RESEARCH ARTICLE

# Exploiting Wavelet Transform, Principal Component Analysis, Support Vector Machine, and K-Nearest Neighbors for Partial Face Recognition

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## ABSTRACT

Facial analysis has evolved to be a process of considerable importance due to its consequence on the safety and security, either individually or generally on the society level, especially in personal identification. The paper in hand applies facial identification on a facial image dataset by examining partial facial images before allocating a set of distinctive characteristics to them. Extracting the desired features from the input image is achieved by means of wavelet transform. Principal component analysis is used for feature selection, which specifies several aspects in the input image; these features are fed to two stages of classification using a support vector machine and K-nearest neighborhood to classify the face. The images used to test the strength of the suggested method are taken from the well-known (Yale) database. Test results showed the eligibility of the system when it comes to identify images and assign the correct face and name.

Keywords: K-nearest neighborhood, partial face recognition, principal component analysis, support vector machine, wavelet transform

## INTRODUCTION

Smart face recognition systems are now widely used in diverse locations such as universities, laboratories, airports, and many other public service facilities that attempt to identify and prevent the intrusion of undesirable individuals into such institutions.[1] Many researches and researchers brought this subject under the spotlight, trying to aid in finding ultimate practical solutions for the final facial identification of suspected or undesirable personnel.

The majority of researches aim at the exploration of new approaches where human qualities are its center of interest, which leads to a facial recognition process that requires a relatively small execution time with easy implementation in many applications.[2,3]

When using wavelet transform for feature extraction, one of the most common and popular methods for extracting facial features are called "Eigenface" technique.[4,5] Eigenface is used by the well-known principal component analysis (PCA) algorithm, which transforms the facial image and reduces its dimensionality into low-dimensional space. PCA converts the image matrix into a reduced single orthogonal vector with some special values called the Eigenface. Applying PCA to more than one image as a training set will align many vectors next to each other, leading to a linear matrix that has some data variances used for later steps.[6]

The next step of the presented automatic recognition system is classification. There are many methods that can be used as classifiers to categorize the input image according to the matrix of data variances resulted from the PCA step. One of these methods is support vector machine (SVM),[7-9] which is basically a binary classifier that is considered a supervised learning algorithm, which aims at finding what is called the optimal hyperplane in the n-dimensional classification space that gives the highest possible margin between classes. SVM achieves this by converting the training set obtained in the

case of complex nonlinear data into a higher dimensional space where it is possible to separate the data by a linear hyperplane. SVM is often reported to achieve better results than other classifiers.[6,10,11]

Another classification method is the nearest neighbor (NN) algorithm.[12-14] According to NN, one set of samples is handled such that these samples can be classified by minimizing the distance among them. Then, the samples can be represented in different classes where the NN method classifies the testing samples by prediction as it calculates the best linear representation for each class. K-NN is applied primarily due to the fact that it is simple and capable of attaining an outcome that resembles the output of more complicated methods as well as its capability of being used in various applications.[15]

Many previous researches have been done in the same field with similar methodology. Some of these works focused on face identification methods that depend on the concept of cloud computing.[1] The main issue that these methods are trying to address is the unformulated aspect of the human face. Here, the authors had suggested a procedure to facilitate the operation of face identification and matching. Then, the intent was to design a structure that adheres to the concept of cloud computing side by side with parallel selection process. The authors claimed that their algorithm qualifies as a capable face identification and resolution method according to the practical results they obtained from the system.

Other works aimed at improving the features gained from facial images by developing methods for this purpose. One of these promising methods is PCA and discrete wavelet transform (DWT),[4] in which DWT is utilized for image compression while PCA is applied for extracting and identifying features from the images. Here, time is to be considered as criteria for measuring the algorithm's performance. The authors declared that their suggested algorithm required less access time than using PCA alone, while achieving up to 93% recognition rate.

Safety and security are of the main goals of face recognition, which can be applied on personal level such as houses,[4] which presents a system that was set up on a robotic platform used to patrol the area to be covered and give a warning in case of an unidentified personnel. First, the face area was segmented using a method called local binary patterns. Afterward, SVM is applied for recognizing the face of interest. The authors stated that their real-time robotic architecture had reached 0.59 precision with Eigenfaces, 0.81with Fisherfaces, and 0.86 with SVM.

