1. Introduction

1.1 Background
Visual information plays an important and vital role in all aspects of the activities performed by human being. Most of the information processed by human brain is visual. Moreover, the visual analysis of surroundings only, enables people to interact with each other. Perhaps one of the important features in this world is the recognition of objects (in terms of color, shape etc.) and the most important one amongst all is the recognition of human faces. Without this capability, the flexibility in interactions, relationships, scrutiny etc. is not possible. The field of face recognition originates from these observations and is considered as the most active research area of computer vision technologies.

While working on the problem of automatic recognition of face images by the computer, the first crucial question that comes in one’s mind is, how are the face images recognized by human brain. Human brain can be considered an intelligent machine with very fast processing, coupled with enormous amount of storage capacity. Human brain continuously keeps storing the information in its sub conscious mind that makes all the difference. Anything that we hear, visualize, feel, taste and smell is initially stored in our sub conscious mind. When we again come in contact with it, our mind processes the said information by applying its intelligence and the information comes into the active mind. This being the case with human brain, the next question that arises is, how can these processes be represented inside the computer system and further, how is the said internal representation to be processed by it. The face images vary a lot in appearance primarily due to the inbuilt characters of the face itself. However, shift in view (pose),
outside environment (lighting, illumination etc.) and changes made in appearance of the face (expression, make-up etc.) also play significant role. The simple solution to this problem may be, to store a number of face images of each individual in different views that cover most of the variations of human face. Practically, this approach will not work and has to be rejected due to the impediments such as large size of the database, lack of storage, and increased complexity in processing. Additionally, for real-life applications it may be difficult to attain enough images in different appearances, of various individuals such as criminals, terrorists, rebels etc. It is due to these bottlenecks that the face recognition is one of the most challenging problems of computer vision [1]. Keeping all these factors in mind, the ‘invariant methods’ are required that are able to conceal most of the appearance diversities of face images from a limited number of available views so as to generate an optimal face recognition system [2].

Face recognition is one of the most interesting research areas. This is, because it addresses challenging problems of computer vision spanning over numerous fields and disciplines. Face recognition, in addition to having a number of practical applications, such as I-card identification, access control, secure monitoring and surveillance systems etc. [3], is a behavior system that is essential for effective communication and dealings amongst people.

1.2 Framework of face recognition
Face recognition is a biometric technique that employs automated methods to verify or recognize the identity of a person based on his/her physiological characteristics. In general, biometric identification system makes use of physiological characteristics such as fingerprint, iris pattern, face or behavioral patterns like handwriting, voice etc. Face recognition is a technique that takes the image of a person (query image) and compares
it with the previously recorded images in the face database. This is done by comparing
the invariant features obtained from the techniques that capture the representative
variability of the faces or the structure, the shape and the face attributes like distance
between the eye centers and nose, upper outlines of the eyes, width of eyebrows etc.
Face recognition has the benefit of being a passive, non intrusive system to verify
personal identity in a natural and friendly way. The main benefit of this technique over
other biometric approaches is that the face images can be taken from a distance even
without the knowledge of the individual being observed as may be required in
identifying the presence of the criminals in a bank or government offices.

1.3 Applications of face recognition
Human beings always have the innate ability to recognize and distinguish faces but
computers have shown the said ability only recently. The technology of face recognition
is used in a number of law enforcement, civilian and commercial applications in which
the reliable identification of individuals is essential.
Face recognition is applied as access control point, to obtain the permission for the
particular services like entering into a building, strong rooms/bank lockers etc. In this
kind of a system, the image of a person is taken by the camera positioned appropriately
at a place called the access point and the captured image is matched against the stored
face database of the same person. If a match is found, only then the access is permitted
i.e. the door is opened.
Now a days, face recognition is being applied in a number of surveillance tasks like
voter identity, issuance of driving licenses, security measure in military areas,
government offices, entry to examinations, ATM’s etc. Properly designed systems
installed at airports, multiplexes, and other public places, can detect the presence of
criminals in the crowd. Other biometrics like fingerprints, iris, and speech recognition cannot perform this kind of mass scanning.

To allow **secure transactions on internet**, instead of using passwords or PIN numbers the face verification may be used. Through this tool the secure transactions can be formulated in *e-commerce* or *m-commerce*, online banking, access to networks and other personal facilities such as *e-health* or *e-learning*. The same concept can also be applied to personal computers by using a webcam to capture a digital image of the individual. The captured face image could replace the password as a means to **log-in**.

IBM Lenovo notebook series comprises ‘VeriFace’ the face recognition software for log-in purposes.

Face recognition technology is also useful for a number of commercial applications like day-care facilities for picking up the children, search for missing children or runaways, card counters in gaming industry, residential security, benefit payments, recording of students attendance etc.

