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A Comparative Study on PCA and KPCA Methods for Face Recognition

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Abstract: ***An online face recognition system is a dynamic topic in the field of biometrics. The human face has a principal role which consists of complicated combination of features that allow us to communicate, express our feelings and emotions. Principal Components Analysis (PCA) and Kernel Principal Components Analysis (KPCA) are techniques that have been used in face feature extraction and recognition. In this paper, we have compared a PCA algorithm with KPCA algorithm, in which AT&T data set is used for comparison, recognition of accuracy, variation in facial expression, illumination changes, and computation time of each method. To find Recall of each algorithm AT&T database is used which shows that Kernel-PCA have better performance.***

Keywords: PCA, KPCA, Face Recognition, Error Rates.

1. Introduction

Most of the face recognition systems recognize human faces automatically which are used in security, cyberspace, etc. But a robust face recognition system in an unconstrained area to detect and recognize any face through different pose, illumination and expression is still a daunting problem. Industries are looking for the system with more accurate and error free face recognition system to meet the complexity of practical scenarios. A face recognition system can automatically verify or identify a person from a digital figure or a video frame. Most of face recognition algorithms identify face images distinctive by extracting face feature, landmarks etc from an image which includes face. A person can be identified by other means than the face such as voice, body shape etc. But, a face part is more distinctive key to a person's identity.

There are number of semi-automated face recognition systems that tried to locate features of face such as eyes, ears, nose, mouthand then applied distance based computation from a common point.

Face recognition basically deals with three steps: Face detection, feature extraction, and face recognition. Face detection involves appearance of face in a given image and its location. Preprocessing and normalization will also govern in this step. The output is location of the face,segmented image and face patches. In feature extraction, the useful features are extracted from face patches. This step will also undergo dimensionality reduction technique to get the significant features as feature vector. The third step is the recognition of face, the extracted image features stored in the database is compared with the input image features. Finally, most identical face class will be obtained and that will undergo classification.

The PCA has been proven as a powerful method for face recognition as its optimal compression scheme minimizes the mean squared error between the original images and their reconstructions for any given level of compression[1].PCA is mathematically defined as a linear transform that transform the data to a new coordinate system such that best variance wich is use to find best eigen-faces. A PCA algorithm computes means, covariance, variances and correlations of large data sets[2].

Traditional PCA only allows linear dimensionality reduction but, Kernel PCA allows us to generalize linear PCA to nonlinear dimensionality reduction[3]. A Kernel PCA algorithm is a nonlinear form of PCA, which works better in complicated spatial structure of high-dimensional features. The following part of the paper comprises of related work,PCA and KPCA and accuracy rate with AT&T dataset.

2. Related Work

Kim *et al.*(2002) presented a Kernel PCA based face feature extraction method, they used polynomial kernel principal components to compute the product space of input pixels to generate a facial pattern. To show the effectiveness of the proposed method, an SVM method was used as the recognition with ORL database [6].

Gan*et al.* (2005)in their research, presented the advantages of PCA, and an improved method. Gan *et al.* did research on the normalization of withinclass average face image. They compared with traditional PCA method, and their results showed more acceptable method to process samples with different class and same class. This showed that a higher correct recognition rate can be acquired, then a better efficiency can be achieved [7].

Timotius *et al.* (2010) presented, that KPCA method is utilized to extract features from the input images, SVM method is applied to classify the input images. They compared the performance of this face recognition method to other commonly-used methods which their experiments show that the combination of KPCA and SVM achieves a higher performance as compared SVM, and the combination of kernel principal component analysis[8].

Ebied, Rala M. *et al.* (2012) in their studies have showed the use of linear and nonlinear methods for feature extraction in the face recognition system. Widely the linear PCA is used in the face recognition to construct the feature space and extract features. A KPCA is extended from PCA to a nonlinear mappings in a higher dimensional feature space. In Kernel function, several parameters have investigated and expected higher recognition performance. The k-nearest neighbor classifier with Euclidean distance is used in the classification step. In their experiments they used a ORL face database which contains variability in expression, pose, and facial details then, results show that KPCA with Gaussian function gave a better recognition rate similar to PCA and higher than Kernel-PCA with polynomial function[9].