## SYSTEM DESIGN

The general structure of this research paper consists of four parts. The first part is preprocessing, including image brightness modification using median filtering, followed by contrast enhancement to the extent that qualifies the image for the second step, which involves general implementation of the partial face recognition system. It includes wavelet transform, PCA, SVM, and K-NN algorithms. In the third part, the recognition system results are reviewed after being applied on a set of training images and compared with the partial face images that are to be distinguished. Part four contains the
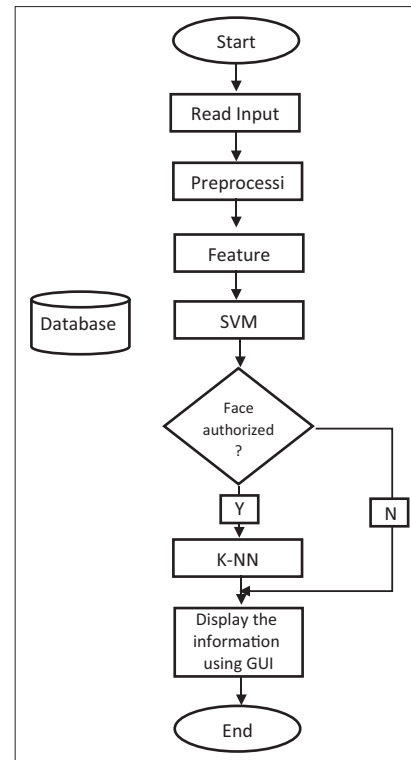


**Figure 1:** Organization of the proposed system

research conclusions. Figure 1 demonstrates the steps of the proposed system as below:

## Preprocessing Step

This step sets the focus on the intensity and brightness features of the image throughout the use of median filtering for enhancing these qualities. The filter acts as a window that sweeps throughout the image pixels, arranging the pixels beneath this window in an ascending order before taking the midpoint and assume it to be the output pixel.[16] This will result in spreading the light evenly across the image. Median filtering can be mathematically expressed as follows:[17]

$$y(x, y) = \text{median} \{g[s, t], (s, t) \in w\}$$

Where, g [s, t] is the degraded image and w is the neighborhood defined by user as a rectangular sub-image window of size m and n. Another algorithm is used depending on the output of median filtering, called contrast enhancement method, which is the method that can be applied to enhance the image appearance. Contrast is identified as the variation between the highest and lowest pixel intensity levels. The equation for adjusting the image histogram for contrast increment is as follows:[18]

$$g(x, y) = \frac{f(x, y) - f_{\min}}{f_{\max} - f_{\min}} * 2^{bbp}$$

Here, the lowest and highest pixel intensity levels are used in the equation and multiplied by the available range of gray levels. After applying the equation, the quality of the image is improved by enhancing the contrast as the difference among the image histogram bins is increased.

## Feature Extraction using Wavelet Transform

A well-known application of wavelet transform in image processing is object detection and classification. DWT aims at providing a representation of time-frequency relevance. In this approach, a group of shifted and expanded wavelet functions $\psi^{LH}$, $\psi^{HL}$, and $\psi^{HH}$ is used to portrait the image being applied for two-dimensional (2D) DWT, with a scaling function $\Phi^{LL}$ that creates an orthonormal basis for $L^2(R^2)$. Provided a J-scale DWT, an image x (s, t) with a size of N × N can be simplified as follows:[19]

$$x(s,t) = \sum_{k,i=0}^{N_{j-1}} u_{j,k,i}\phi^{LL}J,K,i(s,t) + \sum_{b\int B}\sum_{j=1}\sum_{k,i=0}^{N-1} w^b j,k,i\psi^b j,k,i(s,t)$$

With $\phi^{LL}j,k,i(s,t) \equiv 2^{-j/2}\phi\left(2^{-j}s - k, 2^{-j}t - i\right)$

$$\psi^b j.k.i(s,t), \psi^b j.k.i(s,t)$$

$$\equiv 2^{-j/2}\psi^b\left(2^{-j}s - k, 2^{-j}t - i\right), b\int B, B.$$

Where, $N_j = N/2^j$. The coefficients LH, HL, and HH are called DWT or wavelet sub-bands. Feature extraction techniques using wavelet transform aim at investigating the characteristics of the coefficient values that are produced through each step of the 2D-DWT transform of the image and produce feature vectors to be examined during this step and in the following step.

