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Face Recognition System Using Machine Learning Algorithm

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***Abstract*— Face recognition in artificial intelligence is a frequent problem. This application was extensively used in our daily life. Several smartphones were opening phones with facial identification to safeguard private details and used on Facebook to identify instantly when users of Facebook appear in pictures. Several approaches for face recognition have already been suggested until now, but it remains very difficult in real-world situations. A primary technique to differentiate people depends on various conditions, for example, partial facial occlusion, illumination, and posture variety. This paper aims at designing a face recognition approach utilizing machine learning algorithm and principal component analysis (PCA). It is experimented using linear discriminant analysis, multilayer perceptron, Naive Bayes, and support vector machine. Moreover, it has achieved recognition accuracy of 97% & 100% by using PCA and linear discriminant analysis.**

.Keywords*— *Machine learning, face recognition, support vector machine, principal component analysis, Naïve Bayes

I. INTRODUCTION

One of the several wonders that artificial intelligence technology has contributed to the world is facial recognition. To identify the category of every input object, face recognition systems compare face images with a collected group of images called dataset. Facial recognition analysis has become one of the interesting research areas for experts in human-computer interaction applications [1]. In reality, people's identification has been performed by utilizing facial features since the start of time. Face images are used throughout the globe to recognize persons with citizenship identification, identification cards, social security card, intrusion detection, etc.

This process includes segmentation, isolation, and validation of facial features from the unstable environment and likely real faces. The initial effort to identify face was done by calculating unique facial characteristics such as nose size, brows width, and forehead area. Face recognition was introduced as an authentication tool in the latest gadgets. Smartphone vendors including Apple and Samsung have launched their new mobile phone variants with facial authentication functionality [2].

The process of face recognition comprises two major steps, the extraction of the feature and the classification. Raw face pictures can take a lot of time to identify as it results from an enormous amount of pixels. The number of pixels must be reduced. This is called reducing dimensional space or removal of features to save time for the phase of the assessment. The extraction of features corresponds to the conversion of face space into a space of feature [3]. Classification is the mechanism by which the class of variables is predicted. Occasionally classes are referred to as labels or levels. For example, a classifier is utilized to categorize certain characteristics extracted from a face picture and to produce a label that is used to identify a person.

It used principal component analysis for feature extraction purposes and different machine learning algorithms as a classifier. This paper is structured according to the following. Segment II explains the previous researcher-led work for face recognition. In segment III principal component analysis method is explored, in segment IV Machine learning algorithms are described. In segment V dataset used, & process flow is illustrated. Experiments and results are presented in segment VI. Section VII gives future works and conclusions.

II. LITERATURE REVIEW

Z. B. Lahaw et al. [4] introduced a method for face recognition. The suggested work uses linear discriminant analysis, independent component analysis, principal component analysis, and support vector machine algorithms. The experiment is carried out on AT & T Database. This database comprises of 400 face pictures of 40 subjects, every one of which has 10 pictures taken at various stages and with different stances and circumstances of subjects wearing shades. These pictures are grayscale with measurement (112×92). The authors achieved recognition accuracy of 96 % by implementing a hybrid method depending on the Discrete Wavelet Transform (DWT) and principal component analysis (PCA) or linear discriminant analysis(LDA) method for reducing dimension and support vector machine is used for classification of faces.

N. Sabri et al. [5] present work to compare four different machine learning algorithm Multi Linear Perceptron (MLP), Naive Bayes and Support Vector Machine (SVM) classifiers to classify the human face using distance measurements of face geometry. The outcome of all the experiments reveals that The Naive Bayes eliminates the MLP and SVM

classification with the utmost precision. This is attributable to a comprehensive process of SVM and MLP system. Findings show that Naive Bayes achieved a high precision of 93.16 percent.

Face discovery is a significant segment of any facial recognition model as a starting advance to discover faces.. A. Adouani et al. [6] Presents a systematic review of three widely used face detection approaches, namely Oriented Gradient Histogram, hair-like cascade Oriented Gradient Histogram with Linear Binary Pattern cascade and Support Vector Machine. The recommended methods have been developed utilizing Dlib and OpenCV libraries in Python language. The result shows that the HOG+SVM approach is more robust and efficient than LBP and haar approaches with a 92.68 percent total recognition score.

