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Performance comparison of PCA and ICA algorithms-based face recognition system

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Abstract: Face recognition system has become a dominant research area in biometric studies due to its efficiency and accuracy. This technology has been broadly invested in various security applications for the automatic identification of humans. However, the complexity of human faces representation with the large variation in its characteristics and appearances. This complexity involves adopting powerful algorithms that can effectively learn and overcome such problems with less false results. Many algorithms are proposed for this purpose such as the Principal Component Analysis (PCA) and the Independent Components Analysis (ICA), etc. This work focuses on the implementation of a reliable face recognition system using PCA and ICA as recognition methods and the Euclidean Distance (ED) as a face classifier. A comparison is conducted upon the performances of the PCA and the ICA. These two methods are mainly used in this research for image projection and dimensionality reduction. The classification process is performed by using the distance measure scheme that is adopted by the ED classifier. The comparison is taken for the system robustness evaluation in terms of recognizing a given set of face images.

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PCA ve ICA algoritmaları tabanlı yüz tanıma sisteminin performans karşılaştırması

Anahtar Kelimeler
Biyometri
Yüz tanıma sistemi
Kullanıcı doğrulama
PCA ve ICA algoritmaları

Makale geçmişi:
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Öz: Yüz tanıma sistemi, verimliliği ve doğruluğu nedeniyle biyometrik çalışmalarda baskın bir araştırma alanı haline gelmiştir. Bu teknoloji, insanların otomatik olarak tanımlanması için çeşitli güvenlik uygulamalarına geniş ölçüde yatırım edilmiştir.Bununla birlikte, insanın karmaşıklığı, özellikleri ve görünümlerindeki büyük varyasyonla temsille karşı karşıyadır. Bu karmaşıklık, bu tür sorunları daha az yanlış sonuçlarla etkili bir şekilde öğrenebilen ve üstesinden gelebilen güçlü algoritmaları benimsemeyi içerir. Bu amaçla Temel Bileşen Analizi (PCA) ve Bağımsız Bileşen Analizi (ICA) vb. Bu çalışma, tanıma yöntemleri olarak PCA ve ICA kullanılarak güvenilir bir yüz tanıma sisteminin uygulanmasına odaklanır ve yüz sınıflandırıcı olarak Öklid Mesafesi (ED). PCA ve ICA'nın performansları üzerine bir karşılaştırma yapmıştır. Bu iki yöntem esas olarak bu araştırmada görüntü projeksiyonu ve boyutsallık azaltma için kullanılmaktadır. Sınıflandırma işlemi, ED sınıflandırıcısı tarafından benimsenen mesafe ölçü düzeni kullanılarak gerçekleştirilir. Karşılaştırma, belirli bir yüz görüntüsü kümesini tanıma açısından sistem sağlamlığı değerlendirmesi için alınır.

1. Introduction

In the recent years, biometric technologies have received great value of consideration and an increased demand in different security prospects. For instance, iris or retinal scan, fingerprint analysis, digital signature recognition and voice recognition, etc. These systems are the most common biometric applications in which a personal identification is required [1]. The necessity of establishing a powerful technique for personal identification has risen day by day. Face recognition systems are one of the most popular applications in visual computing. Due to the growing scenario of the global security concerns in which various domains involve an automatic identification of individuals such as video surveillance, criminals' detection, financial systems and CCTV, etc [2]. This approach is considered as an emerging technology of

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biometric applications and a significant research area in the computer vision, pattern recognition and Human Computer Interaction (HCI) fields. Face recognition techniques are applied in a wide range of practical sectors such as personal authentication, access control, information security, images processing, etc [3,4,5]. Thousands of organizations and companies around the globe deploy biometric technologies as reliable systems which provide an acceptable level of protection for the monitoring purposes. Face recognition has its own characteristics in terms of the contribution with the participants since this system is a non-intrusive application and friendly system. It does not require a huge cooperation by its own users in order to accomplish the required tasks [3,4]. However, developing such a system for the automatic verification of a human identity is not a simple task. Human faces have dynamic features and characteristics which are subject to change during aging. These changeable characteristics impose difficulties on the automatic recognition systems.

Over the past few years, much research has concentrated on proposing several algorithms and frameworks of face recognition systems which are capable of dealing with such visual models. Not all the proposed methods of face recognition systems are 100% reliable and can efficiently recognize face images under different factors such as illuminations, light conditions, face poses and image quality. Some of these methods outperformed others in recognizing human faces with different rotation angles whereas other techniques performed effectively with various facial expressions [6]. Based on the input data, the face recognition system is categorized into two groups, still-based recognition and video-based recognition [7]. In the still-based face recognition system, a set of static face images is automatically recognized by the system. On the other hand, video-based recognition uses a stream of videos when a set of unknown faces in a real-time system is required to be identified. This paper conducts the still-based face recognition system in which a set of given face images is automatically matched with a pre-stored faces database. The face recognition system in this paper is implemented using two widespread face recognition algorithms, the PCA and the ICA for dimensionality reduction and the ED classifier for face classification. Then, a comparison is taken upon the performances of the PCA and the ICA methods versus a collection of face images.

