1.1 Preamble

Many face detection and recognition techniques have been demonstrated, developed over the past few decades [Vezhnevets, et al.,2003]. In future, we are likely to come across situations where face recognition under partially visible conditions such as pose-variations, illuminations, chrominance, translucent and diffusion etc has to be carried out [De Smet, et.al,2006]. The problem of face recognition under partial visibility conditions is the major objective of this thesis. We experiment partial face recognition with various classifiers as well as with feature fusion schemes consisting of different enhancement techniques taking different benchmark face-datasets like YALE, LFW[Zhu, Pengfei, et al.,2012], and also with datasets created by our own. We investigate and further propose novel as well as robust schemes for enhancing security of face biometrics, and we have also studied the various existing systems to understand their demerits. Eventually we developed partial face recognition technique with good performance levels, enhancing the face-biometric security using huge datasets.

1.2 Overview of Biometrics

Over the last few years, the increased security demands from the modern society have augmented the importance of automatic personal authentication by means of biometrics. Several biometrics such as fingerprints, palm print, hand veins, face, voice, iris, retina, ear and gait have been proposed [Anil K. Jain et.al,2004], each with its own merits and limitations. Fingerprints are at risk of counterfeiting, as well as to reach wrongly preventing access if the fingers are dirty or wet. Signature Recognition
has been used for a very long time. Contemporary technologies are getting better, but still have a lot of false readings even though system has a low cost and use very little additional hardware; it still needs a lot of improvements. The iris and retina recognition devices are too invasive [Latha, L, and S. Thangasamy, 2010]. These systems need users to place their eyes 15-20 inches away from the scanner to take proper picture and this distance is uncomfortable to many as well as it may generate serious diseases. The voice recognition devices cannot be successful, especially when you have a sore throat [Van Lancker, et.al, 1985]. Identifying individuals by ear shape is used in law enforcement applications where ear markings are found at crime scenes. Problem of this biometric is, recognition fails whenever the ear is covered by hair. But face recognition has distinct advantages because of its non-contact process. Face images can be captured from a distance without touching the person being identified, and the identification does not require interacting with the person. In addition, face recognition serves the crime deterrent purpose because face images that have been recorded and archived can later help identify a person. The problem of face recognition system can be stated as given still images or video of a scene, the task is to identify the person in the scene by making use of stored database of faces [Fletcher-Watson, Sue, et al, 2008]. The problem is mainly classification problem, where recognition system trains the images of known persons and stores in the knowledge base. During recognition, it classifies the newly coming probe image into one of the classes. Face recognition has applications [Huang Thomas, et.al,2011] mainly in the field of biometrics, access control points, law enforcement, security and surveillance systems, retrieval of images from mugshot databases in police departments, suspect versus perpetrator verification, facial reconstruction, victim and missing person identification, design of human computer interfaces, multimedia communication, medical diagnosis and treatment planning.

Biometrics refers to the automatic recognition of persons based on their physical or behavioral attributes. Several biometric traits such as signature, voice, fingerprint, iris, retina, ear and face have been explored [Ross, and Anil K. Jain, 2004]. But Face recognition technology is more efficient [Liu, Chengjun,et.al,2002] and widely accepted by public compared to other biometrics due to its invasive property [Sheridan, Carol, et al, 2006]. Face images can be captured from a distance without touching the person and the identification does not require interacting with the person. Face recognition
finds many applications in the field of access control points, law enforcement, security and surveillance systems, victim and missing person identification.

Over the past few decades, the user identification and authentication gradually increasing because, the irrespective of field’s society needs biometric security control everywhere in world. Passwords and ID’s are very familiar for detection and identification. Now a day’s biological authentication techniques across, iris, voice, fingerprint, Palmprint and face etc are moving a crucial, major role and attracting very challenging interests for many researchers in the field of biological and human interaction computer in the form of vision. Among them, face recognition is an amicable alternative because; identification can be completed in an easy way without stopping activities of user [Rikli, et al,1999 ].