J. Fan et al. [7] discuss the multiple, manifold training graph-based method of face recognition l. The approach suggested is known as Enhanced Adaptive Locality Preserving Projections (EALPP). Two methods have been incorporated into EALPP: Maximum Margin Criterion (MMC) and Locality Preserving Projections (LPP). The experiment is performed on four different face datasets (YALE, ORL, UMIST, and AR). Preprocessing was performed during the tests to determine the face between all four database objects. All objects are matched in size, alignment and the two eyes in the same place

Sujata G. Bhele and V.H. Mankar [8] have attempted to examine a significant number of papers covering the latest developments in the area of face recognition. The current study demonstrates that new algorithms need to develop using hybrid techniques of soft computing tools like ANN, SVM, SOM that produces better output for better face recognition. The author has attempted to examine a significant number of papers covering the latest developments in the area of face recognition. This analysis examines all of these techniques with criteria that face recognition problems such as lighting, variation, facial expressions. PCA recognized as the Karhunen-Loeve technique is among the most common techniques for selecting features and reducing dimensions. The technique of recognition, defined as the eigenface technique, describes a facial characteristics location which diminishes existing data space dimensionality. A dominant technique for facial recognition is the linear discriminant analysis (LDA). It produces an appropriate representation that converts the existing data space linearly into a low-dimension feature domain where the data is well isolated. Support Vector Machines (SVM) are among the most valuable classification problem methods. One perfect example is face recognition. The added benefit of the SVM classifier with a standard neural network is that SVMs can attain better generalization precision.

Face detection is a technique of analyzing a face from a picture that has numerous features in that image [9]. Face detection is a difficult task as faces are not static and modify in size, appearance, color, etc. Face detection becomes more difficult when the image is not visible and obscured by anything else and no proper lighting, camera focusing, etc. Viola Jones method is utilized to identify a face and principal component analysis for face recognition. By combining the Viola Jones algorithm and Principle component analysis results in quick detection and high precision. The algorithm has been checked on the database with much more than 1000 images but with some false positives, it gives 90% accuracy. That Eigenvalue is an Eigenvector, and it shows how many images are different from the average image. It is possible to eliminate the original vector which corresponds to the small Eigenvalue as it has no vital information.

III. PRINCIPAL COMPONENT ANALYSIS

A principal component analysis (PCA) is an extracted feature algorithm that is dedicated to improving and using in this research work. This approach is expected to examine the dataset collectively, which implies that the image will not be evaluated and its attributes will not be extracted individually due to the intensity of (PCA), which sets the foundation for extracting a feature based on evaluating all datasets. Thus, the empirical data set needs to be properly selected not only for the training stage but also to remove the feature needed to evaluate the data set. It also implies that the feature for one examine image cannot be extracted individually; the test results must be compared and the PCA algorithm applied to the database and the test image must be applied to extract its features. PCA is a computational empirical strategy that is mostly utilized in image recognition, and there are various reports in the literature about the first use of PCA. Pearson's usually best-known early paper was in 1901[10]. It focuses itself, however, actually on strategies established to research scientists and engineers, focused in general and especially on the analysis of the eigenvector. This emphasizes matrices related to present-day numerical algorithms.

PCA is among the major ways of improving the data element with the least amount of information being lost. Across several ways, this approach is used including mathematical modeling, computational biology, image analysis, data processing, etc.[11]. Faces are described in the PCA system as a linear arrangement of weighted eigenvectors termed as Eigenfaces. Such eigenvectors are generated from the image database's covariance matrix. The proportion of Eigenfaces obtained will be equivalent to the number of images in the database.
PCA is a useful method for multidimensional hyperspace data analysis. Data extraction is experimental as an unsupervised technique of learning, assuming that there is no prior information of the input data structure.

IV. MACHINE LEARNING

Machine learning is among the subcategories in artificial intelligence, which continue with an algorithm that allows systems to recognize. This includes, supervised learning and unsupervised learning [12]. Supervised machine learning method involves using a defined feature set to maintain some

classification features and requires feature learning from the test including its input and output. Using labeled training data, a supervised learning algorithm learns, allows us to estimate unanticipated data results. The unsupervised approach involves an input learning system and no predicted output variables are given. Cluster analysis, association mining algorithms are several examples of unsupervised learning approaches. Unattended learning algorithms enable us to execute more complicated tasks than supervised learning.