2. Face Recognition System Concepts

Face recognition systems became a hot topic in the automatic identification systems of human biometrics [8]. FRS has a long history of research which started in the early 19th century. Face recognition in earlier stages was mainly relying on human intervention in which a priori knowledge was essentially required by the designers. However, the vital improvement in the computer industry has resulted in the appearance of high-speed and high-performance computers which significantly made a breakthrough in the face recognition performance [9]. The first research in this topic was carried out on facial features by Bertillon, Allen and Parke that is highly related to face recognition. The first attempt of Bertillon was made on a database of face networking in which interesting recognition results were achieved. In Allen's research, an enhanced face recognition system was attained by adding effective features to the system. Parke introduced a high-quality face model which was carried out in a computer system [9]. Later on, a statistical method for facial features representation using ED classifier was adopted by Kaya and Kobayashi [9]. For a long time, human biometric identification applications became an interesting topic. In the early 80‟s, real development was carried out by many universities and research institutions on such automatic identification systems.

As known, human beings have unique facial characteristics which differentiate one another [10,11,12). Many efforts by scientists and researchers from different fields have evolved in studying the characteristics of the human [12]. Earlier in the 1960s, several researches concluded that various developments were carried out on improving human biometric recognition systems [13]. Face recognition is a significant area in computer vision, pattern recognition, physiology and human computer interaction fields. The advantage of adopting a reliable and accurate face recognition system achieved interesting results to be applied in the personal identification and verification applications [14]. Many other biometric technologies such as fingerprint scanning, retinal or iris scanning and signature verification are widely used these days for biometric identification. Figure 1 shows the magnitude of adopting different biometric techniques in comparison with face recognition systems [4].

Generally, a typical face recognition system is divided into four main processes:

- Images acquisition or collecting
- Images pre-processing
- Facial features detection
- Face matching and recognition

As shown in Figure 2, the first process is image acquisition. In this process, a set of face images is taken from a face database and used in the experiments of the system [13]. In images pre-processing, this process does the face detection where the facial features regions such as eyes, nose and mouth are located using different face detection methods. Therefore, a set of normalization processes is included in the images preprocessing stage. For example, images cropping and images resizing, etc. This stage has a significant impact on the overall face recognition performance especially when all the face images are normalized to have one size [15,16]. The third stage is extracting the facial traits, in this process the conducted face recognition techniques project the basis features (face spaces) which represent most of the variance in the facial features of the initial face images. In other words, each given face image is represented as a collection of points of those subspaces (principal components). In the final stage, an unknown face image will be matched with the extracted subspaces which lead to the recognition process of the input image.

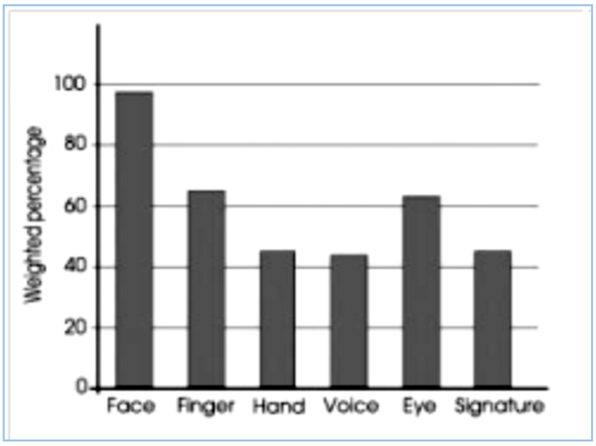

Figure 1. Magnitude of different biometrics technologies

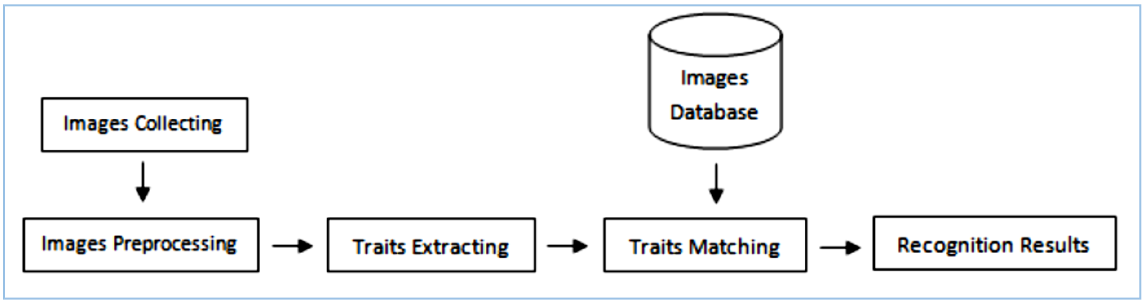

Figure 2. General processes of a typical face recognition system

In general, there are two approaches to face image representations in face recognition systems. First is the appearance-based approach and second is the feature-based approach [17]. The appearance-based approach is more popular than the feature-based approach. Many face recognition methods adopt the subspace scheme that is widely used in the appearance-based approach of image representation. In this approach, a face image is being matched with a set of subspaces (face spaces) which are decomposed from the initial face images. An image, in the context of computer vision, is made up of thousands of small pixels which together indicate the dimensionality of a particular image. However, when a given face image is being matched with the original face images, this leads to one of the most popular problems in image processing which is the image dimensionality. The high dimensionality of an image is a well-known obstacle in face recognition systems as this issue causes high computational complexity and it consumes most of the memory storage [17]. Therefore, adopting a dimensionality reduction method is quite important to avoiding the negative impact of such obstacles on the overall system performance. Many dimensionality reduction methods have been proposed for this purpose. Such methods are PCA, ICA and Linear Discriminant Analysis (LDA). All these algorithms are based on the subspace scheme in the face recognition system.