Biometrics can be mainly divided into two main categories:

- **Physical Biometrics** [Jain, Anil, et.al 2007 ] - based on physical characteristics (face, fingerprints, hand geometry, iris, retinal, vein, voice, etc)

- **Behavioral Biometrics** [Jain, Anil, et.al, 2007 ]- based on behavioral characteristics (Handwritten recognition, signature, keystroke, etc)

Biometric systems have become very essential components in almost all security aspects. These systems perform the recognition of a human being based on physiological and behavioral characteristics. Physiological characteristics are related to the shape of the body. Biometric traits such as face, fingerprint, iris, hand geometry fall under this category. Behavioral characteristics are related to behavior of a person. Signature, voice, character strokes etc. are some of the biometric traits which fall under this category. Among the various physiological traits, face has gained much attention in recent years [Jain, Anil K., et.al, 2004] as it has been found to be a good and reliable biometrics for human verification and identification.

Face recognition is nothing but expected to identify faces, present in images or videos. During face recognition process, we are categorizing system in to two ways. Firstly, authentication/identification and secondly, recognition /detection.
1.3 Applications

- **In standard biometric laboratory**

  In pattern recognition, image processing is used for identifying the objects in images and then machine learning is used to train the system for the change in pattern.

- **Law Enforcement**

  Fast identification of suspects supports efficient crime investigation.

- **Physical security**

  Analysis of faces in video streams enables real-time identification persons.

- **Border Control**

  Face recognition technology is employed in e Gates for automatic passport checks.

- **Image Sharpening And Restoration**
Image sharpening and restoration refers here to process images that have been captured from the modern camera to make them a better image or to manipulate those images in way to achieve desired result. It refers to do what Photoshop usually does.

- **Machine/Robot vision**
  Apart from the many challenges that a robot face today, one of the biggest challenge still is to increase the vision of the robot.

- **Image database investigations**
  Searching image databases of licensed drivers benefit recipients, missing children, immigrants and police bookings.

- **General identity verification**
  Electoral registration, banking, electronic commerce, identifying newborns, national IDs, passports, employee IDs.

- **Access Control**
  In many of the access control applications, such as office access or computer logon, the size of the group of people that need to be recognized is relatively small. The face pictures are also caught under natural conditions, such as frontal faces and indoor illumination. The face recognition system of this application can achieve high accuracy without much co-operation from user. The following are the example. Face recognition technology is used to monitor continuously who is in front of a computer terminal. It allows the user to leave the terminal without closing files and logging out. When the user leaves for a predetermined time, a screen saver covers up the work and disables the mouse & keyboard. When the user comes back and is recognized, the screen saver clears and the previous session appears as it was left. Any other user who tries to logon without authorization is denied.

### 1.4 Face Recognition

In this section, we present a brief explanation of the face identification and recognition research, its applications and technical challenges. We will also describe its contribution as a successful biometric trait. Face biometric is considered as one of the most reliable and invariant biometrics characteristics in line with iris and
fingerprint characteristics [Ratha, Nalini K, et.al, 2004]. Face recognition has recently received significant attention as one of the most successful applications of image analysis and understanding, especially during the past several years. At least two reasons account for this trend: the first is the wide range of commercial and law enforcement applications, and the second is the availability of feasible.

Face recognition is nothing but expected to identify faces, present in images or videos. During face recognition process, we are categorizing system in to two ways.

1. Authentication/identification- determining a person's identity. It answers the question - who is this person? And in which recognition /detection- confirming a person's identity.

Figure 1.2 Various human facial expressions [Pantic, Maja, and Leon J. M. Rothkrantz, 2000]
A face recognition system is a computer-driven application for automatically identifying a person from a digital image. It does this so by comparing extracted facial features in the live image with that of one from face database. This system is expected to identify faces present in images and as well videos.

### 1.4.1 Partial Visibility Cases

The following are the summary of the main theme in face detection:

1. **Illumination condition** [Soriano, Maricor, et al., 2000]: different lighting and the quality of camera directly affect the quality of the face.

2. **Occlusion** [Rea and Mark S, 1984]: face detection not only deals with different faces, however, it also needs to deal with any optional object.