## PCA

PCA[4,13] is a well-known numerical process that can convert an amount of related cases into a less amount of unrelated cases called principal components. The largest possible sum of the data variability is contained in the first principal component and the largest possible sum of the remaining variability is contained in each subsequent component.[4]

PCA reduces the feature space from a bigger amount of quantities into a less amount of aspects in a "non-dependent" process (the specification of a particular dependent case is not presumed). PCA is applied mainly for data compression or dimensionality reduction (i.e., the election of a group of cases from a bigger, more correlated group). Therefore, original cases (images in our system) enjoy the greatest amount of correlations with the principal component. Mathematical PCA can be presented in the points below:

1. The facial pictures to be trained can be represented as R:

$$R_1, R_2, R_3, R_4\ldots\ldots R_n$$

2. Extracting the average facial image from the set of image scan can be done by:

$$V = \frac{1}{n}\left(R_1 + R_2 + \ldots + R_n\right)$$

The difference between each instance with the average is:-

$$Q = \left|R_1 - V\right|\ldots\ldots\ldots\left|R_n - V\right|$$

3. The covariance matrix can be computed as below:

$$M = \frac{1}{n-1}QQ^T$$

Here, the matrix M is created by aligning n orthogonal vectors, each of which contains some facial image features called Eigenfaces. That is, each vector contributes in the original set by a weight vector W, such that:

$$W_n = u_n^T Q_n$$

Where, $u_n^T$ represents the features of the facial image's orthogonal vectors.

## Classification

Classification is the final part of the system. In this part, two stages of classifier are used. In the first one, SVM is used for determining whether the person in the image authorize to access or not, while in the second stage, K-NN is applied to find the nears image of the person.

*Classification using SVM*

One famous approach that is occasionally used for classification and regression applications is SVM. It is classified as supervised machine learning method that is deeply inspired by statistical learning theory and uses the concept of finding the optimal hyperplane for maximizing the separation between classes.[8,20] Hyperplane is realized by computing vectors obtained from training data named support vectors. SVM tries to address the constraint optimization issue below:[7]

$$\min_{\omega,\xi_i,b}\left\{\frac{1}{2}||w||^2 + C\sum_i \xi_i\right\}$$

Subject to:

$$y_i\left(<\phi(X_i), w> + b\right) \geq 1 - \xi_i \,\forall_i = 1,\ldots, n$$

$$\xi_i \geq 0 \,\forall_i = 1,\ldots, n.,$$

From the previous equation, *w* represents the vector's weight and *b* indicates the bias added to find the orthogonal hyperplane distance from the origin point. Slack variables are expressed in $\varepsilon_i$ in addition to a user-defined complexity factor *C*. Due to the presence of slack variables, it is possible that some instances will not be present on the hyperplane, leading to classification errors. Following the existence of an upper limit for the count of misclassification measure, this kind of SVM is called a soft margin classifier.[20]

*Classification using K-NN*

This method classifies the given attributes using a set of features obtained from the training database examples. It can be implemented by calculating the distance between the trained vectors obtained from the previous steps with the input partial face image to obtain the relevance with each of the available classes. Using the Euclidean rule,[13] the algorithm tries to determine how much is the similarity between the input face images with the set of training data.[12] Euclidian rule is used to determine the distance between two vectors, X = (x1, x2..,, xn) and Y = (y1, y2..,, yn) as the following:[14]

$$D(X,Y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$$

Depending on the equation above, the minimum difference is calculated, then the input facial image is given the label of NN class.

## IMPLEMENTATION AND RESULTS

The algorithm presented in this paper is tested versus the well-known (Yale) face database, which is used as a training database to train the recognition system against the input image to find the extent of similarity and to recognize the image as one of the face classes available in the dataset. The Yale face image database includes intensity images of 15 persons stored as GIFs; each person has 11 images to present one facial expression or pattern. The patterns are normal, happy, sad, sleepy, surprised, wink, center-light, left-light, write-light, with glasses, and with no glasses, thus yielding 165 images. For training, 60 images are utilized, leaving the rest of 105 to be applied for testing. The graphical user interface designed for the system is displayed below in two cases, one for authorized face image and the other for an unauthorized image.

Among the 105 images used for testing, the system resulted in the following parameters:

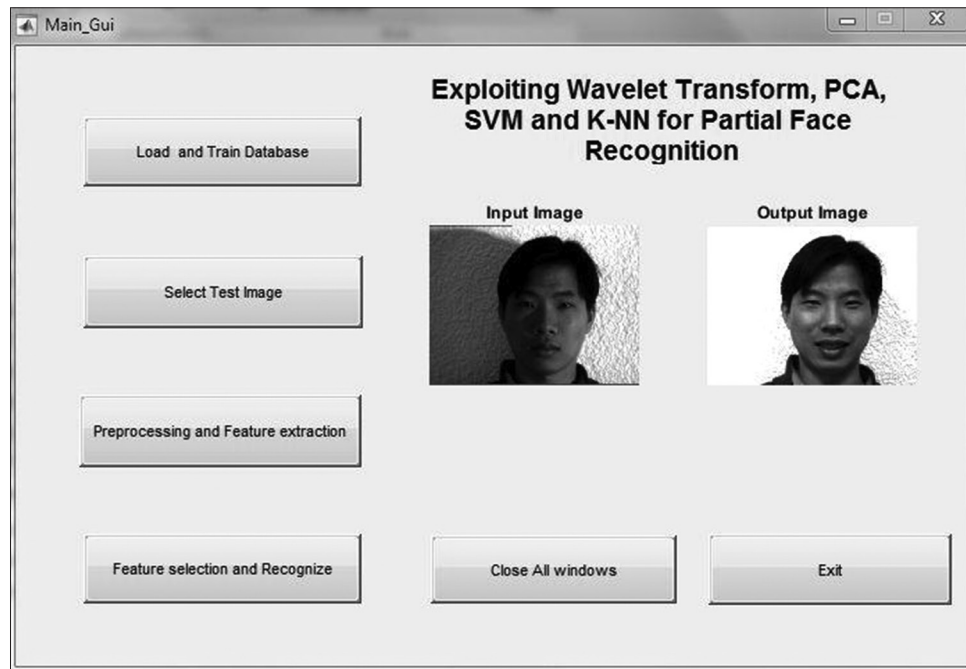- Authorized personnel who are correctly accepted (true positive or TP)=35



**Figure 2:** Graphical user interface of the proposed system (accepted image)
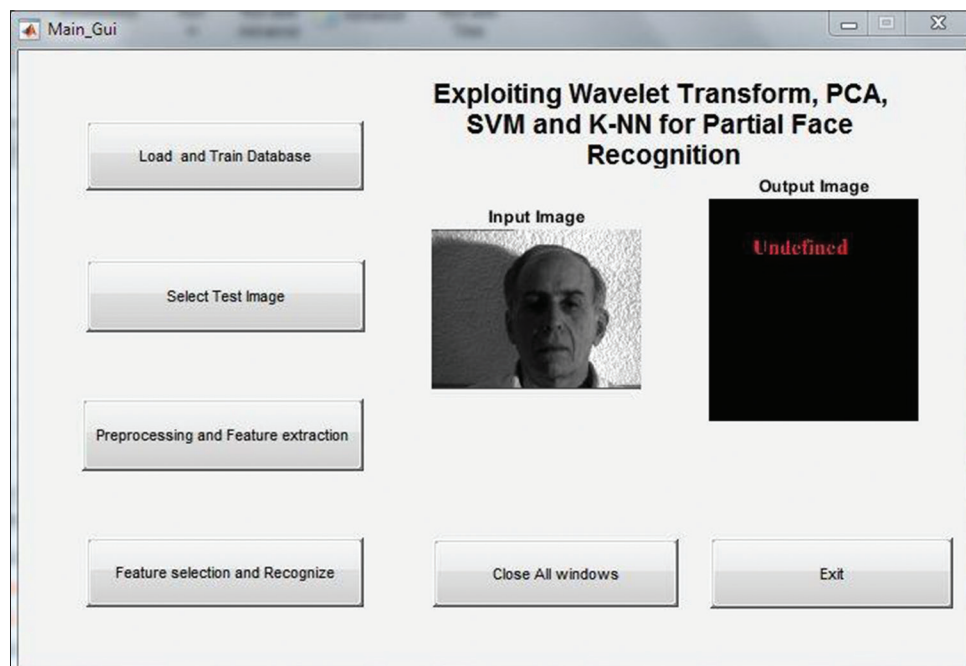


**Figure 3:** Graphical user interface of the proposed system (declined image)

- Unauthorized personnel who are correctly rejected (true negative or TN) = 65
- Authorized personnel who are incorrectly rejected (false positive or FP) = 1
- Unauthorized personnel who are incorrectly accepted (true negative or FN) = 35.

Due to the statistics above, accuracy can be calculated as follows:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} * 100\% = \frac{35 + 65}{35 + 65 + 4 + 1} * 100\%$$

$$= \frac{35 + 65}{35 + 65 + 1 + 4} * 100\% = 95.238\%.$$

Therefore, the given system can reach classification accuracy of 95.238%.

## CONCLUSIONS

In this paper, an image processing system is built for partial face recognition. It relies on various techniques for preprocessing, feature extraction and selection, and classification. It is inferred that the system is able to recognize the faces of the dataset in different expressions and light source position and intensity. It is also noticed that the system outperforms other methods in the field by giving higher accuracy rate with lower misinterpretation percentage. However, the system is expected to achieve higher accuracy rates by enhancing the approaches currently in use, such as applying adaptive median filtering or using one of the available clustering techniques before classification.

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