3. Background and Related Work

FRS has a long history of research which started in the early 19th century. Face recognition in earlier stages was mainly relying on human intervention in which a priori knowledge was essentially required by the designers. However, the vital improvement in the computer industry has resulted in the appearance of high-speed and high-performance computers which significantly made a breakthrough in the face recognition performance [9]. The first research in this topic was carried out on facial features by Bertillon, Allen and Parke that is highly related to face recognition. The first attempt of Bertillon was made on a database of face networking in which interesting recognition results were achieved. In Allen's research, an enhanced face recognition system was attained by adding effective features to the system. Parke introduced a high-quality face model which was carried out in a computer system [9].

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Kaya and Kobayashi [9]. For a long time, human biometric identification applications became an interesting topic. In the early 80‟s, real development was carried out by many universities and research institutions on such automatic identification systems. As known, human beings have unique facial characteristics which differentiate one another [11,12]. Many efforts by scientists and researchers from different fields have evolved in studying the characteristics of the human [12]. Earlier in the 1960s, several researches concluded that various developments were carried out on improving human biometric recognition systems [4,13]. Face recognition is a significant area in computer vision, pattern recognition, physiology and human computer interaction fields. The advantage of adopting a reliable and accurate face recognition system achieved interesting results to be applied in the personal identification and verification applications [14]. Many other biometric technologies such as fingerprint scanning, retinal or iris scanning and signature verification are widely used these days for biometric identification. Figure 2.1 shows the magnitude of adopting different biometric techniques in comparison with face recognition systems [4].

The other traditional security applications of personal identity verification such as Personal Identification Number (PIN) and Identity Document (ID) card have been considered as insecure methods especially when these techniques are easy to be stolen and used by unauthorized users. Thus, with the continuous growth of security issues like surveillance and access control, the need to develop a stable face recognition system that can accurately verify a person's identity has obviously increased [11]. Face recognition systems are one of the most deployed applications of human biometrics verification systems that cannot be easily stolen, lost, or personated by unauthorized or fraudulent persons [14]. However, designing robust face recognition is not an easy task [3].

Key advantages of a face recognition system are non-intrusive applications and it requires fewer efforts by its own users to accomplish the identification task. Despite the features of the face recognition system, it has a complexity which impacts the overall system performance [3]. In general, human faces have a wide range of variations in their facial features such as eyes, noses, mouths and chin, etc [2]. A number of factors is often mentioned by many researchers in which face recognition system performance is directly affected. For instance, illumination or lighting conditions, face viewing conditions, face poses, aging changes and facial expressions [2, 3, 4,18]. Therefore, several algorithms are designed to overcome the difficulty that is imposed by these conditions. Examples of those face recognition algorithms are PCA, ICA and LDA.

These methods are dominant in image representation and commonly used as face recognition algorithms. In general, the accuracy of a typical face recognition system in essence depends on two significant processes, (1) face detection and (2) facial features recognition [3,4,5]. Firstly, detecting facial features such as eyes, nose and mouth can be located and extracted by using different techniques. Then, a dimensionality reduction process is required in order to enhance the overall system performance. This task is accomplished by using the PCA and the ICA as dimensionality reduction techniques which will reconstruct the basis features vectors that are obtained for image projection in order to be used in the classification process.

4. Machine-based Face Recognition System Applications

Over the past 30 years, considerable efforts have been exerted by many psychophysicists and engineers' communities on the analysis of face recognition disciplines [19]. Although the human brain intelligently recognizes different objects based on their visible features and makes a decision in which category each object belongs to. But the human brain cannot recognize thousands of faces through aging changes. Machine-based face recognition systems have been competing for the last few years. This trend has brought a new research area in the fields of computer vision, images analysis and pattern recognition [7]. In addition, there are two significant factors in which face recognition systems have been widely employed as an active machine-based application.

First, the spanned applications of face recognition in both commercial and law enforcement domains. Second, the wealth of feasible technologies that are available and deployed for a long time. Table 1 lists some of the common applications of face recognition systems [7].

Generally, these various applications of machine-based face recognition systems have been categorized into two main types: static matching and real-time matching [7,19]. The static matching conducts a static image format such as driving license, credit card, mug shots and passports. On the other hand, real-time matching uses video-based recognition like surveillance videos processing, CCTV and other technologies. However, machine-based face recognition outperforms compared to human brain recognition.

Due to its maturity of the learning within heterogeneous environments under different constraints and requirements [7,19]. Even though the existing machine-based face recognition systems have attained impressive achievements in different research disciplines, these systems have some drawbacks in which the performance is imposed by different obstacles. An essential problem of machine-based face recognition application is stated when the system operates in a changeable environment such as an outdoor area where many illuminations and light conditions impact negatively on the overall system outcomes. Thus, images processing engineers have been exerting considerable research on the literature analysis of such machine-based face recognition systems [7].