A. Linear Discriminant Analysis

An appealing selection for face recognition is the linear discriminant analysis (LDA). LDA is a mathematical strategy for categorizing samples of some undiscovered classes depends on known class samples [13]. LDA is a numerical parameter that has a separate parameter and constant class-based parameter. LDA approach is categorized in two ways

1) Class dependent transformation- It significantly increases the dispersal ratio of deviation to dispersion within deviation.

2) Class independent transformation-- It significantly increases the ratio of overall dispersal to deviation within deviation.

By retaining as much category biased information as possible, LDA performs dimensionality reduction. This restricts the challenge to one dimension from the dimensions of d.

B. Naive Bayes Classifier

One of the popular supervised learning methods that are often used for classification purposes is a Naive Bayesian classifier. A classifier is called naive because it recognizes the possibilities that are connected are not based on the further. Naive Bayes is a system of classification invented by Thomas Bayes. This system, which learns from information and predicts the likelihood of each class [14].Naive Bayesian classifier is a probabilistic classifier and claims significantly that the attributes are isolated from each other depending on the theorem of Bayes. Traditional applications of this classifier involve spam filtering, face detection, prediction of sentiments, etc. Different types of naive Bayes classification techniques are as follows

1) *Multinomial Naive Bayes:*
   This is used to classify textual data, i.e. whether a text belongs to the classification of different classes such as sentiments, news categories, polarity, etc. The classifier's variables are the occurrence of the terms in the textual data.
2) *Gaussian Naive Bayes:*
   Another extension of naive Bayes is named Gaussian Naive Bayes that is utilized in real value features. To evaluate the data distribution certain functions can be utilized, but the Gaussian is the simplest way to work if only the average and standard deviation from the training data are to be calculated.

C. Support Vector Machine Classifier:

Support Vector Machine (SVM) is regarded as the significant classifier that generates reliable results in concerns with face recognition. For the nearest qualified instances, they accomplished by constructing a hyper plane with the highest possible Euclidean distance. Vapnik is the founder and developer of the support vector machines (SVM). The SVM is well known among researchers because of the characteristics and reliability of the empirical results. SVM is a robust machine learning system that is more capable of analyzing the hidden consistency of different data sets. Its main feature is to boost the ability of learning machines to generalize. SVM describes the vectors of the data feature in the feature space, the support vector corresponds to those specimens from the training data nearest to the categorized hyperplane.

$$ErrD\ (\emptyset) = ProbD\ \{(x, y) : \emptyset(x) \neq y\} \qquad (1)$$

The SVM method has several significant advantages in overcoming classification tasks. It has a lesser prediction time. The globally optimal solution in classification will ensure the precision of the objective identification classifier. However, there are some drawbacks like it takes more time to train the model. For processing big scale data, space complexity and time complexity increase linearly with the size of data [15].

D. Multilayer Perceptron Classifier:

Perceptron is Rosenblatt's first perceptron system in 1958. It is made up of two layers of neurons. It is a binary-class system of linear classification [16]. The eigenvector of the object is considering as input whereas the class of object is treated as output. The output layer is the neuron of a multilayer perceptron, termed as the rationale unit of the threshold. MLP could be interpreted as a classification technique of logistic regression in which the data is first processed by a trained, nonlinear computation. This computation transforms the input of the data into a domain where it is linearly distinguishable. The hidden layer is used to represent the middle layer of the neural network[14]. To render MLPs a consistent approximation, a single intermediate layer is necessary. There may be more than one sequential layer in the multilayer perceptron. When considers take the usual example of the three-layer network, Input is given at the first layer, the output will be at the last layer and the hidden layer is considering as middle layer. The input data is inserted into the layer of input and get the output from the layer of output. To make the system more complicated depending on our function, it enhances the number of the intermediate layer as it requires dataset and proposed method.