3. **Uncontrolled background** [Weir, Matthew R., et al., 2001]: face detection system can not only detect faces on simple environment. In reality, people are always located on complex background with different texture and object.

4. **Image orientation** [Henry, Walter L., et al., 1988]: face images directly vary for different rotation about the camera’s optical axis. Image orientation directly affects the angle of the face.

5. **Image condition** [Deutsch, Morton, 2009]: This problem includes factors such as intensity, resolution, camera lighting, background, characteristics of image capturing device and distance between camera and person, plays an important role in the process of face detection.

### 1.4.2 Related Applications

Many applications are dependent on segmentation such as information retrieval, information extraction [Vezhnevets et al, 2003]. Segmentation will help to remove noise which improves accuracy of the results. Image segmentation also got numerous applications some of them are: Diagnosis, study of anatomical structure, object location in satellite images, military imaging etc. Real time Scenarios are much closer to Partial Visibility [De Smet, et al., 2006]. At present face recognition has wide area of applications such as security, law enforcement. Imaging conditions, Orientation, Pose and presence of occlusion are huge problems associated with face recognition. The
performance of face recognition systems decreases due to these problems approach to
describe face image variation. A face recognition technique that is robust to all
situations is not available. Some techniques are better in case of illumination, some
for pose problem and some for occlusion problem. Partial visible Biometrics offers
greater security and convenience than traditional methods of personal recognition.
Wireless biometrics for high end security and providing safer transactions from
wireless devices under partial visibility. Applications of partial biometrics technology
in identifying DNA patterns for identifying criminals, and achieve better accuracy

1.5 Literature Survey

Biometrics has come to occupy an increasingly important role in human identification
primarily to their universality and uniqueness. As a result of this evolution, a new
breed of techniques and methods for user identity recognition and verification has
appeared based on the biometric features that are unique to each individual. Examples
of common biometrics used include iris, DNA, voice patterns, facial patterns and
fingerprint [Lin J and Ming J, 2009]. Among these face is more popular biometric
modality and has been used for personal identification in many areas. The popularity
is due to the fact that face never changes [H. Chen, P. Belhumeur et al., 2009] and also, it
has been proven that even identical twins have different facial appearances. The
results proved that the Marker Controlled Watershed Segmentation Method [Marsico
M., et al., 2010 ] is best suited for extracting the features which was evident from the
high true detection rate and low false detection rate obtained. This proves that the
proposed method can detect features on face images more accurately.

In recent years, face recognition has received substantial attention from both research
communities and the market, but still remained very challenging in real applications.
A lot of face recognition algorithms, along with their modifications, have been
developed during the past decades. The contemporary face recognition algorithms can
mainly be classified into two categories [P. Quintilian et al., 2001]:

1. Model-based schemes [J. Wright, and A. Y. Yang, 2009]: which uses shape and other
texture of the face, along with 3D depth information?
2. Appearance-based schemes [J. Wright, A. and Y. Yang, 2009]: which uses the holistic texture features? Until now, face recognition systems have been treated as a homogeneous entity. Face Forensics Partial Face Recognition technology [] is unique in that it takes just part of a face and matches it with same parts in a database of complete faces. This is real value in forensic and investigative environments where only part of a face may be available, for example surveillance images, body parts after an explosion, burn victims, a photograph where only part of a face is visible, etc. Face recognition systems for personal identification, which are developed by several vendors, achieve very high recognition accuracy. However these systems do not achieve comparable recognition rates, as the Face Recognition Vendor Test (FRVT) indicates in several reviews [Flanagan and Patricia,2010]and few technical developments like high resolution cameras or even 3D (depth sensing) cameras make the face recognition more reliable. Thus in constrained environment with the use of special equipment, face recognition accuracy reaches almost 100% in full face visibility and these studies have been discussing importance of different facial features when the face recognition is done by humans. Particularly eyebrows and ocular areas [Boddeti, Vishnu Naresh, et al., 2011] are really very important features and omitting them make a huge drop in face recognition accuracy.