Face recognition systems are no longer limited to the identity verification and surveillance tasks alone. Several tools have started utilizing the face recognition technology to realize the human intentions, actions and behavior for designing future smart environments [4]. For example, a smart home is able to recognize its owner, his family, friends and guests and also able to remember the preferences of the owner and his family. It may be able even to understand what are they asking and looking for. Different gestures and expressions may also be interpreted by it and as such this system is likely to be able to facilitate them. The face recognition technology has become an essential tool in the development of these kinds of intelligent applications.
1.4 Current state of the art

The efficiency of face recognition algorithms has improved significantly since 1993. This has been possible due to the independent evaluations and common challenge problems sponsored by a number of government agencies for solution. The Facial Evaluation Recognition Technology (FERET) database and its evaluations have become the de facto standard in this technology. The state of the art techniques in face recognition are provided by the three independent FERET tests that are accomplished by evaluating the algorithm’s ability on the basis of different parameters, categories of images and various versions of algorithms. The categories of images are divided on the basis of lighting changes, people wearing glasses and the time between the acquisition of the database image and the test image. From this, one can have a better understanding of the face recognition techniques. This can also help in assessing the accuracy and the strengths and weaknesses of individual algorithms. Moreover, this provides a general platform to researchers for the comparison of their work on this system, and also the selection of applications that can be successfully addressed through their work [5].

The Face Recognition Vendor Test (FRVT) 2002 evaluation, conducted by the National Institute of Standards and Technology (NIST) and sponsored by the US Department of State (DoS), is another benchmark dataset [6]. Recently, NIST has started Multiple Biometric Grand Challenge (MBGC) problem that provides MBE 2010 evaluations to the researchers in this area. The evaluations contain 40,000 still images for face recognition under uncontrolled environments and 3D scan [7]. The FERET and DoS datasets are comparable with each other because both of them have similar image resolution, and produce similar results on any baseline algorithm over the common face
variations. These expert evaluations have provided the academia, the industry and the researchers with the performance benchmark and unbiased assessment of the efficiency of this technology. The results provided depict that the present progress in the face recognition techniques is not satisfactory especially when the recognition of face images is tested on the images collected outside the studios under uncontrolled environments. Some efforts have been made to solve these real world problems like uneven lighting variations, pose, aging and occlusion of some parts of faces, etc., but the results obtained in terms of the recognition accuracy, have confirmed the difficulty being faced in this venture.

The face recognition methodology consists of two basic tasks namely identification and verification. In the identification task, an algorithm is provided with a face which is compared with the enrolled images. While in case of the verification task, an algorithm is provided with a face image and a claimed identity. The algorithm must accept or reject the claim. The performance of these methods is compared by evaluation of two types of errors namely the false reject rate (FRR) and the false accept rate (FAR). A ‘false reject’ occurs when the system does not accept a valid claim and on the other hand a ‘false accept’ occurs when the system accepts an invalid claim [8]. In this research work, the recognition performance is measured in terms of the recognition percentage and FRR.

1.5 Survey and review of literature
The first semi-automatic face recognition was designed in early 1960’s wherein the facial feature points (such as eyes, nose, mouth etc.) were located manually from the face images and then the distance and ratios between the common reference points were measured by the computer [9]. In 1970’s, a total of 21 specific feature points had been
used by Kanade et al. [10] for automatic recognition of the face images. In 1988, Kirby and Sirovich applied the principal component analysis (PCA) based on a standard linear algebra technique to the face recognition methodology [11]. This approach was considered a milestone in this area and it provides numerous research directions. In 1991, Turk and Pentland developed a face recognition system using *Eigenfaces* technique that enabled reliable real time face recognition system [12]. However, the environment factors were a constraint. In 1997, Belhumeur et. al proposed *Fisherface* technique based on Fisher’s Linear Discriminant (FLD) [13]. Enormous extensions to the eigenface and fisherface approaches have been worked out so far. The said techniques include Two-Dimensional PCA (2DPCA), Two-Dimensional LDA (2DLDA), Two-Directional Two-Dimensional PCA (2D^2PCA) and Two-Directional Two-Dimensional LDA (2D^2LDA) etc., [14-16]. Due to ample research ongoing in this area, there exist a significant number of feature extraction approaches in literature to represent the face images. These existing face recognition approaches are broadly classified in two categories - global feature extraction approaches and the local feature extraction approaches [17].

