategies individually as discussed above.

Figure 10- NIR and VIS image of test subject-1

Figure above shows the NIR and VIS images of test subject-1 chosen randomly from the CASIA image database.

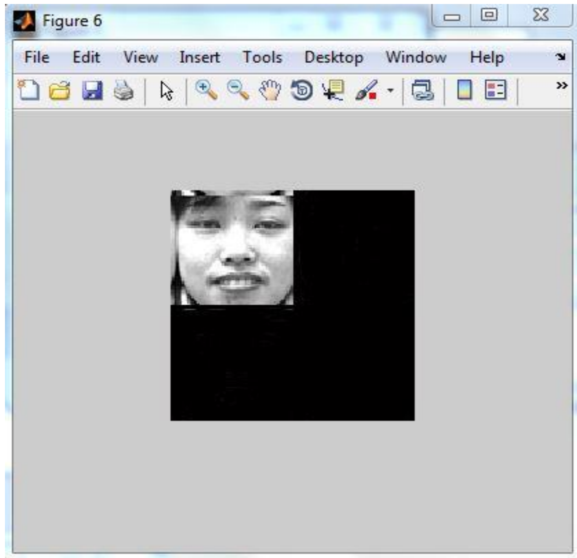


Figure 11- 1-level DWT representation

Above figure shows the 1-level of image decomposition done by the DWT.

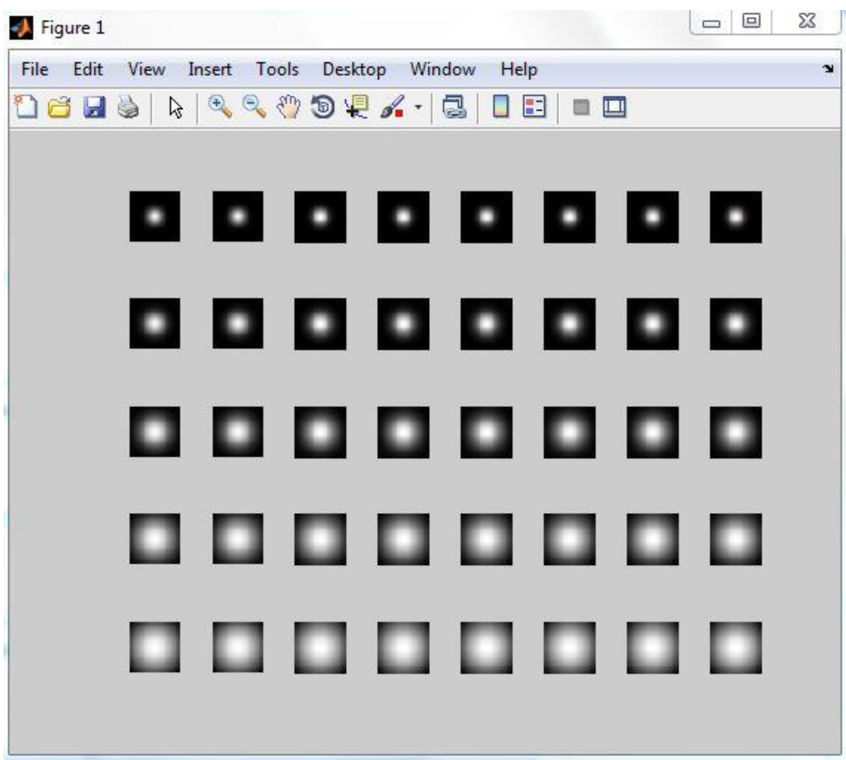


Figure 12- Magnitudes of Gabor filters

The figure shows the Gabor filter bank generated after the images are exposed to Gabor filter module.

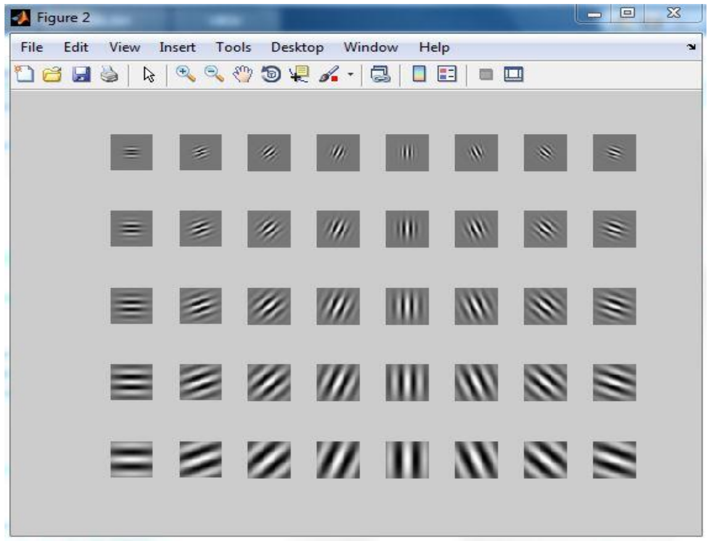


Figure 13- Real parts of Gabor filters

```
Command Window
  Values for False Acceptence and False Rejection
  Scheme 1 False Accepetence:
       2.100000000000000e+01
       1.575000000000000e+01
       1.050000000000000e+01
       2.100000000000000e+01

  Scheme 1 False Rejection :
      16
      12
       8
      12

  Scheme 2 False Accepetence:
      36
      27
      18
      36

  Scheme 2 False Rejection :
      24
      18
      12
      18

  Execution time for scheme 1 :
       2.095093429999997e+01

  Execution time for scheme 2 :
       2.250002423000001e+02
```

Figure 14 - FAR and FRR values from both schemes

The figure shows the match score values generated after the resulting fused image is compared with a template image in database. We can see from values for scheme-I are better than that of scheme-II.

