Abstract

In computer vision applications face recognition has become one of the famous biometric techniques having a number of real world applications like human/computer interaction, surveillance, authentication, computer user interfaces and so on. The sensitivity of available classifiers to factors like illumination, pose variation, real world problems, uncontrolled environment and lack of robust features for classification are amongst the main problems that the researchers are facing so far. The objective of this study is to formulate a set of new approaches of face recognition, that are robust against various conditions of human face recognition including face recognition under controlled/ideal conditions, varying lighting conditions, facial expression and pose conditions, which give higher accuracy as compared to some recent existing approaches.

In general, the recognition of face images is based on their description by a set of measurable quantities called invariants that are insensitive to particular deformations and provide enough discrimination power to distinguish among various persons. Thereafter, only these invariant features are used in the recognition process and as such these extracted invariant features should be able to describe the appearance and structure of faces with only a few parameters and should efficiently represent the variations likely to occur in the face images of same or different persons.

Moment based invariant features provide compact representation of the images and the same are invariant to the image rotation and the noise. Due to this quality, these are the
widely used image descriptors in several applications like character recognition, image analysis and image retrieval. In this study, the performance of radial moment based approaches namely Zernike moments (ZMs) and pseudo Zernike moments (PZMs) have been analyzed for the recognition of face images. The valuable extension to these approaches has been proposed that significantly improve the accuracy of face recognition at a rapid rate with reduced dimensionality and less computation.

Since the magnitude of moments is invariant to rotation, therefore, previously their magnitude had been considered a feature vector comprising of several orders. Recently, it has been observed that the phase component of ZMs also captures useful information for image representation. After applying the phase correction to remove the effect of rotation from the phase coefficients, both the magnitude and the phase features of ZMs have been utilized as invariant image descriptors called CZMs. The CZMs approach comprises of double the number of features in comparison to that of the ZMs approach. The feature extraction time of the ZMs and the CZMs approaches is same. However, twice the number of features reduce the computation time, because for CZMs approach one has to compute less number of invariants as compared to that of ZMs to achieve the same or better results. The exhaustive experiments are performed on UMIST pose database for rotation variations, JAFFE expression database for scale variations, and popular ORL and standard FERET databases for the comparison of recognition results. From the experimental results it has been observed that the performance of CZMs is better than that of ZMs approach.
In addition to the requirement of invariant and discriminative features for classification, the selection of an appropriate distance metric is also necessary. The performance analysis of ZMs and PZMs approaches has been carried out by using Optimal Similarity Measure (OSM) in comparison to the use of Euclidean distance metric ($L_2$-norm).

The OSM in itself uses both magnitude and phase coefficients of these approaches. The OSM differs from the traditional approaches because these compare only the distance between the magnitude features by using the $L_2$-norm. Whereas the OSM utilizes the value of optimal phase shift between the training image and the query image that is obtained by minimizing the distance between them. From the exhaustive experiments performed on suitable face databases, it has been observed that PZM using the OSM achieves better recognition rate, against illumination and expression variations, as compared to that of the ZMs approach.

It is well known that, all of the attributes in feature vector do not have the same competence of discrimination, i.e. some of the coefficients have more strength to classify the face images than that of the others. Careful selection of this set of features, with higher discrimination strength, may increase the recognition performance. In particular, the discriminative features must have the small intraclass and large interclass variation. Herein, a statistical method is used to estimate the discrimination ability of all the extracted coefficients of ZMs and PZMs approaches whereas for the classification of face images, only the coefficients with higher discrimination value are used in the feature vectors meant for these approaches. The performance of the evaluated Discriminative ZMs (DZMs) and Discriminative PZMs (DPZMs) is compared to that of
the corresponding conventional approaches with respect to the illumination, expression, scale and rotation (pose) variations. Experimental results achieve approximately 2-4% improvement in the results with the use of the discriminative features in comparison to that of conventional ZMs and PZMs approaches. An extension to these DZMs and DPZMs approaches has also been proposed by combining them with PCA and FLD namely Discriminative ZMs+PCA (DZMs+PCA), Discriminative PZMs+PCA (DPZMs+PCA), Discriminative ZMs+FLD (DZMs+FLD) and Discriminative PZMs+FLD (DPZMs+FLD), which results in significant improvement in recognition performance, with reduced dimensions and less computational complexity.