Upadhayay *et al.* (2013) in their survey presented fundamentals of KPCA and an up to date review of techniques KPCA. They notified the benefits of KPCA over PCA. Finally, they found that KPCA is an appropriate technique for face recognition systems. Thus by reviewing existing face recognition system, KPCA for face recognition system can have a highest recognition[10].

Lei, Yinjie, *et al.* (2014) in their research presents a computationally efficient 3D face recognition system based on a novel facial signature called Angular Radial Signature which is extracted from the semi-rigid region of the face. They used their proposed system to extract the mid-level features from the extracted angular radial signatures(ARS) to improve the discriminative power. Then this mid-level features are concatenated into a single feature vector and fed into a Support Vector Machine (SVM) to perform face recognition. The proposed approach addresses the expression variation problem by using facial scans with various expressions of different individuals for training. They have used Face Recognition Grand Challenge database and the 3D track of Shape Retrieval Contest datasets, and a superior recognition performance has been achieved. Their system experimental results show that the proposed system achieves very high Verification Rates of 97.8% and 88.5% at a 0.1% False Acceptance Rate for the neutral vsand nonneutral experiments on the FRGC and the SHREC 2008 datasets respectively, and 96.7% for the ROC experiment of the FRGC dataset [11].

Zhou, Fei *et al.* (2015) in their survey proposed a novel approach for single image super resolution. Their method is based on the idea of learning a dictionary which can capture the high order statistics of high resolution images. It is of central importance in image super resolution application, since the high order statistics play a significant role in the reconstruction of high resolution image structure. KPCA is adopted to learn such a dictionary. A compact solution is adopted to reduce the time complexity of learning and testing for KPCA. Meanwhile, kernel ridge regression is employed to connect the input low resolution image patches with the high resolution coding coefficients. Their experimental results show that the proposed method is effective and efficient in comparison with state of art algorithms[12].

3. PCA Method

Principal component analysis (PCA) is a mathematical procedure, similar to singular Value Decomposition(SVD), that transforms a number of correlated variables into a number of uncorrelated variables called principal components. It is an efficient technique for dimensionality reduction and classification based on the variations on data. PCA performs better in many high dimensional linear complex systems such as image processing, face recognition etc. PCA express the data as a linear combination in a vector form. PCA steps involve calculation of eigen vector and eigen values to know the common and unique variance of the variables and measures the variance in all the variables which is accounted by a specific factor. So the total variable variance with all components are used to produce the best Eigenfaces.In face recognition analysis, recognition of face is done by projecting the test face image with eigen space of trained images and weight vector. The face features obtained from covariance matrix represents the Eigen-face, which is stored to obtain the eigen values. The PCA method also helps to work in lower dimensional space, and the overall complexity can be reduced. However PCA might perform poorly for nonlinear problems and works better for Gaussian distribution only. There are number of extension of PCA for better performance such as,Improved PCA, Fuzzy PCA, Incremental PCA,Kernel PCA etc.

3.1 Improved PCA

In improved PCA, an original face image can be represented as a two-dimensional face matrix. In most methods face image matrix must be converted into a high-dimensional vector. It is very difficult to process the face image matrix. Reduction of dimensionality and obtaining the best features is always a big concern in PCA. PCA transforms a high-dimensional image into a low-dimensional by statistical features, and eigenvectors of covariance matrix from a set of face image samples are used to represent the whole face features approximately. In improved method based on normalization of a class, average face image is presented, which has the advantages of enlarging classification distance between different class samples. In Improved PCA, class average faces of training samples are computed to normalize training samples and then the eigenface space is computed. The training and testing samples are projected into the eigenface space to get their features more accurately.

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3.2 Fuzzy PCA

A PCA method does not always show the real similarities structure on the data in the higher dimensional space. Fuzzy two-dimensional principal component analysis combines the two-dimensional principal component analysis and fuzzy set theory. A 2D-PCA preserve the total variance by maximizing the trace of feature variance, but cannot preserve local information due to pursuing maximal variance. So, the fuzzy two-dimensional principal component analysis algorithm is proposed to achieve the distribution of local information of original samples.