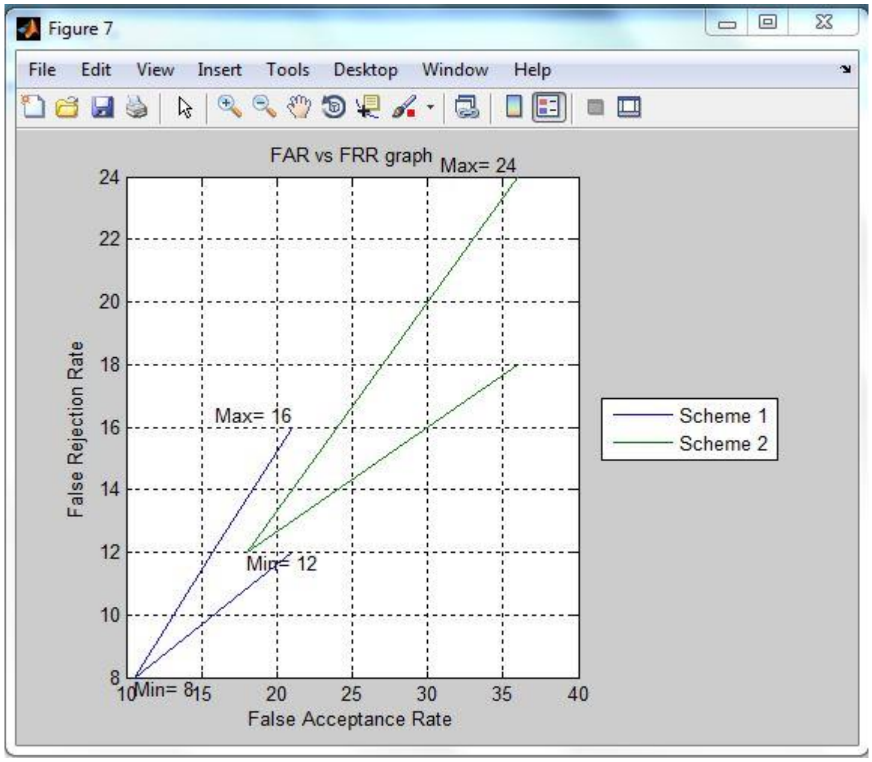


Figure 15- FAR vs FRR graph

The figure above shows the comparison graph for FAR and FRR values between both schemes with first DE strategy. Here we can see the scheme-I is outperforming scheme-II in FAR.

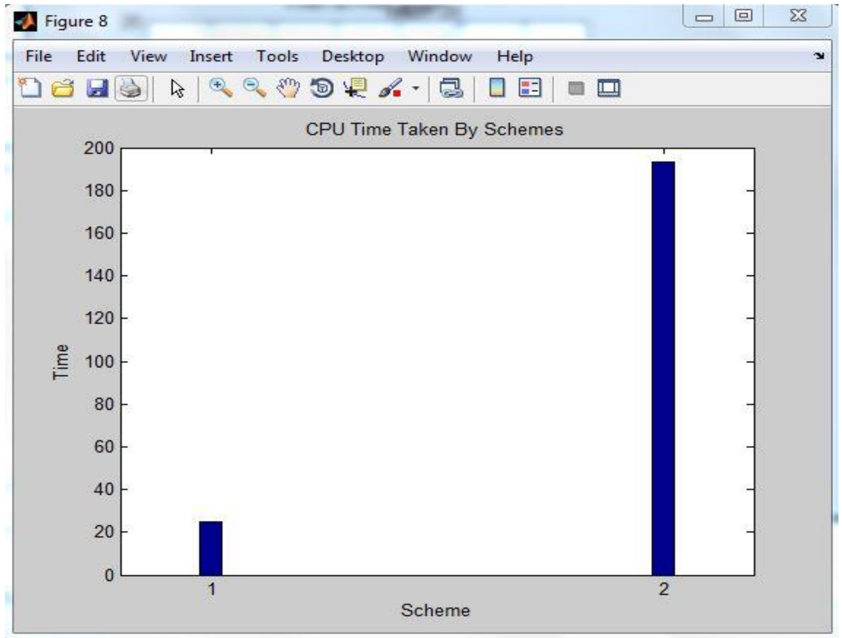


Figure 16- CPU time comparison graph

```
Command Window
Values for False Acceptence and False Rejection
Scheme 1 False Accepetence:
     1.300000000000000e+01
     9.750000000000000e+00
     6.500000000000000e+00
     1.300000000000000e+01

Scheme 1 False Rejection :
    16
    12
     8
    12

Scheme 2 False Accepetence:
     2.300000000000000e+01
     1.725000000000000e+01
     1.150000000000000e+01
     2.300000000000000e+01

Scheme 2 False Rejection :
     1.300000000000000e+01
     9.750000000000000e+00
     6.500000000000000e+00
     9.750000000000000e+00

Execution time for scheme 1 :
     1.641130520000002e+01

Execution time for scheme 2 :
     1.996968801000000e+02
```