E. Olivetti Face

The ORL Database of Faces comprises a compilation of facial images captured at the laboratory from April 1992 to April 1994. There were 400 images from 40 different subjects in the ORL database. Face dataset includes 10 PGM-format grayscale images with a 92 x 112-pixel size of 40 people [3]. This database poses difficulties because of variants such as facial expression (eyes closed or open, neutral or smiling face)

and facial features (no glasses/glasses) with a threshold of close to ten degrees for lateral movement. The images are arranged in 40 folders (one for each subject) with type S_X names, where x denotes the subject number (between 1 and 40). The collection of sample images is represented in Fig. 1

Fig. 1. Sample images from ORL Dataset

F. Process flow

The process is started by making features extraction by applying PCA on the input image. The dataset is divided into three configurations A, B & C. In configuration A the dataset is divided into two parts, First part contributes 60 % for learning and 40% of data for evaluating purpose. In configuration B the dataset is divided into two parts, First part contributes 80 % for learning and 20% of data for evaluating purpose. In configuration C the dataset is divided into two parts, First part contributes 90 % for learning and 10% of data for evaluating purpose. After the extraction of features, a machine-learning algorithm is applied to classify the faces.

V. EXPERIMENTS AND RESULT

A. Proposed Face Recognition Approach

Fig.2 displays the implemented system's fundamental proposed flow diagram. In general, it consists of 3 modules:

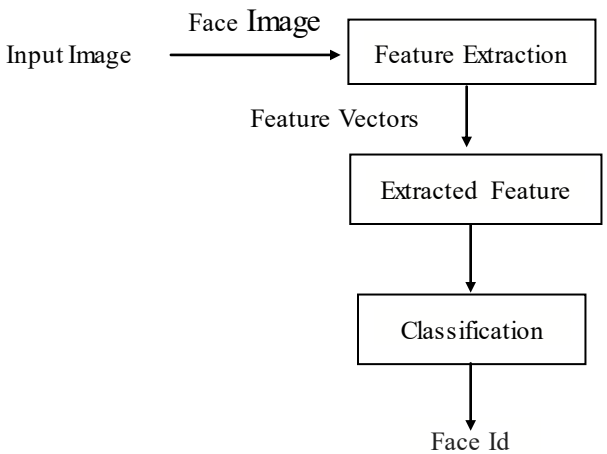

Fig. 2. Proposed Face Recognition Approach

Input Image: Face picture is utilized as input to the extraction process of the feature.

Feature Extraction: Transforming the actual image towards a more lightweight, and therefore more fundamentally different illustration. Here, principal component analysis (PCA) is used. PCA considers a different set of parameters such that all the parameters are orthogonal and measured by the deviation of the data within them. It implies that, first, there is a more essential principle axis.

Extracted Features: This is the output of the Feature Extracted method. Extracted features will give as input for the classifier.

Classifier: Evaluating the facial expression is achieved by the classifier for a specified feature matrix. The machine-learning algorithm is used as a classifier. It has been experimented using linear discriminant analysis, multilayer perceptron, naive bayes, and support vector machine.

Classified Class: Different face identity is used as classified classes, it has 40 classified classes one for each individual in the dataset.

B. Principal Component Analysis

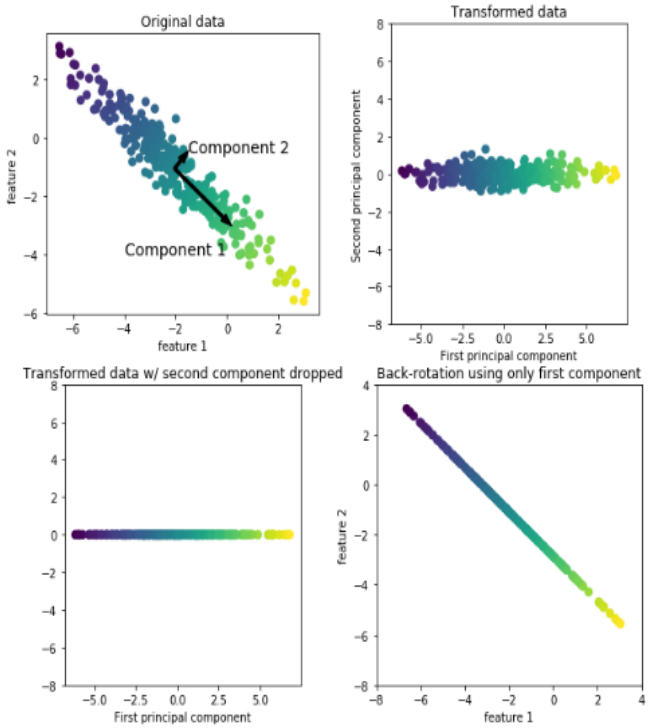

Fig. 3. Specific Example of Two-Dimensional Dataset

Fig. 3 displays a specific example of a two-dimensional set of data. The first image shows the color of the initial data points. Next, the algorithm determines the path of the total variance called "Component 1." It corresponds to the position most of the information is correlated with, or the properties most correlated with each other. Then, if the algorithm is orthogonal, it will determine the path during the first direction that includes the most data. There is only one feasible two-dimensional configuration at the right angle, but in high-

dimensional areas, there will be other orthogonal directions. Fig. 4 shows the PCA projection for 10 individuals.