Method presented in [Lin, Jie, Ji Ming, and Danny Crookes, 2009], makes use of the extensions of Posterior Union Model (PUM) and similarity measure is determined among the class containing single sample per class. This thesis has also tried to overcome the problems of single training images and use of large feature vectors. Experiments performed on XM2VTS dataset and AR face database obtained recognition rates of 98.8% and 91.5%, respectively. In [E. Elhamifar and R. Vidal, 2011], Local Salient (LS-ICA) technique was used to compute the local basis of face images. Further, this method was compared with Local Non-Negative Matrix Factorization (LNMF) and Local Feature Analysis (LFA). The LS-ICA architecture retains those regions of face images that contain important facial features like eyes, lips, nose, eyebrows etc., first they formed the basis and then they aligned in order for recognition. In [Y. Liu, et al., 2010], Multi-Key point Descriptor (MKD) representation for both the gallery dictionary and the probe images. Multitask sparse representation is for each probe face and the Sparse Representation-based Classification (SRC) approach is applied for face recognition. A general partial face
recognition approach without requiring face alignment, the MKD-SRC framework that works for both holistic and partial faces and outperforms SRC in addressing the one sample-per-class problem. A new Key point descriptor, called the Gabor Ternary Pattern (GTP), which outperforms the Scale Invariant Feature Transform (SIFT) descriptor [L. Juan and O. Gwen, 2009] and a fast atom filtering strategy for MKD-SRC to address large-scale face recognition (with 10000 gallery images). We have addressed the problem of recognizing a face from its partial image and proposed an alignment free approach called MKD-SRC [Liao, Shengcai et al., 2013]. The approach represents each face image with a set of Key point descriptors (GTP and SIFT) and constructs a large dictionary from the gallery descriptors. In the descriptors of a partial probe image can be sparsely represented by the dictionary and the identity of the probe can be inferred accordingly. A comparison with two commercial face matchers, Face VACS and PittPatt shows that MKD-SRC particularly with the proposed GTP descriptor is well suited for general partial face recognition problem. In case partial face cannot be detected our approach can still provide a matching score will give a manually cropped face region. Given a general framework of MKD SRC it would be useful to apply MKD SRC to other image classification areas such as object categorization.

In [J. Wright, A. Y. Yang, 2009], they have proposed a novel system for human face detection in gray images. The system shows highly accurate results independent of scale, position, lighting condition and complex background. They have used simple and efficient approach to segment the source image. A neural network-based face detector would then be applied to examine small windows of an image and decide whether each window contains a face. Texture descriptors such as mean, standard deviation, smoothness and X-Y-Relieves are measured and entered besides the image as input data to form solid feature vector. ANN-based classifier is tested using three sets of experiments: A conventional image-based feature vector, texture-based feature vector and finally integration of both texture analysis and image feature vector. Experimental results show that a combination of both pixel intensities and texture descriptors provide robust scheme for training and classification. Image segmentation shows that up to 52% of the search space is reduced by following this method. Therefore, improvement in detection speed is achieved. One limitation of the current system is that overlapping elimination fails in relatively few cases. The main
limitation of the current system is that it detects only frontal faces with a ±10° rotation.

Artificial Neural Networks (ANN) had been applied successfully in many pattern recognition problems and various neural network architectures have been proposed in [G. B. Huang, et al., 2007]. The face templates are learned from a set of face training images, these learned templates are then used for detection.

From the survey of above literature, it is clear that the subspace based algorithms have a consistent progress since last two decades and even now continue to yield newer and better results. In particular during the last five years, there has been expansion of investigation and implementation needs for real time video/streaming problems. This and other concerns are driving the research community to even focused activity now.

1.6 Motivation

The human face is a stable structure that does not change much in shape with the age and with facial expressions and in which partial face is a workable new class of biometrics since the face has desirable properties such as universality, distinctiveness and stability, although no one has proved that each person’s partial faces are unique and limited surface of the partial face allows faster processing compared with face.

Most of Indian population is situated in villages and there are labours in fields and because of the field work the fingerprint and face becomes partially visible and sometime totally not visible. Thus developing face recognition techniques under partial visibility condition is of great significance to the society in the Indian context.

1.7 Validity Measures

In this thesis we are used validity measures to validate the system performance level and accuracy.