Figure 17 - FAR and FRR values from both schemes

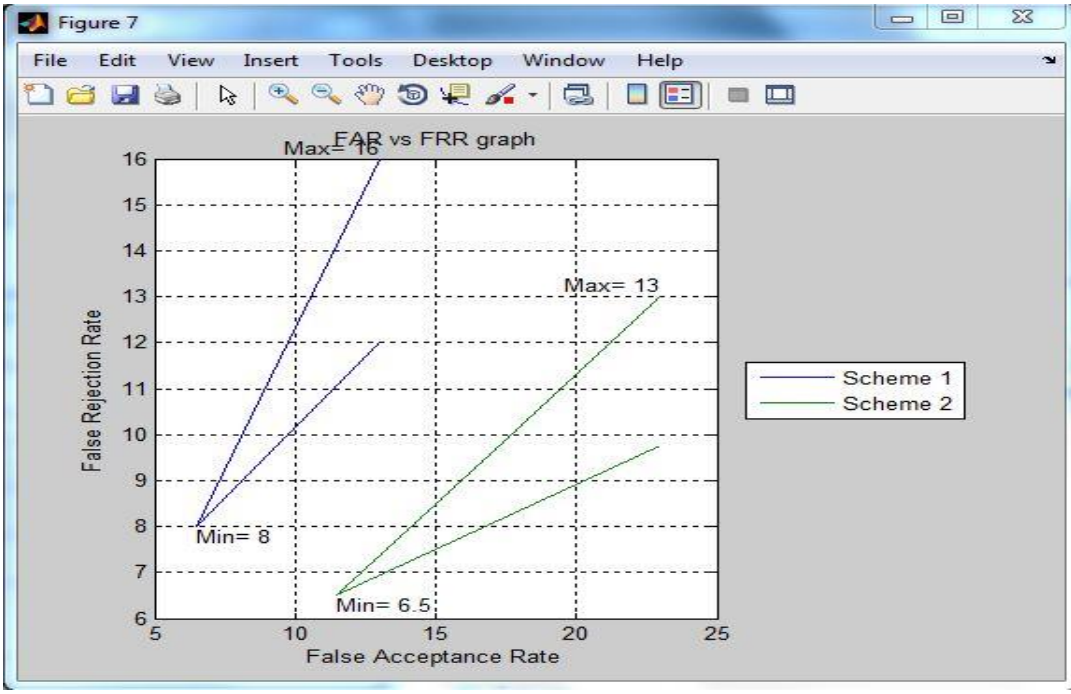


Figure 18- FAR vs FRR graph

The figure above shows the comparison graph for FAR and FRR values between both schemes with second DE strategy. Here we can see the scheme-I is outperforming scheme-II in FAR.

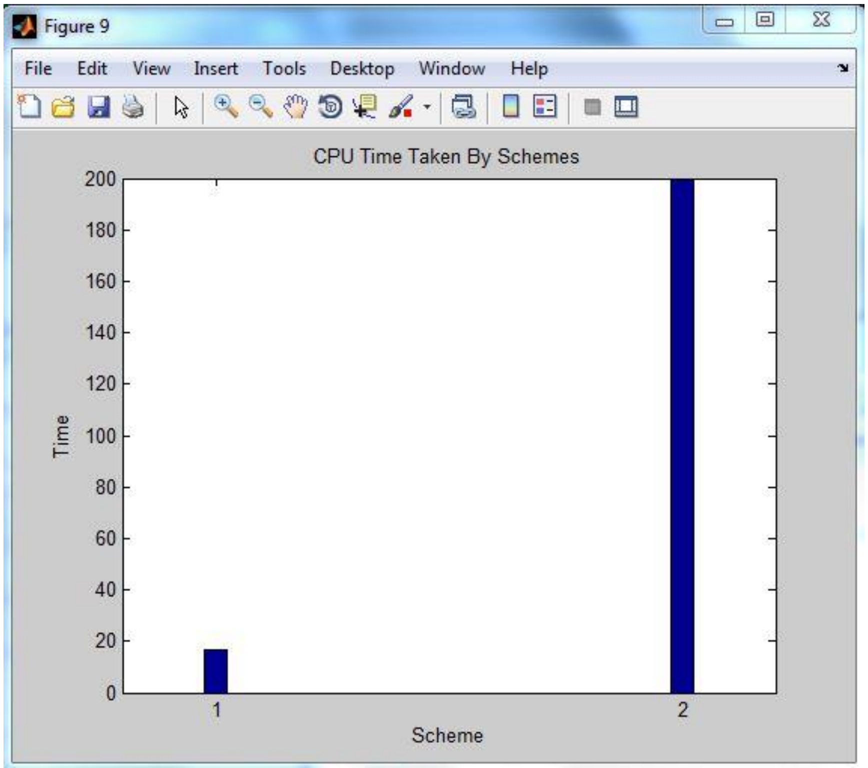


Figure 19- CPU time comparison graph

Figure above shows the comparison between both schemes for second DE strategy. Here we can see that scheme-I is very fast in execution as compared to scheme-II.