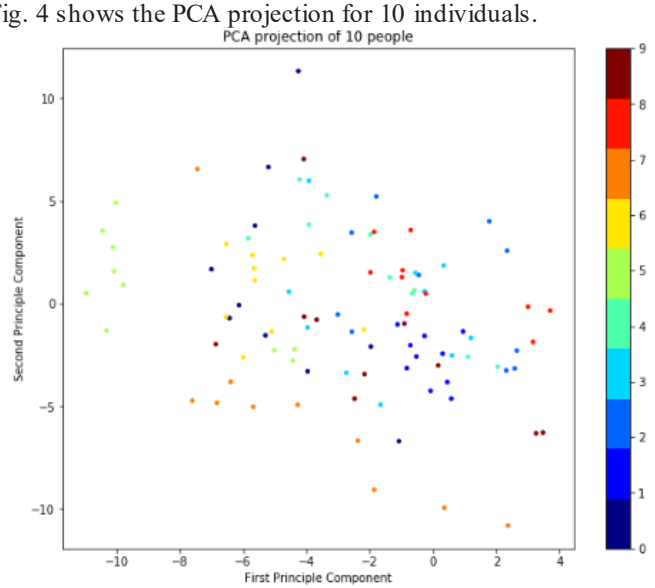

Fig. 4. PCA Projection for 10 Individuals

Eigenface is useful to extract useful facial information that might or might not necessarily relate to human perception of facial characteristics like nose, mouth, and eyes. This eigenfaces faces are the main components of a facial distribution, or identically, the covariance matrix of a collection of facial images, where N-pixel image is regarded to be a point in N-dimensional space.

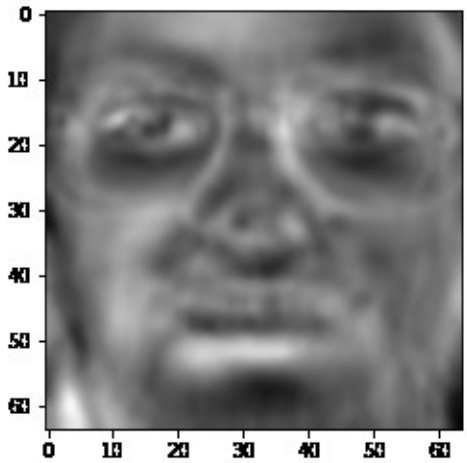

Fig. 5. Single Eigen Face of Most Significant Eigenfaces

Fig. 5 represent the single eigenface of most significant eigenfaces. Eigenface is also used to lower the complexity of calculation and storage, a significant number of variables can be used to depict every facial image. This eigenface is given as input to the classifier to detect the individual.

C. Experiment Results

Table I represent a comparison between different machine algorithm in terms of precision, recall, f-1 score, support for 60:40 ratio of the dataset.

TABLE I Comparison of Various Machine Algorithms for 60:40 ratios

Machine Learning Algorithm	Olivetti Face(60:40)		
	precision	*avg recall*	*avg f1-score*
PCA+Linear Discriminant Analysis	0.93	0.93	0.93
PCA+Multilayer Perceptron	0.89	0.88	0.88
PCA+Naive Bayes	0.85	0.85	0.84
PCA+Support Vector Machine	0.9	0.9	0.9

Table II represents a comparison between different machine algorithm in terms of precision, recall -1 score, support for 80:20 Ratio of the dataset.

TABLE II Comparison of Various Machine Algorithms for 80:20 ratios

Machine Learning Algorithm	Olivetti Face(80:20)		
	precision	*avg recall*	*avg f1-score*
PCA+Linear Discriminant Analysis	0.97	0.97	0.97
PCA+Multilayer Perceptron	0.94	0.91	0.91
PCA+Naive Bayes	0.91	0.91	0.9
PCA+Support Vector Machine	0.94	0.94	0.93

Table III represents a comparison between different machine algorithms in terms of precision, recall, f -1 score, support for 90:10 Ratio of the dataset.