Table 1. Face recognition system applications

Areas	Specific Applications
Entertainments	Video game, virtual reality, training programs
	Human-robot-interaction, human-computer-interaction
Smart Cards	Drivers‟ licenses, entitlement programs
	Immigration, national ID, passport, voter registration
	Welfare fraud
Information Security	TV Parental control, personal device logon, desktop logon
	Application security, database security, file encryption
	Intranet security, internet access, medical record
	Secure trading terminals
Law Enforcement and Surveillance	Advanced video surveillance, CCTV control
	Portal control, post event analysis

5. Face Detection

Face detection is a significant process in a typical face recognition system which is considered as an extensive research field in images processing for the last few years [20,21]. In order to obtain an accurate performance of a face recognition system, a framework of face detection has to be not only efficient but also carry out the process of facial features detection effectively [22]. As well known, the human brain detects and recognizes various objects based on the known characteristics of those objects. The main purpose of face detection is to find out the location of facial features such as eyes, nose and mouth in a given face image [21]. However, face detection became challenging due to the high range of variability in the human faces' characteristics and their appearances such as eyes shapes, noses and mouths [21,23]. Therefore, various techniques of face detection are proposed which refer the accuracy of any face analysis application to the efficiency of face recognition and detection processes. Although many face detection algorithms exist to accomplish this essential process, some of them have their own strengths and weaknesses. Examples of these algorithms are HAAR classifier, AdaBoost, Local Binary Pattern (LBP), Support Vector Machine (SVM) and Histogram of Oriented Gradients (HOG) [8,23].

The computational complexity and the lack of the proper accuracy are the most common problems of the face detection algorithms. In this research, an automatic detection of facial features is employed using a well-known algorithm (Viola-Jones) face detection [24]. This method locates facial features regions in an image which contains eyes, nose and mouth based on a rectangular box that extracts these features. This algorithm is implemented based on MATLAB toolboxes which have built-in classes and functions to implement Viola-Jones face detection algorithm. The MATLAB Computer Vision System Toolbox provides a well implementation of this algorithm by using a built-in function called (*vision.CascadeObjectDetector*) which controls the detection of different objects based on the above mentioned algorithm. For example, in order to detect eye area in a given face image, a particular detector (*EyeDetect*) is passed to (*vision.CascadeObjectDetector*) function. In this paper, a default detector for the face area (*FDetect*) is passed to the main function (*vision.CascadeObjectDetector*) in order to extract the region of the facial features (eyes, nose and mouth) in a single rectangle. Figure 5 shows multiple rectangles are used to detect different facial features in a given face image. Figure 6 shows a sample of successful face detection in a single rectangle based on the Viola-Jones algorithm.

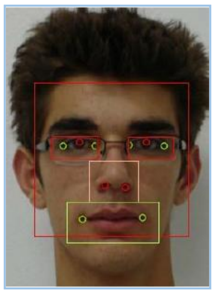

Figure 5. Face detection of a face image with spectacles with multiple rectangles

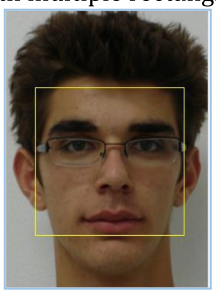

Figure 6. Face detection of a face image with spectacles with single rectangle

6. Face Recognition System Algorithms

In this section, a critical analysis is discussed for two of the most common face recognition methods the PCA and the ICA. The background and related work on these two algorithms are presented as well.

6. 1 Principal Components Analysis (PCA)

The continuous increase of data complexity and its enormous generated information has made data analysis a more difficult challenge for analysts [25,26]. In general, the human face from the computer vision point of view is considered as a complex and multidimensional visual object [18]. These real-world data sets (e.g. human faces) have complicated data structures. However, developing a computational technique to deal with the complexity of such high-level problems, face recognition, is a difficult task [25,27]. In face images representation, there are two main categories of face representation: appearance-based approach and features-based approach in which appearance-based is being widely used [17]. A face image in the appearance-based approach is represented by a point in a space of features which is spanned by a number of decomposed face images (low-dimensional) from the original face database [17,28].

As a face recognition concept, a given face image is matched with a set of pre-stored face images (high-dimensional). This leads to an inefficient recognition system due to the large computations generated from the huge amount of data and the consumption of the memory storage [17]. Therefore, a mechanism for dimensionality reduction must be conducted to solve such problems. The successful scheme, subspace also known as face space, was firstly proposed by Kirby and Sirovich in 1987 to represent a sequence of face images [18,11,29]. This approach reconstructs a set of signal data with a high dimension based on linear or non-linear transformation into a low-dimensional subspace. The subspace framework has its advantages among other image representation schemes in terms of learning capacity, computational speed and simplicity.

In 1991, Turk and Pentland introduced a theoretical approach for face recognition based on the subspace scheme. This approach seeks for the most significant facial features among a set of face images and projects them into the principal components of the original given face images [18]. The proposed theory by Turk and Pentland is called Eigenfaces which is one of the most successful applications of the PCA algorithm. Eigenfaces are a set of basis face images which are the decomposed features of the initial set of face images. PCA is one of the most common subspace methods which was first used for dimensionality reduction in face recognition systems. Later on, a development was carried out by Turk and Pentland in 1991 for the use of the PCA algorithm for facial features analysis [30,31]. PCA also known as Karhunen-Loeve Transform (KLT) is an unsupervised computational approach which has been widely deployed as a powerful technique for facial representation based on linear direction [27, 31,32,33,34]. The linear projection of PCA conducts second-order statistical relationships (orthogonal) among the image pixels in a vector. When a large number of high-dimensional face images with minor features are discarded, other small numbers of those variables (images dimensions) which have significant features, i.e. most variance, are retained with low dimension based on linear direction. Those latent features with the greatest variability are known as eigenfaces or eigenvectors [26].