Figure 20- NIR and VIS image of test subject-2

Figure above shows the NIR and VIS images of test subject-2 chosen randomly from the CASIA image database.

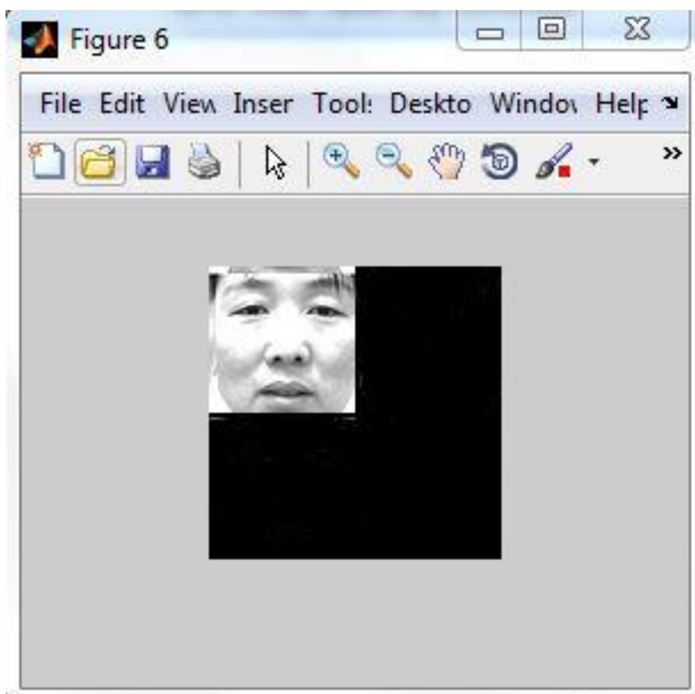


Figure 21- 1-level DWT representation

```
Command Window
Values for False Acceptence and False Rejection
Scheme 1 False Accepetence:
     2.600000000000000e+01
     1.950000000000000e+01
     1.300000000000000e+01
     2.600000000000000e+01

Scheme 1 False Rejection :
     2.600000000000000e+01
     1.950000000000000e+01
     1.300000000000000e+01
     1.950000000000000e+01

Scheme 2 False Accepetence:
     3.000000000000000e+01
     2.250000000000000e+01
     1.500000000000000e+01
     3.000000000000000e+01

Scheme 2 False Rejection :
    32
    24
    16
    24

Execution time for scheme 1 :
     2.082613350000008e+01

Execution time for scheme 2 :
     1.979028685999999e+02
```

Figure 22- FAR and FRR values of both schemes

Above figure shows the match score values generated after the resulting fused image is compared with a template image in database for both schemes with first DE strategy.

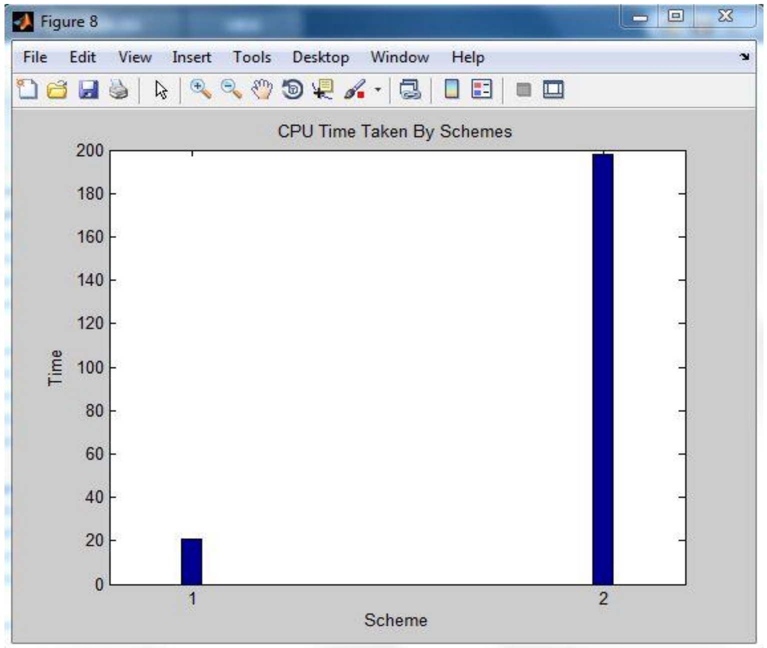


Figure 23- CPU time comparison graph

Figure shows the comparison between time taken for execution of both schemes using first DE strategy. Scheme-I outperforms scheme-II.