Global face recognition methods are based on statistical approaches wherein the features are extracted from whole face image. In this approach, every element in the feature vector will refer to some holistic characteristic of face images. Since the global data of an image is used to determine the feature elements, as such the data that are irrelevant to facial portion, such as hair, glasses, shoulders and image background, may result in creation of erroneous feature vectors that can affect the recognition results [18]. Most frequently used global methods include subspace based methods, spatial frequency techniques and the moment based methods. The Eigenface and Fisherface
based approaches, discussed above, fall under the category of subspace based methods. The spatial-frequency techniques such as Fourier transform (FT) [19], discrete cosine transform (DCT) [20], etc. are useful in extracting the facial features at some preferred frequency. In these methods, firstly the images are transformed to the frequency domain and thereafter, the coefficients of low frequency band are taken as the invariant image features. The moment invariants, are the most widely used image descriptors in most of the image analysis and pattern recognition applications such as character recognition, palm print verification, image retrieval etc. Some of these moment invariants such as Hu’s seven moment invariants and the orthogonal radial moments (Zernike moments, Pseudo Zernike moments and orthogonal Fourier-Mellin moments) possess the property of being invariant to image rotation [21-23]. The same can be made invariant to translation and scale after applying the geometric transformations [24]. Since their magnitude is invariant to rotation, therefore, their magnitude coefficients are considered as a feature vector comprising of several orders. The Zernike moments (ZMs) approach is observed to extract the global information of images most effectively than any other global approach [25]. Some work using magnitude features of the ZMs and the pseudo Zernike moments (PZMs) in recognizing the face images have been already done [26-33]. MPEG-7 uses some of these moment based approaches as region based shape descriptors for image retrieval [34]. Though the global face recognition techniques are most common and well-liked in face recognition, recently lot of work is being done on local feature extraction methods as well because these are considered more robust against variations in facial expressions, noise and occlusion. Recently, Facial feature extraction has become an important tool in automatic recognition of human faces. Extracting the basic features like eyes, nose and
mouth exactly, is necessary for most of the feature based approaches. These structure-based approaches deal with local information, related to some interior parts of the face images that include features of nose patch, distance between the eye-centers, mouth width or height etc. These methods can be classified in two categories. Firstly, the sparse descriptor that initially divides the face images into patches and then illustrates its invariant features. Secondly, a dense descriptor that extracts the local features pixel by pixel over the input image. Amongst the sparse descriptors, the scale invariant feature transform (SIFT), introduced by Lowe [35] consists of the useful characteristics of being invariant to scale and rotation. The discriminative SIFT (D-SIFT) features are effectively used for facial expression recognition by Soyel et al. in [36], but it is partially invariant to illumination. Adaptively weighted patch pseudo Zernike moment array (AWPPZMA) approach is proposed by Kanan et al. in [37] wherein the features are extracted from a partitioned face image containing PZMs based moment information of local areas instead of the global information of the face. This method generates superior results against occlusion, expression and illumination variations even when only one exemplar image per person is available in the database. Gabor wavelet is one of the most frequently used and successful local image descriptor in face recognition. The Gabor wavelet incorporates the characteristics of both space and frequency domains. The local features extracted by using the Gabor filters are invariant to scale and orientation and are able to detect the edges and lines in face images [38]. Local binary pattern (LBP) is widely used dense descriptor due to the simplicity in extracting the local features and its excellent performance in various textures and face image analysis tasks [39]. Several variants of LBP are provided in literature to generate compact feature set for face analysis and for representing the improved classification
performance [40-42]. In addition, some researchers have used this descriptor either as a dense descriptor or as a sparse one [43]. Recently, the Weber’s law based dense local descriptor called Weber’s law descriptor (WLD) is established by Chen et al. [44], incorporating powerful image representation ability along with useful characteristics of optimal edge detection despite invariance to image illumination and noise variations etc. The experimental results devoted to the texture analysis and face detection prove the robustness of this descriptor with reference to scale, illumination, noise and rotation variations.

Though, a number of global and local methods have been devised for representation of face images, still no single approach is found to be suitable in most of the situations. Presently, the researchers are working on the techniques that combine the global and local features together because the information conveyed by these two feature sets, is different. The global features are related to the general characteristic of whole face while the local features describe the finer details inside the face images. The combined subspace based approach, using both global and local features obtained by applying LDA based method is proposed by Kim et al. in [45]. Fang et al. have proposed fusion of global PCA features and Haar wavelet based local features for face verification [46]. Local and global information extracted by using the DCT coefficients along with the Fisher classifier developed for high dimensional multi-class problem has been proposed by [47]. The hierarchical ensemble of global and local information is presented by Su et al. in [48] to build the robust face recognition system. Recently, Liu and Liu [49] presented an approach for face recognition by fusing together the color, local spatial and the global frequency information. This method comprises of multiple features of face
images derived from, the LBP, DCT, the hybrid color space and the Gabor image representation.

1.6 Challenges in the field of face recognition
The challenges associated with face recognition can be attributed to the following factors:

- **Pose**: The images of a face vary due to the relative camera-face pose (frontal, tilted, left/right profile, upside down). Face images also directly vary with the different rotations of camera’s optical axis.