By using linear distribution of the input data, it transfers a set of correlated face images into a set of uncorrelated variables based on an orthogonal direction in the mean square sense with maximizing the variance between the data. Therefore, the PCA obviously reduces the dimensionality while mapping the data based on the linear transformation of a set of face images into small face spaces with low dimensions. This loss of facial information is less when the variance (features variability) in images spaces is trivial. These face spaces are also known as eigenspaces [35]. The experimental results of Turk and Pentland research were performed using the PCA method based on the subspace scheme with different face views which attained 96% of accurate classification results. There are two reasons for using the PCA. First, the data interpretation and secondly is the dimensionality reduction. In data interpretation, the PCA tends to project the most important features of a set of large data when the features variance is discovered. The key advantages of the PCA method are reducing the high dimensionality of a large data set, decreasing the computational efforts, and effectiveness to perform in a real-time system [14,36]. The PCA has been widely applied as a powerful statistical method in different fields such as data analysis, images compression and pattern recognition.

$$y = f(x) \qquad (1)$$

6.2 Independent Components Analysis

Numerous methods for dimensionality reduction in face images representation have been studied for a long time such as the ICA [37,38, 39, 40, 41,42, 43, 44]. In the last twenty years, the ICA has been investigated and proposed in different applications especially in pattern recognition fields like the face recognition system. The

ICA is a generalization method of PCA algorithm which means that the PCA is considered as the baseline of evaluating the ICA performance [43,44, 45]. So, ICA is a statistical method that concerns on both second-order and high-order dependencies among the coefficients of the observed data sets (face variables) [39, 43,44, 46]. On the other hand, the PCA conducts only the second-order statistics while undertaking the computations of the eigenfaces (principal components) of the covariance matrix. This leads to the fact that the ICA captures basis vectors of the decoded face images which have more localized features in the projection distribution since the ICA can project these basis features beyond the second-order relationships (non-orthogonal) between their pixels [47].

The complexity of face data structure in which a large amount of important information seems difficult to be captured by only second order statistics (linear-non) [26]. The ICA tries to capture the most significant information among a set of face images and to store them in the high-order relationships [47]. The main idea behind this method is to find out the best decomposition of a given set of signal observations and convert them into statistical components which are independent from one another [38,43,46]. A successful application of the ICA is the separation of mixed signals like the blind source separation method or what is known as Blind Signal Separation (BSS). ICA was first applied in face representation and recognition by Bartlett and Sejnowski in 1997 in which two of ICA architectures were suggested (Architecture I and Architecture II). In their research, Infomax algorithm was used to implement both of ICA architectures when both architecture performances were evaluated on a subset of the FERET face database. The obtained results by Bartlett and Sejnowski reported that both of ICA architectures I and II performed effectively in face recognition [43]. While another algorithm, the fixed-point algorithm was adopted by Yuen and Lai in 2000 to implement the ICA scheme in calculating the independent components. In [43] the researchers have used two versions of PCA algorithms as baseline methods to evaluate ICA performance in face recognition. Three different face databases FERET, AR and AT&T were used, they found that PCA version I that is involved in ICA Architecture I has a vertical centralizing process on the basis features vectors. Also, in ICA Architecture II which includes PCA version II, there was a whitening horizontal centralizing process performed while calculating the independent components.

As a conclusion of the experiments in [43], they found that there is no obvious difference in the performance between the ICA Architecture I and II and it's related the PCA versions. In the other hand, some experimental results reported that both of the whitening and centering processes in the PCA have significant effects on the ICA performance in face recognition [43]. In [48] authors have conducted a comparative study on both PCA and ICA methods performances when their experimental results showed that the ICA Architecture II outperformed PCA. Similarly, to the work of [48], the obtained consistent results of [35] have concluded that the PCA outperformed the ICA Architecture I. In contrast to Moghaddam and Jin study, when they argued about the results of [48], they reported that the PCA and the ICA methods have no different performances that should be mentioned [43]. In this work, the ICA method is implemented using fixed-point algorithm which involves PCA whitening process while generating the principal components. Therefore, the ICA performed effectively in some experiments while in some other experiments the ICA could not generate the best basis features (i.e., ICs) which negatively affected the overall performance.

7. Face Classification Methods

Images classification in both computer vision and images recognition fields has been considered as a significant approach. Due to the high complexity in recognizing different images categories, face classification topic plays a vital role in the face recognition system. However, facial images classification has a vital impact on face recognition performance. A key problem in most of the classification algorithms is how to classify the numerical image features and make a decision with which class belongs to which category [2, 49,50,51]. In general, the classification schemes conduct a wide range of image classification decision theories [49,52]. Several studies and researches have been carried out on developing reasonable classification algorithms which are capable of attaining impressive results in solving classification problems [49,50,51]. The majority of the classification theories are based on an assumption that a given face image has one or more properties (features) in which each feature belongs to one of multiple distinct classes [49]. One of the most common image recognition classifiers is the linear classifier [52]. This classifier has received considerable attention by many pattern recognition researchers due to its efficiency and accuracy in classifying numerical images. This classifier is based on the distance measurement of the classified images as the main images classification criteria [52]. Variety of distance classification approaches are investigated and studied such as the ED classifier, Cosine Distance (CD) and the Mahalanobis Distance (MHD) methods [49]. This work uses one of the most common image classifiers, the ED classifiers based on the distance measure [50]. Due to the feasibility and simplicity of the ED, the classification of face recognition systems is done by using this classifier. More details about this classifier and its procedure in the face recognition system are described in the following section.