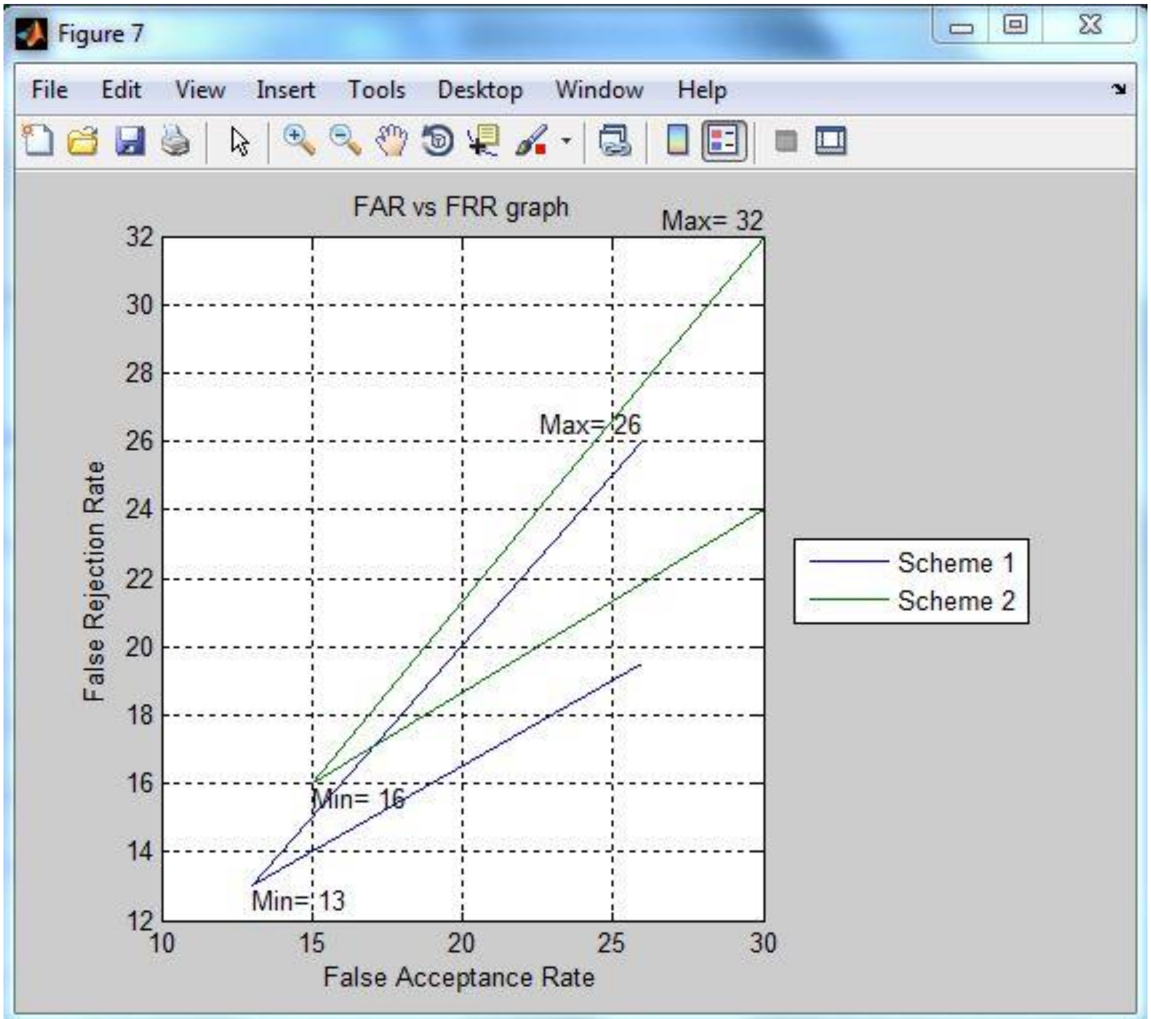


Figure 24- FAR vs FRR graph

The figure above shows the comparison graph for FAR and FRR values between both schemes with first DE strategy. Here we can see the scheme-I is outperforming scheme-II.

```
Command Window

Values for False Acceptence and False Rejection
Scheme 1 False Accepetence:
     1.300000000000000e+01
     9.750000000000000e+00
     6.500000000000000e+00
     1.300000000000000e+01

Scheme 1 False Rejection :
     1.100000000000000e+01
     8.250000000000000e+00
     5.500000000000000e+00
     8.250000000000000e+00

Scheme 2 False Accepetence:
    20
    15
    10
    20

Scheme 2 False Rejection :
    12
     9
     6
     9

Execution time for scheme 1 :
     1.673890730000005e+01

Execution time for scheme 2 :
     2.690081243999999e+02
```

Figure 25 - FAR and FRR values from both schemes

Above figure shows the match score values generated after the resulting fused image is compared with a template image in database for both schemes with second DE strategy. Values of scheme-I are better than scheme-II.