- **Facial expression**: The appearance of faces considerably changes due to facial expression and emotions.

- **Occlusion**: Faces may be partially occluded by other objects. For example, in an image of a group of people, some faces may partially occlude other faces (face identification). The presence or absence of facial features such as beard, mustaches, and glasses may also occlude the face. Further, there is a great deal of variation among these components as regards to shape, color and size. Moreover, these components may not be present in all the face images of an individual.

- **Image setting conditions**: When the image is formed, factors such as lightning and camera characteristics affect the appearance of a face.

- **Age**: A person’s looks vary drastically with age, resulting that the images of same person taken after gap of one or two years may not match with the images previously taken in database.
• **Size of the database:** The performance of the system is significantly affected by the total number of images and the number of images of an individual in the database. Total number of images taken in the training set as well as the number of images per person selected in it also affects the results, i.e. more the number of images in the training set, better the results.

Though a significant amount of research has been done on face recognition under the conditions of pose, illumination, database size, etc., but due to great demand of this technology in many emerging real world applications and the lack of robust features and classification schemes for face recognition task, the researchers are paying a lot of attention to this area. Again the sensitivity of classifiers to illumination, pose variation, real world problems and uncontrolled environment, are the major problems that the researchers are facing so far. However, some effort has been made to deal with some of these problems [50-51].

### 1.7 Research objectives

The objectives of this research work include the study and development of a set of face recognition algorithms with the capabilities of good discrimination, low complexity and small size of feature vector, leading to faster performance than the existing approaches in this field. The main goals of this study are as follows:

1. To establish and understand the implementation details of some existing algorithms.

2. To study and propose improved automatic face recognition algorithms by covering most of the attributes of existing algorithms.

3. The developed methods should be fast and will cover most of the conditions of human face recognition, i.e. face recognition under controlled/ideal condition,
varying lighting condition, varying facial expression and varying pose at higher accuracy as compared to the existing systems.

1.8 Major contributions and achievements
The main aim of this research is to look for and develop promising descriptors for robust face recognition. The techniques discussed, analyzed and developed in this research work can be directly applied to particular applications of face recognition, face retrieval, surveillance and many more. A comprehensive study of some well established face and pattern recognition algorithms has been done. The moment based invariant features are most successful in character and image analysis applications. However, the same have been explored only to a small extent in the recognition of face images. An earnest effort has been made to thoroughly analyze and establish the same through this humble exercise. The major contribution of this research work towards improvement in the field of face recognition approaches is summarized as follows:

1). The importance of the phase coefficients of ZMs, in addition to their magnitude coefficients is evaluated. For this purpose, the performance of complex Zernike moments (CZMs) approach is examined on numerous parameters such as image reconstruction ability, change in image size/scale and pose etc. The performance of optimal similarity measure (OSM) proposed for ZMs is also compared to that of Euclidean distance measure for classifying the face images on suitable databases with different variations. These approaches have been originally proposed for the image retrieval and have not been explored for the recognition of face images.

2). The discrimination competence of the features of ZMs and the PZMs approaches is thoroughly evaluated and the recognition performance of face images is also
examined by taking only some precise and highly discriminative features in the
feature vector.

3). Development of an efficient and novel technique that enables the use of individual
real and imaginary components of ZMs (after removing the effect of rotation from
them) as rotation invariant features of an image. These are the modified ZMs
component features which are found to be tolerant to pose variations present in face
images.

4). Development of a hybrid two-stage face recognition approach that combines the
traits of global features in the first stage and of local features in the second stage.
The proposed approach is highly robust against illumination changes and generates
promising results over other variations.

5). Development of an approach that combines two complementary feature sets of ZMs
and the LBP/LTP descriptors together to exploit reliable face recognition both in
speed and performance parameters against the scale, pose, illumination, expression
and the noise changes.

6). Analysis and comparison of all the algorithms presented during this work has been
done. The approaches proposed in this research work have been extensively
analyzed with respect to various parameters and against different variations present
in the face images. The performance of these approaches has been compared to that
of the recent and well established methods.

1.9 Outline of the thesis
The rest of the thesis is organized as follows:

Chapter 2 provides a brief overview of the various targeted face recognition methods
for both global and local face recognition approaches and the similarity measures used
for the classification of face images. In chapter 3, the CZMs and the OSM are explored for the recognition of face images. In chapter 4, the analysis of discriminative competence of the features of ZMs and PZMs is presented. Chapter 5 depicts the practices involved in the proposed component features of ZMs and analysis of its relative performance over suitable databases. Chapter 6 includes the particulars of two proposed hybrid approaches along with the results obtained from the same over the suitable face database. Chapter 7 contains the comparative analysis of the performances revealed by the approaches used in this research work. The summary of important findings and discussion of future research directions are presented in chapter 8.