7.1 Euclidean Distance Classifier

In the past few years, considerable research has been done on pattern recognition approaches. Image classification in both image processing and pattern recognition is considered as a complicated task, due to the complexity and the multidimensionality problems of image features [52]. However, face recognition accuracy depends highly on the efficiency of classification performance. The ED classifier has been widely deployed in image recognition as a linear classifier. It conducts the minimum distance measurement approach in classifying images features. The ED also known as Euclidean Metric is an ordinary distance measure technique that measures the distance among two points and uses the Pythagorean formula [2]. Measuring the distance between two given images is a difficult task from a computer vision point of view [50]. In comparison with those more complicated classification methods like Support Vector Machine (SVM) and Neural Network (NN), distance measuring methods suffer from the complexity of measuring computations as well as the difficulty to be embedded with other powerful face classification techniques [50].
Therefore, in face recognition applications, the ED classifier recognizes an image by taking the distance of unknown image data and measures it with the next closest one (the smallest distance) of the known features templates (face spaces) as the basis of classification task [2,50]. In other words, the classification template in which the unknown image data category is classified based on the smallest distance matching with the one which has the maximum similarity among the known features of pre-stored classes [2,50]. However, the ED with its simplicity is still sensitive to any deformation [50]. A general research analysis was done on the most popular face databases.

This analysis is discussed and some face databases are tabulated in the face databases analysis section. Image pre-processing steps are illustrated in the images pre-processing section with their obvious effects on the used face images. Then a general discussion about the structure of the face images database is described in the face database structure section.

8. Face Databases Analysis

Human face in computer vision is a multidimensional and complex object. There are many parameters which make a face subject to change [28, 53]. Such parameters are aging, pose orientation, head size and face obscuring (eyeglass effects) [53]. Many human face databases are designed and have been introduced to evaluate face detection and recognition algorithms. For instance, ORL, MIT, Cambridge, Bern, YALE B database, FERET, AR, AT&T and FEI face databases are the most widely used face databases [28,53]. These face databases are used in face recognition experiments under various conditions such as different facial expressions, illumination conditions, face poses, images backgrounds, etc. All these face databases are freely available for academic research purposes and can be downloaded from the official source link of face recognition [54]. Some of these face databases are analyzed and listed in Table 2 as below.

Table 2. Face databases analysis

Database Name	Total Images	No. of Individuals	Images Size	No. of samples per subject	No. of Females	No. of Males	Images Format	Images Type	Facial Expressions
FEI Face Database	2800	200	640x480 pixels	14	100	100	JPG	RGB	two expressions neutral and smiling
ORL Face Database	400	40	92x112 pixels	10	4	36	PGM	256 Grey	different lighting, facial expressions (open / closed eyes, smiling / not smiling) and facial details (glasses / no glasses)
Yale Face Database	165	15	80x80 pixels	11	1	14	GIF	256 Grey	smile, surprised, neutral, annoyed, open eyes and closed eyes, glasses/without and different light conditions
Indian Face Database	440	40	640x480 pixels	11	20	20	JPG	256 Grey	four expressions neutral, smile, laughter, sad/disgust

8.1 FEI Face Database

The FEI face database based frontal face view is mainly d in this project for testing and evaluating the conducted face recognition system in this project. This face database is a Brazilian face database which contains a large set of face images. The face images in this database were taken between June 2005 and March

2006 at the Artificial Intelligence Laboratory in Sao Paulo University in Brazil. This database contains face images of different members of the university staff and students. In general, this face database is used for research purposes due to its large number of face images and variety of illumination conditions and face rotation with up to 180 degrees. Figure7 shows some samples of FEI face images [54].

The FEI face database has 2800 face images. The images resolution is arranged at 640 by 480 pixels. The total number of individuals or distinct subjects is 200 subjects in which each subject has 14 samples with different face rotation angles. Mainly, there are two facial expressions that are considered in this database: neutral and smiling expressions [24]. The number of males and females in this face database are equal (100 males and 100 females).

A subset of the FEI face database is taken to carry out the experiments for testing and evaluating the face recognition system performance of this research.

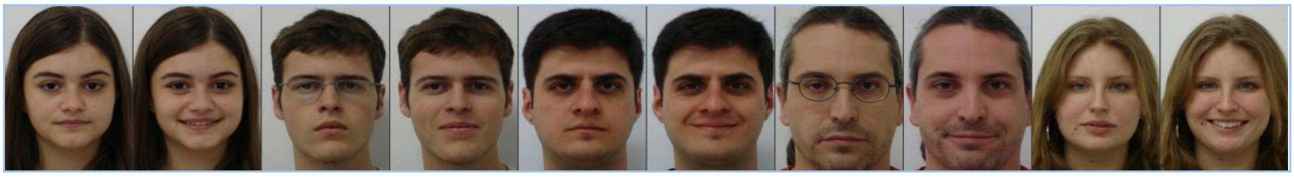

Figure 7. Samples of FEI face database images

8.2 Face Database Structure

Face images are the main input data to any face recognition system. In this work, a subset of face images is taken from FEI, the Brazilian face database and used to test and train the face recognition system the methods PCA and ICA. This subset of the FEI face database is divided into two main datasets, testing and training datasets.