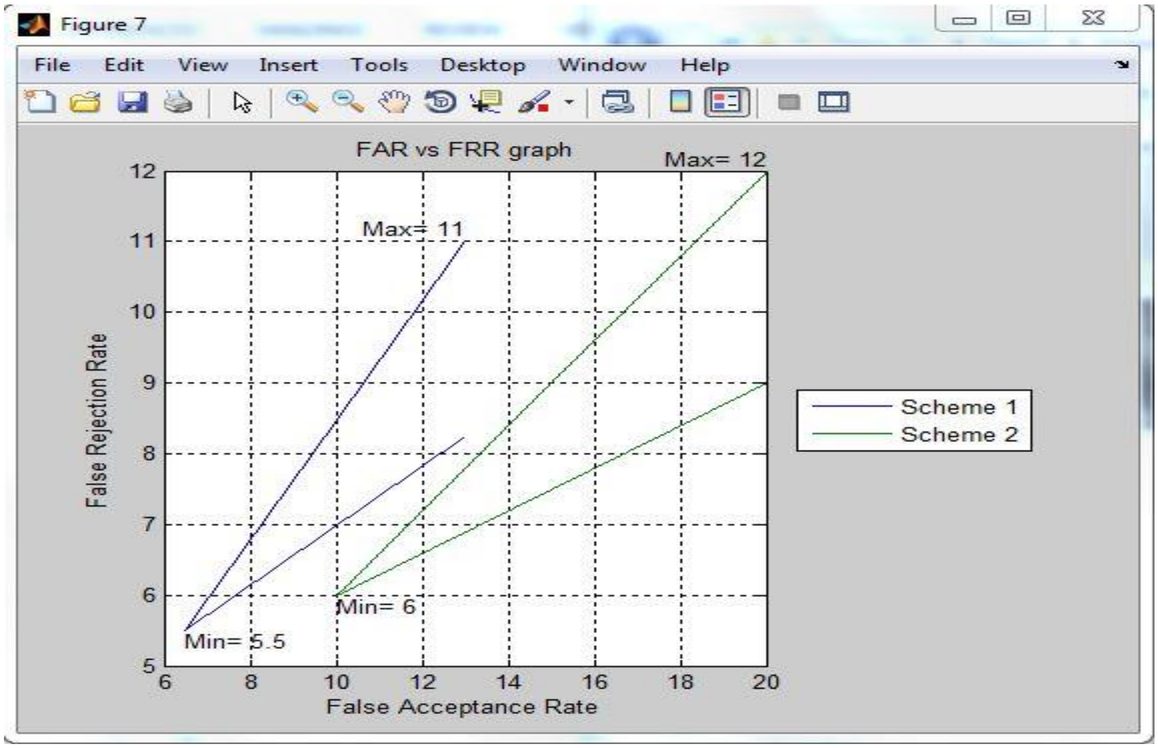


Figure 26- FAR vs FRR graph

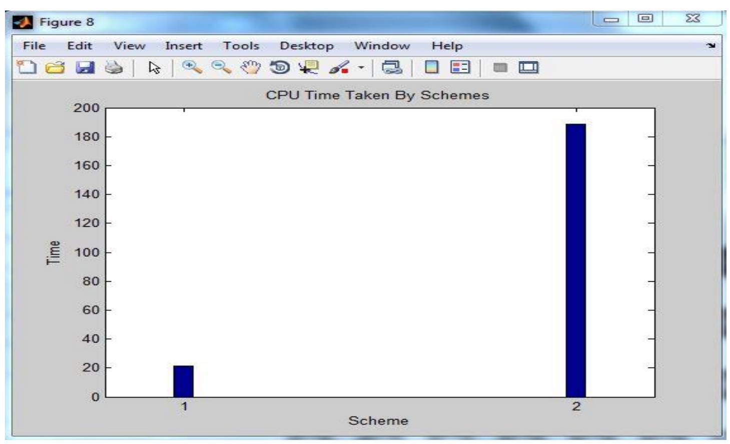


Figure 27- CPU time comparison graph

Figure above shows the time taken for execution by both schemes using second DE strategy. We can see that scheme –I is much faster than scheme-II.

## 4.4 Results Discussion

Below is the table representing the minimum, maximum, CPU time and median values for both schemes from 30 test subjects chosen from CASIA image database.