TABLE III Comparison of Various Machine Algorithms for 90:10 ratios

Machine Learning Algorithm	Olivetti Face(90:10)		
	precision	*avg recall*	*avg f1-score*
PCA+Linear Discriminant Analysis	1	1	1
PCA+Multilayer Perceptron	0.97	0.97	0.97
PCA+Naive Bayes	0.95	0.95	0.93
PCA+Support Vector Machine	1	1	1

From Table I, II, and III it is clear that the different machine algorithms in terms of precision, recall, f -1 score, support for accuracy for different dataset configurations. Accuracy of Configuration C is highest for the entire machine algorithm as compared to configuration A & B. PCA + Naïve Bayes achieves the accuracy of 85% for configuration A, 91 % for configuration B and 95% recognition accuracy for configuration C. PCA + Multilayer Perceptron achieves an accuracy of 89% for configuration A, 94 % for configuration B and 97% recognition accuracy for configuration C. PCA+Linear Discriminant Analysis achieves an accuracy of 93% for configuration A, 97 % for configuration B and 100% recognition accuracy for configuration C.

D. Experiment Results

It contrasted the suggested approach to the existing ones in [4], [5], and [6] to show the significance of the results obtained. Table IV summarizes this comparative analysis. This comparative analysis demonstrates that the suggested techniques to face recognition applications are efficient. Opposed with other works, the PCA with a machine learning algorithm improves face recognition rate. Fig. 6 represents the comparative study of different approaches. Thus the results presented are more relevant when contrasted to face recognition schemes for PCA+LDA, PCA+MLP, PCA+NB, and PCA+SVM.

TABLE IV Comparative Study

Approaches	Method Used	Accuracy (%)
[4]	DWT+LDA+SVM	96
[5]	Naive Bayes	93.16
[6]	HOG+SVM	92.68
Proposed Approach	PCA+SVM (80:20)	94.00
	PCA+SVM (90:10)	100.00
	PCA+LDA (80:20)	97.00
	PCA+LDA (90:10)	100.00

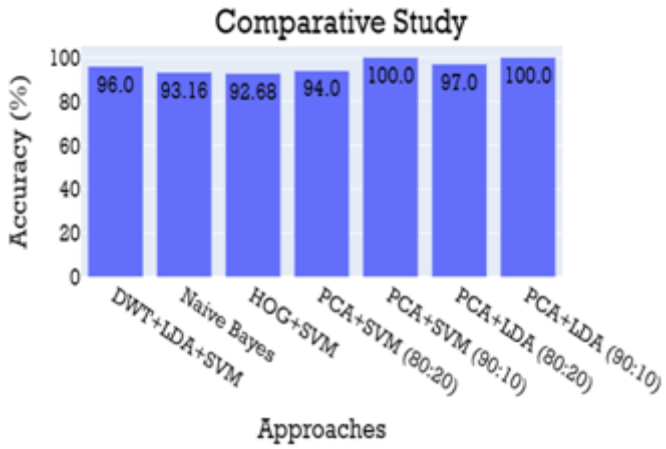

Fig. 6. Comparative Study

VI. CONCLUSION AND FUTURE WORK

In this paper, an investigation is used to automatically detect the face of the person. The ORL dataset is used for performing experiments. Firstly, the dataset is segmented into two sections in three different configurations A (60:40), B (70:40), and C (90:10). The first section is utilized for learning purposes and the second section is utilized for system evaluation. The vital information is extracted from the input images using PCA. Later, it is experimented using linear discriminant analysis, multilayer perceptron, naive Bayes, and support vector machine. These have achieved recognition accuracy of 97% on configuration B & 100% on configuration C by using PCA and Linear Discriminant Analysis. Subsequently and on future research, by reviewing other databases such as GTF and YALE dataset, more face detection difficulties such as orientation variation, lighting, poses, and facial expression variations will be found. Besides, other face detection techniques can be applied and tested to improve this research.