3.3 Incremental PCA

In the last decade many PCA based face recognition systems have been developed. But PCA based face recognition system is hard to scale up because of extra burden memory and the computational cost. Because of this limitation, an incremental approach is developed. The major limitation of existing PCA methods is that there is no guarantee on the approximation error. So IPCA methods have been studied for resolve this problem.

3.4 Kernel PCA

KPCA method allows a linear PCA method to nonlinear dimensionality reduction. Since PCA works on linear fashion, non-Gaussian distributed data causes PCA to fail, and also non-parametric, Kernal PCA extends PCA into nonlinear and parametric. It also fit for non-Guassian dataset. The KPCA is extended from PCA method to represent nonlinear mappings in a higher dimensional feature space. The KPCA is used for the nonlinearity of face recognition problem by using a nonlinear kernel function then a dimensional reduction is performed. The images are first transformed from image space into a feature space. In the feature space, the variety of the data become simple.

4. PCA Steps

The steps involved in PCA are described below.

4.1 Face vectors and Normalization

Once we have created a training set then all images in training set converts each to vector column.Thus, the image represented by the size of N *N converts to a $1 * N^2$ vector column form. A normalization process will be performed to face vectors obtained by removing all common features that all images share. This allows each faces to left its unique features. For normalization, the average vector (Mean) is subtracted from face vectors, using equation (1).

$$Mi = \sum_{i=0}^{mn} \sum_{i=1}^{p} face\_Db(i,j) \qquad (1)$$

4.2 Covariance Matrix and Eigenvectors

The main step involved in PCA is calculation of covariance matrix, as PCA assumes that basis vector is an orthonormal matrix. The matrix gives the largest variances in an m-directional space, which is the principal component. The covariance is calculated using the formula given in equation (2).

$$C=AA^T \qquad (2)$$

Where A= $\{N_{f1,}N_{f2,}N_{f3,} \ldots \ldots \ldots \ldots N_{fm,}\}$

But the size of the covariance matrix ,

C=$A_{N^2*M}.A^T{}_{M*N^2} thus C_{N^2*N^2}$,

which is huge. Therefore the dimensionality of the eigen vector has to be reduced.

4.3 Dimensionality Reuction of Eigen Vector

With a high dimensional eigenvector matrix, system will run slowly or run out of memory.Reduction of high dimensional eigenvector matrix to low dimensional eigenvector matrix is done using equation (3).

$$C=A^T A \qquad (3)$$

This will result into a low dimensional eigenvector matrix with size of C=$A_{M*N^2}.A^T{}_{N^2*M} thus C_{M*M}$.

4.4 Best K Eigen-Faces and Weight vector

In the last steps because of a huge computational time to find Eigen-vectors, reduction of high dimensional eigenvector matrix to low dimensional eigenvector matrix is done to find best K Eigen-Faces, The selected K Eigen-Faces should be in the original dimensionality of the face vector space, but we find the significance K Eigen-Faces in low dimensional eigenvectors, then for representing the original dimensionality,we have to move back to high dimension eigenvector which is done by below formula (4).