Table 1- Image verification Scheme-I result values

| Image Verification Scheme-I | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Subjects | DE strategy-I | | | | | DE strategy-II | | | | |
| | FAR | | FRR | | CPU time | FAR | | FRR | | CPU time |
| | Min | Max | Min | Max | | Min | Max | Min | Max | |
| 1 | 10.5 | 21 | 8 | 16 | 20.95 | 6.5 | 13 | 8 | 16 | 16.41 |
| 2 | 13 | 26 | 13 | 26 | 20.82 | 6.5 | 13 | 5.5 | 11 | 16.73 |
| 3 | 9.5 | 22 | 8.8 | 27 | 19.43 | 5.7 | 14 | 7 | 13 | 17.23 |
| 4 | 10.5 | 25 | 9 | 21.5 | 21.15 | 7.5 | 10.2 | 8 | 18 | 16.45 |
| 5 | 9 | 22 | 14.5 | 27 | 20.16 | 7.9 | 19.7 | 8.5 | 14 | 19.12 |
| 6 | 8.2 | 18 | 10.5 | 19 | 20.23 | 5.5 | 11.5 | 6.5 | 13 | 16.12 |
| 7 | 9.9 | 25.5 | 8.1 | 29.3 | 20.89 | 8 | 23.1 | 7 | 13 | 17.18 |
| 8 | 7 | 23.7 | 11.4 | 27.9 | 21.43 | 7.4 | 18.3 | 8.5 | 12.5 | 19.22 |
| 9 | 11.2 | 17.4 | 8.5 | 19 | 21.16 | 6.6 | 19.3 | 10 | 15.5 | 21.25 |
| 10 | 8 | 23 | 9.2 | 25.5 | 20.16 | 7.6 | 17.1 | 8.5 | 19 | 21 |
| 11 | 8.5 | 25 | 13.2 | 29.5 | 18.23 | 6.5 | 13 | 5 | 13 | 17.11 |
| 12 | 7 | 21 | 8 | 21 | 19.24 | 7.5 | 11.5 | 7.5 | 15 | 16.25 |
| 13 | 6 | 18.5 | 10 | 17 | 21.45 | 11.2 | 17.5 | 10 | 17 | 16 |
| 14 | 10.5 | 25 | 10.5 | 23 | 23 | 5 | 10 | 9 | 23 | 15.89 |
| 15 | 14 | 26 | 12 | 29 | 17.45 | 11 | 21.5 | 12.5 | 29 | 15.67 |
| 16 | 8 | 18 | 7 | 21 | 19.89 | 8.5 | 19.5 | 7.3 | 21 | 17.45 |
| 17 | 9.5 | 24 | 7.5 | 19 | 21.65 | 8.5 | 18 | 7.5 | 19 | 20 |
| 18 | 10.5 | 21.5 | 7.5 | 25.5 | 26.23 | 8.9 | 21 | 7.5 | 25.5 | 19.21 |
| 19 | 12.4 | 23 | 7.8 | 27 | 21 | 11.5 | 16 | 9 | 18 | 16.23 |
| 20 | 10.2 | 27 | 6.3 | 18.4 | 23 | 11 | 17 | 6 | 25 | 17.12 |
| 21 | 7.5 | 19.5 | 9.5 | 20.5 | 23.12 | 5.5 | 14 | 6 | 12 | 18.45 |
| 22 | 7.9 | 23.5 | 10.5 | 18 | 20.22 | 6.5 | 14 | 7.5 | 14 | 17 |
| 23 | 12 | 19.7 | 13.5 | 25.4 | 19.23 | 9.5 | 18 | 6.5 | 14.5 | 17.34 |
| 24 | 14.5 | 18 | 14 | 18 | 20.87 | 5.6 | 15.5 | 8 | 16.5 | 18.75 |
| 25 | 11 | 16 | 7.5 | 16 | 19.67 | 7.1 | 13 | 5 | 23 | 16.26 |
| 26 | 7.5 | 17.5 | 6.5 | 19 | 18.34 | 7.5 | 16 | 7.5 | 15 | 16 |
| 27 | 7 | 15 | 13.7 | 15 | 17.11 | 8.5 | 13.5 | 6 | 12 | 17.17 |
| 28 | 9.5 | 18.8 | 19.5 | 19 | 19.99 | 7.5 | 11 | 9.5 | 16 | 19.29 |
| 29 | 8 | 20.5 | 13 | 21.5 | 19.78 | 10 | 17 | 5.5 | 17 | 15.34 |
| 30 | 11.5 | 19 | 8 | 16 | 23.56 | 10.5 | 18 | 11 | 14.5 | 18 |
| Median | 9.5 | 21.25 | 9.35 | 21 | 20.525 | 7.5 | 16 | 7.5 | 15.75 | 17.145 |

Below is the table representing the maximum values for both schemes from both test subjects. Results are based on second DE strategy.