REFERENCES

[1] R. Ebrahimpour, N. Sadeghnejad, A. Amiri and A. Moshtagh, "Low resolution face recognition using combination of diverse classifiers," *2010 International Conference of Soft Computing and Pattern Recognition*, Paris, 2010,pp.265-268.doi: 10.1109/SOCPAR.2010.5686495

[2] H. Baqeel and S. Saeed, "Face detection authentication on Smartphones: End Users Usability Assessment Experiences," *2019 International Conference on Computer and Information Sciences (ICCIS)*, Sakaka, Saudi Arabia, 2019, pp.1-6.doi: 10.1109/ICCISci.2019.8716452

[3] P. Dinkova, P. Georgieva, A. Manolova and M. Milanova, "Face recognition based on subject dependent Hidden Markov Models," *2016 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Varna, 2016, pp. 1-5.

[4] Z. B. Lahaw, D. Essaidani and H. Seddik, "Robust Face Recognition Approaches Using PCA, ICA, LDA Based on DWT, and SVM Algorithms," *2018 41st International Conference on Telecommunications and Signal Processing (TSP)*, Athens, 2018, pp. 1-5. doi: 10.1109/TSP.2018.8441452

[5] N. Sabri et al., "A Comparison of Face Detection Classifier using Facial Geometry Distance Measure," 2018 9th IEEE Control and System Graduate Research Colloquium (ICSGRC), Shah Alam, Malaysia, 2018, pp. 116-120.doi: 10.1109/ICSGRC.2018.8657592

[6] A. Adouani, W. M. Ben Henia and Z. Lachiri, "Comparison of Haar-like, HOG and LBP approaches for face detection in video sequences," *2019 16th International Multi-Conference on Systems, Signals & Devices (SSD)*, Istanbul, Turkey, 2019, pp. 266-271. doi: 10.1109/SSD.2019.8893214

[7] J. Fan, Q. Ye and N. Ye, "Enhanced Adaptive Locality Preserving Projections for Face Recognition," *2017 4th IAPR Asian Conference on Pattern Recognition (ACPR)*, Nanjing, 2017, pp. 594-598. doi: 10.1109/ACPR.2017.123

[8] Sujata G. Bhele and V.H. Mankar, A Review Paper on Face Recognition Techniques,in The International Journal of Advanced Research in Computer Engineering and Technology (IJARCET) vol 1, Issue 8, October 2012.

[9] H. S. Karthik and J. Manikandan, "Evaluation of relevance vector machine classifier for a real-time face recognition system," 2017 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia), Bangalore,2017, pp. 26-30.doi: 10.1109/ICCE-ASIA.2017.8307832

[10] K. Pearson, *"On Lines and Planes of Closest Fit to Systems of Points in Space",* Philosophical Magazine 2, 1901,pp 559–572, http://pbil.univ-lyon1.fr/R/pearson1901.pdf .

[11]. W. Y. Min, E. Romanova, Y. Lisovec and A. M. San, "Application of Statistical Data Processing for Solving the Problem of Face Recognition by Using Principal Components Analysis Method," 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Saint Petersburg and Moscow, Russia, 2019, pp. 2208-2212.

[12] B. K. Bhavitha, A. P. Rodrigues and N. N. Chiplunkar, "Comparative study of machine learning techniques in sentimental analysis," 2017 International Conference on Inventive Communication and Computational Technologies (ICICCT), Coimbatore, 2017, pp.216-221, doi: 10.1109/ICICCT.2017.7975191

[13] F. Mahmud, M. T. Khatun, S. T. Zuhori, S. Afroge, M. Aktar and B. Pal, "Face recognition using Principle Component Analysis and Linear Discriminant Analysis," *2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*, Dhaka, 2015, pp. 1-4. doi: 10.1109/ICEEICT.2015.7307518

[14] E. B. Putranto, P. A. Situmorang and A. S. Girsang, "Face recognition using eigenface with naive Bayes," *2016 11th International Conference on Knowledge, Information and Creativity Support Systems (KICSS)*, Yogyakarta, 2016, pp. 1-4.doi: 10.1109/KICSS.2016.7951418

[15] H. Dai, "Research on SVM improved algorithm for large data classification," *2018 IEEE 3rd International Conference on Big Data Analysis (ICBDA)*, Shanghai, 2018, pp. 181-185.

[16] J. Shi, X. Zhu and N. Niu, "A Research on Multi-Layer Perceptron Diagnosis Model Based on D Matrix," 2018 Prognostics and System Health Management Conference (PHM-Chongqing), Chongqing, 2018, pp. 769-773, doi: 10.1109/PHM-Chongqing.2018.00137