$$U_i=AV_i \qquad (4)$$

V_i = high dimensional eigenvector
U_i = low dimentinal eigenvector

5. PCA process

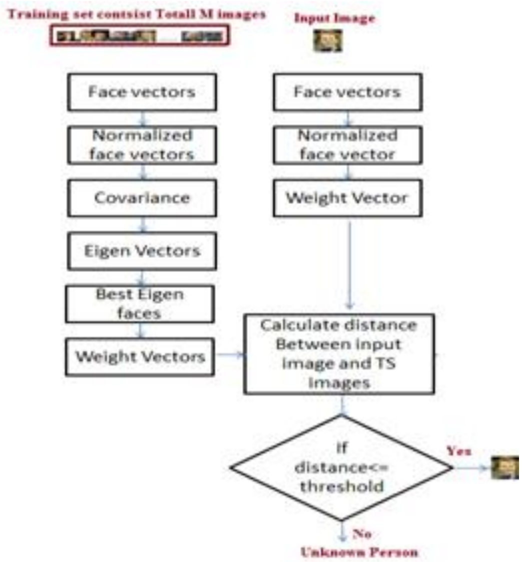

Figure1: PCA process for face recognition

6. Kernel PCA process

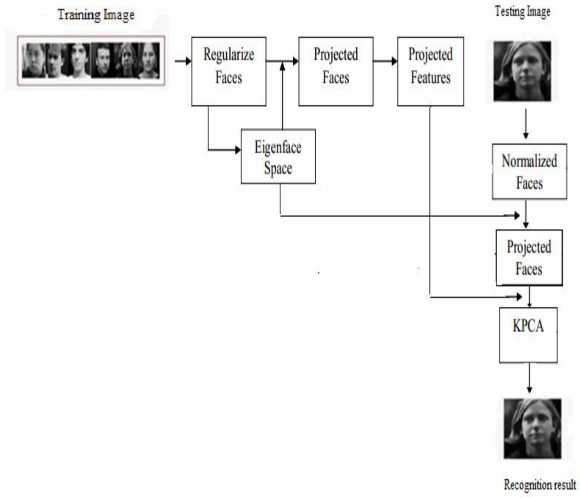

Figure 2: Kernel PCA process

7. The Standard Kernel PCA Steps

7.1 Construct the kernel matrix K from the training data set which shows in equation (5).

$$K_{i,j} = K(x_i, x_j) \quad (5)$$

7.2 Compute the Gram matrix K′ using Equation(6).

$$K' = K - 1_n K - K 1_n + 1_n K 1_n \quad (6)$$

7.3 Solve the vectors ai(substituteK with Kak)by using the equation (7).

$$Ka_k = \lambda_k N a_k \quad (7)$$

7.4 Compute the kernel principal components using equation(8).

$$y_k(x) = \phi(x)^T V_k = \sum_{i=1}^{k} a_{ki} K(x, x_i) \quad (8)$$

where $K(x, x_i)$ is given by Guassian Kernel function.

8. Error Rates Between PCA and Kernel PCA

We have used Yale database with a dataset of 486 for both PCA and KPCA. The error rate of each method is calculated and is given in the table 1.

Table1: Error rate in training and testing data

Error rate	Training data	Testing data
PCA	9.35%	25.32%
KPCA	7.90	13.56%

9. Performance Evaluation

The recall, precession and overall accuracy is calculated by taking 410 images from 41 different persons in 10 different poses. The result is shown in Table 2.

Table 2: compartive PCA,KPCA

KPCA		PCA	
Recall	Precison	Recall	Precision
86.58%	89.19%	75.60%	82.30%

The Accuracy rate for PCA and KPCA is shown by ROC plots in figure [3],[4].

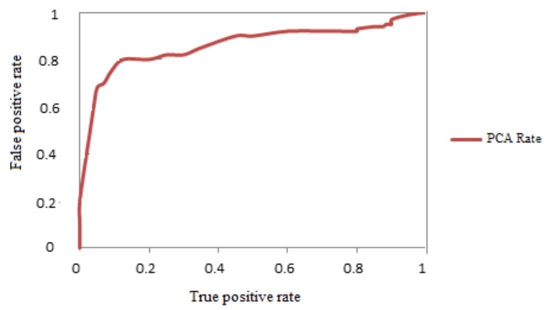

Figure 3: ROC plot for PCA

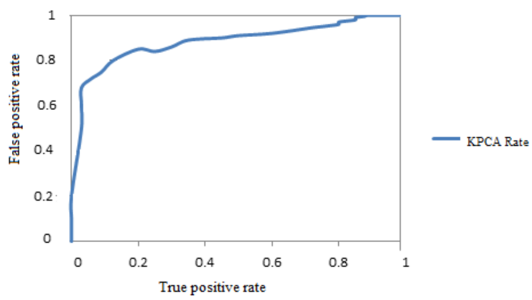

Figure 4: ROC plot for KPCA

10. Conclusion

In this paper we compared two different algorithms using theAT&T datasets for face recognition. The error ratein trainingset and test data in AT&T database has shown that KPCA with less error produced better result.The recognition accuracy, variation in facial expression, illuminationchanges, that with use of a AT&T dataset shows KPCA for face recognition have better performance.

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