In this project, the structure of the selected face database is described as follows:

In the training dataset, a total 160 images are used in which 80 individual subjects of 40 males and 40 females are selected. For each of these 80 classes (subjects) there are two samples provided with two main facial expressions: neutral and smiling. The images labeling of the training dataset is designed to make each two sequence numbers belong to one particular individual. For example, a face image with the sequence 1 and a face image with the sequence 2 belong to a particular class. Successively, a face image with the sequence 3 and a face image with the sequence 4 belong to another subject and so on.

Figure 8 shows samples of training images with their labeling scheme. On the other hand, the test dataset has a total of 40 images of 40 individual subjects which consist of 20 males and 20 females in which each subject has one sample image. Figure 9 shows samples of test dataset images with the same images labeling scheme of their classes in the training dataset. All the face images are converted from RGB colored images into grayscale (black and white) in order to increase the speed of the mathematical calculations and reduce the time consuming and memory usage. Then, the size of the face images is changed from 640 by 480 pixels into 64 by 64 pixels which results in reducing the dimension of the face images.

Figure 8. Samples of training images with labeling

Figure 9. Samples of test images with labeling

9. Images Pre-processing

The major objective of face recognition systems is to achieve a high level of accuracy in recognizing given a set of face images [55]. Generally, in computer vision any given image is made of a contribution of a huge number of small units called pixels. The quality of image pixels has a vital impact on the pattern classification process of the face recognition system. In order to enhance the efficiency and reduce the computational complexity of face recognition algorithms, image pre-processing is a fundamental and important process which must be applied on the input images to the face recognition system. Pre-processing of face images is a vital and significant step in any face recognition system due to its direct effects on the system performance [13]. Therefore, many factors can decrease the system accuracy if the input images will not be pre-processed. Such factors are the quality of face images and the size of the images, etc. Hence, these factors affect facial features detection and classification efficiency. Therefore, various image pre-processing techniques exist and are widely proposed for this purpose. Such techniques are normalization, scaling, cropping, resizing and image resolution, etc. The block diagram of the adopted images pre-processing steps is described in Figure 10 below [13].

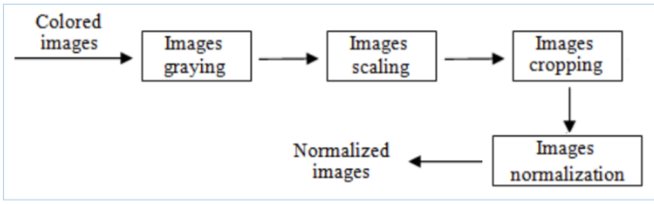

Figure 10. Images pre-processing steps

After detecting the facial features regions in the input face images, some pre-processing steps were conducted. As shown in Figure 10, the first step is collecting a group of color face images from the FEI face database. Then, converting these images into grayscale in which black and white images are obtained which greatly reduces the large amount of data size. Then, scaling the face images was done so the final images all have one size (64 x 64) pixels whereas the original face images have large size with (640 x 480) pixels. In images cropping, the most important features were captured and the rest areas were discarded in order to increase the system recognition efficiency. Figure 13 shows a sample of pre-processed face images which is taken from the FEI face database. The data density of the pre-processed face image is plotted as image histogram in Figure 14.

Figure 11. Sample of face image without images pre-processing

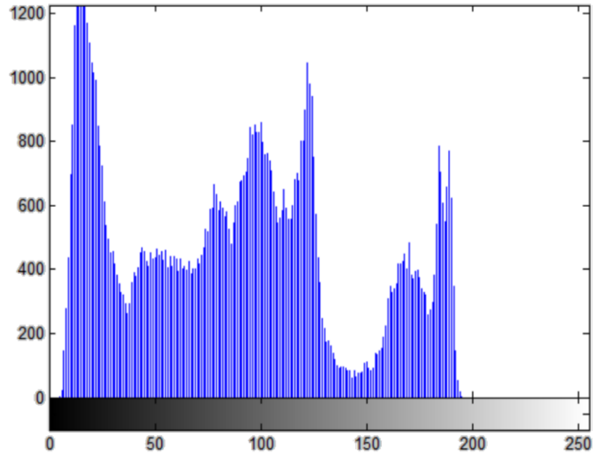

Figure 12. Histogram of face image without image pre-processing

Figure 13. Sample of a face Image with images pre-processing

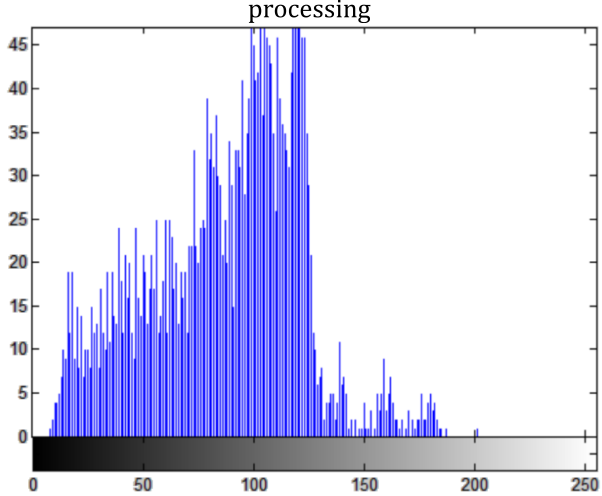

Figure 14. Histogram of a face image with images pre-processing

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10. Introduction to PCA and ICA Mathematical Theories

This section discussed in details the mathematical theories of the PCA and ICA along with their arithmetic formulas.