Table 1- Image verification Scheme-I result values

| Image Verification Scheme-II | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Subjects | DE strategy-I | | | | | DE strategy-II | | | | |
| | FAR | | FRR | | CPU time | FAR | | FRR | | CPU time |
| | Min | Max | Min | Max | | Min | Max | Min | Max | |
| 1 | 18 | 36 | 12 | 24 | 225 | 11.5 | 23 | 6.5 | 13 | 199.67 |
| 2 | 15 | 30 | 16 | 32 | 197.9 | 10 | 20 | 6 | 12 | 269 |
| 3 | 18 | 32.5 | 17.5 | 36.5 | 224 | 10 | 19 | 5 | 11.5 | 249.34 |
| 4 | 18.5 | 36 | 18 | 32 | 194.34 | 11 | 26 | 9 | 20 | 213 |
| 5 | 13 | 32 | 18 | 38 | 19.12 | 9.5 | 18.5 | 12 | 20 | 207.23 |
| 6 | 17 | 28 | 21 | 32 | 229.34 | 13 | 25.5 | 8.5 | 19 | 224 |
| 7 | 19 | 35 | 17 | 32 | 213 | 9 | 21 | 11 | 19 | 198 |
| 8 | 17.5 | 32.5 | 19 | 37 | 227.23 | 12 | 24 | 12 | 24 | 225.34 |
| 9 | 18.5 | 30 | 15 | 28 | 224 | 8.5 | 19.5 | 8 | 19 | 199.46 |
| 10 | 20 | 36 | 18.5 | 35.5 | 198.34 | 7 | 18 | 8 | 13 | 226 |
| 11 | 18.5 | 29 | 19 | 38 | 225 | 14 | 17.5 | 15 | 20 | 194 |
| 12 | 19 | 30 | 19.5 | 35 | 198 | 8 | 21 | 6 | 12 | 196.67 |
| 13 | 17.4 | 32 | 19.5 | 29.5 | 226 | 8.5 | 24 | 8 | 16.5 | 247.34 |
| 14 | 19.5 | 37 | 15 | 32.4 | 194.23 | 7.5 | 14 | 7 | 16 | 234 |
| 15 | 15 | 32 | 17.5 | 29 | 196.56 | 6.5 | 18.5 | 8 | 19 | 267.45 |
| 16 | 17.5 | 33 | 17 | 34 | 220.34 | 10 | 23 | 8 | 13 | 289.89 |
| 17 | 19 | 33.5 | 19.5 | 35 | 215 | 14 | 26 | 11.5 | 23 | 198.98 |
| 18 | 16.5 | 32.5 | 18 | 34 | 228 | 8.5 | 19 | 8 | 16 | 197.56 |
| 19 | 17.5 | 32 | 12 | 28 | 218 | 9.5 | 22 | 9.5 | 22 | 191.75 |
| 20 | 21 | 36 | 17 | 32.5 | 198.89 | 11 | 21.5 | 5.5 | 12 | 267 |
| 21 | 19.5 | 24 | 15.5 | 27 | 197.56 | 11.5 | 23 | 6 | 13 | 239.89 |
| 22 | 17.5 | 31.5 | 18 | 35 | 191.75 | 10 | 25 | 7 | 14 | 269.41 |
| 23 | 16.7 | 26 | 15 | 29 | 223.45 | 7 | 14 | 6.6 | 15.5 | 259 |
| 24 | 19 | 32.5 | 16.5 | 35 | 209 | 13 | 25 | 9.5 | 19.5 | 197.98 |
| 25 | 17 | 31 | 19 | 38 | 221 | 11.5 | 21.5 | 12 | 20 | 227.56 |
| 26 | 16 | 32 | 15 | 31.5 | 196.79 | 14 | 30 | 8.5 | 16 | 201.75 |
| 27 | 16.5 | 29.5 | 17.5 | 28.3 | 216.39 | 11 | 23 | 8 | 17 | 264 |
| 28 | 17.5 | 37 | 19 | 36.5 | 198.56 | 7.5 | 14.5 | 6 | 11 | 269.89 |
| 29 | 15 | 28 | 15 | 28 | 194 | 7 | 15 | 9.5 | 20 | 229 |
| 30 | 18 | 32.5 | 17.5 | 34 | 201 | 9 | 21 | 6.5 | 14 | 198 |
| Median | 17.5 | 32 | 17.5 | 32.45 | 211 | 10 | 21.25 | 8 | 16.25 | 225.67 |

Using both schemes separately with first and second DE strategies, we can see from the above tables that for image verification scheme-I median values of FAR and FRR are much less as compared to image verification scheme-II.

Also the CPU time taken by the scheme-II is very high as compared to scheme-I. Based on these results its clear that out of these two novel approaches for image verification, scheme-I which is using wavelet transform with two different DE strategies is more efficient and even second DE strategy more efficient than first DE strategy.

# Chapter 5
# Conclusion and Scope

In our work the emphasis is given to achieve a framework for face verification process with more accuracy to separate imposter and genuine scores. The use of metaheuristic algorithm like DE which has advantages like finding the true global minimum without worrying about initial parameter values, its fast convergence , only few applicable parameters and its various strategies makes it good choice for the optimization. The combination of NIR and visible images has shown some good results earlier. NIR images are good choice in case if illuminations are there as they are less sensitive to it than the visible images.

We have created two image verification frameworks using DWT and Gabor Filter. While DE is used in both schemes as population optimization algorithm. The values for FAR, FRR and CPU time are calculated both schemes .Results concluded that the first scheme comprising of DWT and DE is much better than second scheme comprising of Gabor filter and DE.

For future work we can add more image processing components e.g. after image is fused we can add any feature selection component like KDA or KDDA. This way more precise results can be achieved. We can also compare results with more DE strategies or other robust algorithms.

# List of References


1. R. Storn, K. Price [1997]*," Differential evolution - a simple and efficient heuristic for global optimization over continuous spaces"*, Journal of Global Optimization 11: pp. 341–359.

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# APPENDIX

## List of Abbreviations

- DE – Differential Evolution
- PSO – Particle Swarm Optimization
- FAR – False Acceptance Rate
- FRR – False Rejection Rate
- DWT – Discrete Wavelet Transform
- IDWT – Inverse Discrete Wavelet Transform
- NIR – Near Infrared Images
- VI – Visible Images