A novel method to utilize the real and imaginary parts of ZMs as rotation invariant image descriptors has been proposed. This method includes a technique to remove the effect of rotation from the said components of ZMs. The evaluated modified real and imaginary components of ZMs \( (ZM_{\text{component}}) \) have been used as invariant image descriptors. The performance of the proposed component features of ZMs has been analyzed on grayscale face images and binary character images, in comparison to the ZMs approach (comprising of magnitude features) for face recognition and the character recognition, respectively. Because of the use of two-component feature vectors, the number of features is doubled in this approach as compared to that of the magnitude features of ZMs alone. Thus, for the recognition of face images the ZMs of lower order are required. This results in low computation cost, less susceptibility to image noise and numerical instability, in addition to imparting better recognition rate. Experimental results on well calibrated FERET and ORL databases show that the
The proposed $ZM_{component}$ approach is robust to image rotation and gives better recognition rate over the classical ZMs method, comparatively at low orders of moment and therefore this approach has been recommended for pose invariant face recognition.

In order to achieve the optimal face recognition, it has been observed that combining the feature sets invariant to global variations as well as to the local changes of the face images would be an efficient approach. On the basis of this observation, in this work, two hybrid face recognition methods have also been proposed. The first one is the two-stage face recognition approach that combines the global and the local features on the basis of their different roles. The traits of the global features are taken in the first stage while that of the local features in second stage. The novelty of this work is two fold: 1) an efficient approach used to combine the global and local features based on the human psychology to trace and memorize the known persons by locating some similar faces from the overall appearance of different persons, and later on, identify the specific individual on the basis of their interior differences like shape of eyes, nose, etc., 2) Provides the weights to individual face patches in extraction of local features, that is based on the averaged discrimination competence of features within a patch. In the second stage of this method, the comparison is made amongst the local features of query image and that of the images of similar persons (located by using the global features), instead of taking the full training database. The division of database in this manner significantly reduces the complexity of the method in the second stage. From the detailed experiments performed on suitable face databases, it has been observed that the proposed hybrid method is robust against expression, pose, occlusion and the noise
variations. It is worth mentioning that the results against illumination variation are highly robust.

In the second hybrid method, fusion of two complementary feature sets, i.e., the ZMs descriptor and the LBP/LTP descriptor has been proposed. ZMs descriptor comprises of good global image representation capabilities and is also invariant to image rotation and noise. The LBP/LTP descriptors capture the innate details inside some local parts of face image and are insensitive to illumination variations. Thus, the fusion of these two feature sets is observed to encompass the traits of both of the said autonomous approaches. In this study, the performance of diverse feature sets of ZMs (i.e. magnitude features, combined magnitude and phase features and the real and imaginary component features) coupled with that of LBP/LTP has been analyzed on suitable face databases. The fusion of the said diverse feature sets of ZMs and the LBP/LTP descriptor provide various combined approaches namely $ZM_{mag} + LBP$, $ZM_{magPhase} + LBP$, $ZM_{component} + LBP$, $ZM_{mag} + LTP$, $ZM_{magPhase} + LTP$, $ZM_{component} + LTP$.

The exhaustive experiments performed in a comprehensive and deterministic manner on FERET, ORL and Yale databases, demonstrates an improvement of approximately $10-30\%$ in the recognition results of the said combined approaches as compared to the ones achieved by these approaches individually.

The later part of the thesis analyzes the relative performance of all the approaches suggested in this research work. The results obtained from the exhaustive experiments
performed on some well known face databases have been presented to demonstrate the effectiveness of the proposed methods.