We use Precision, Recall and F-measure to measure the performance of the proposed system. The mathematical formulations are as follows.

\[
Precision = \frac{\text{[Retrieved face]}}{\text{[Relavant face]\cap[Retrieved face]}}
\]
In Chapter 3, we capture full and partial face images as RGB and convert it into grayscale than binary image. Next extract the features from the image such as colors, shape, textures. Later combine the features to classify by using the methods Histogram of Oriented Gradients (HOG) and Nearest Neighbor Classifier (NNC) and the result of the classification will be matched with the full face image and partial face image by using the performance measures such as recalling, precision, F-measure etc and the recognition results will be displayed.

In Chapter 4, are used the mathematical formulation is as follows:
Classification Accuracy = No. of Correctly classified sample/No. of testing samples.
The comparison results of proposed model with other different partial face recognition models are shown.

In Chapter 5, of the recognition rate of different partial conditions towards testing class cases. In above graph, X-axis shows that different partially occluded class cases and Y-axis shows that accuracy Rate for different classifiers.

• Classifiers Fusion

The classifiers fusion is done based on the following formulation:

\[ \text{Accuracy Rate for classifier fusion} = \frac{\text{Classifier 1 accuracy rate for class i} + \text{Classifier 2 accuracy rate for class j}}{2} \]

\[ \text{1.4} \]
1.**8 Research Overview and Contributions**

To underscore the research contributions in the thesis, following are the list of ideas presented in different chapters of this thesis:

1. We have proposed some novel mathematical linear regression based algorithms for efficient and robust face recognition under partially visible conditions in different domains.

2. To enhance the performance levels in detection and recognition, we have justified the need for a mathematical process and Graph Matching is going to use for face recognition under partial visibility.

3. Accuracy evaluation of different classifiers and features level fusion algorithms under several real time occluded face conditions.

4. Conducted comprehensive experiments to study the vigorous of existing facial algorithms under different noise conditions. In addition, we have implemented and matching the features using template matching. The proposed algorithm has been testing with AR dataset and results obtained are satisfactory.

5. Investigated analysis of experiment and discusses the design issues of detection of a person in a crowd.

**1.9 Organization of the thesis**

The subsequent chapters in the thesis have been divided into seven main chapters: a chapter for describing tools and techniques used in our work, four chapters each for representing the contributions of the work in mathematical domain, graphing domain and combined fusion domain and application oriented respectively. Finally a chapter for presenting the consolidated results obtained as part of performance evaluation process.

The rest of the thesis is organized as follows:

Chapter 1 is about general preface to the existing methodologies and technologies and proposed work.
Chapter 2 discusses the effectiveness of the system to detect and recognize the human faces in partially occluded conditions and shows better results in different illuminations of face orientations. Few design approaches have been introduced to recognize full face images, but in our model, we demonstrated mathematical linear regression (Parameters: Straight line-Slope, Intercepts) based algorithms face recognition under partial visibility like face images occlusion, part of the facial image and some facial expressions.

Chapter 3 presents new technique for partial face recognition based on fusion. It provides feasible way to locate the positions of two eyeballs, near and far corners of eyes, midpoint of nostrils and mouth corners from face images. This approach would help to extract useful features on human faces automatically and improve the accuracy of face recognition. A whole occluded face recognition system proposed on HOG feature and NN Classifier.

Chapter 4 provides proposed a novel method to carry out partial face recognition technique based on graph matching. Experimentations were performed and results were presented to show the proposed system is capable of effectively detecting and recognizing the human faces in partially occluded conditions and worked better in different illuminations of face orientations.

Chapter 5 proposes, face detection and recognition system in a crowd. And methodology for investigating the color face segmentation is proposed. Apart from this, the face recognition system which recognizes a people in a crowd, and the variants that are frequently encountered by the face recognizer is demonstrated. The proposed algorithm has been testing with AR dataset and our own created datasets and results obtained are satisfactory.

Chapter 6 gives the comparison results of proposed model with other different partial face recognition models are shown.

Chapter 7 has overall summary and the major contributions of the thesis along with the scope for future research work are presented.