10. 1 Introduction to PCA Mathematical Theory

The PCA method is one of the most successful applications of the subspace scheme that is discussed in an earlier section of this paper. The general procedure of the PCA method in the face recognition system based on the subspace scheme is to seek for the most variance in the facial features of a set of face images. Then, PCA reconstructs these images into the principal components which represent the basis features of the original face images [18]. In other words, the PCA tries to project features vectors which reveal the most important information given a set of face images [17]. These projected vectors are called Eigenfaces. Eigenfaces are the principal components of a group of face images. The PCA introduces the basis components of each face image as a low dimension face space based on the corresponding eigenvectors to the high eigenvalues of the covariance matrix [16,32]. This means that each face image is represented as a combination of the feature spaces which are spanned by a number of eigenfaces [28]. The block diagram of the PCA method based on the subspace approach is illustrated in Figure 15 [17].

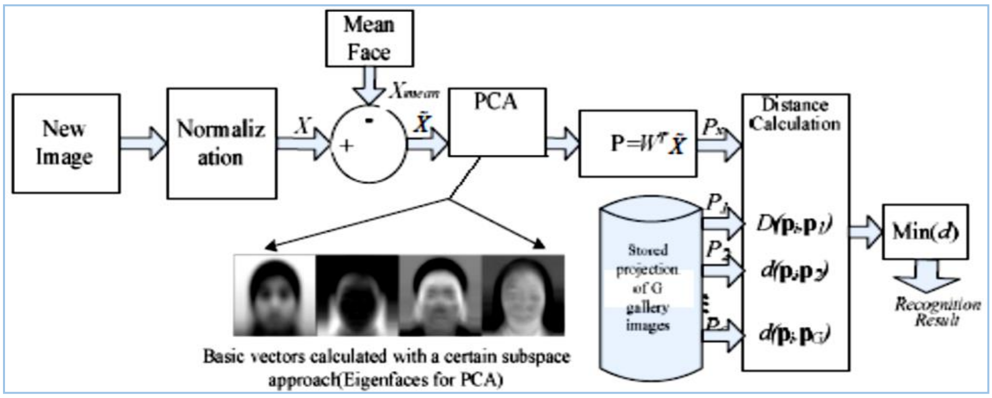

Figure 15. Block diagram of PCA method based the subspace scheme

The following steps illustrate the processes of the PCA method in face recognition system:

(1) By considering a set of training face images are stored in a data matrix of size *m*n*, *m* represents the number of face images in which each column of the matrix represents one image in the dataset [11]. In this project, the total number of training face images are 160 which means that the data matrix has *m* = 160 columns. The dimension of each image is 64 x 64 pixels, so *n* = 4096 which represents the number of the features in each image.

$$I = I1, I2, \ldots\ldots Im \quad (2)$$

(2) The second step is calculating the mean face (the average face) of the original training face dataset (*m*). Figure 16 shows the mean face that is generated by PCA method. This mean face is calculated as written in the equation below:

$$\overline{I} = \frac{1}{m} \sum_{i=1}^{m} Ii \quad (3)$$

(3) In order to calculate the mean adjusted images, first the mean face that is obtained from formula 2 (Equation 3) is subtracted from the whole face images of training dataset using the equation below:

$$\varphi = Ii - \overline{I} \quad (4)$$

Figure 16. Sample of mean face calculated by the PCA method

Calculating the covariance matrix *C* by using the formula below:

$$C = \varphi - \varphi^t \quad (5)$$

where φi = φ1, φ2,… φm.

(4) By creating the covariance matrix (*C*) in the previous step using (Equation 5) eigenvectors and their correspondent eigenvalues can be obtained as follows:

$$CV = \lambda V \quad (6)$$

where *V* represents a set of eigenvectors with their associated eigenvalues λ. By the selection of eigenvectors based on their corresponding eigenvalues and sorting the eigenvectors $V_i \varepsilon V$ according to their associated eigenvalues $\lambda_i \varepsilon \lambda$ from high to low where $V_i = V_1, V_2, \ldots, V_m$ [11]. Therefore, these mean adjusted images (φ) that are calculated in (3) will be projected into the eigenfaces. In the classification process, each new test image should be mean centralized by subtracting the mean face. This means, each test image after subtracting the mean face it will be projected into the eigenfaces. The classification process compares each projected test image with those eigenfaces (principal components) that are decomposed from the training images [11]. Figure 17 shows samples of the eigenfaces which are generated by PCA method in this work.

Figure 17. Samples of eigenfaces generated by the PCA method

The PCA method has been widely deployed as an effective computational technique in the face recognition system for dimensionality reduction. In addition, PCA is an efficient statistical method for face representation due to its simplicity, the fast computations and the learning capacity. In spite of these advantages of PCA, however, it has some disadvantages. Examples of such drawbacks of PCA are the extensive computations and the complexity in dealing with large data size of face images (3D face images). Due to the large dimension of such data and its huge covariance matrix, the computations of eigenvectors are time-consuming [16,31,32].

10.2 Introduction to ICA Mathematical Implementation

Many algorithms are introduced to implement ICA techniques in the face recognition system. For example, Infomax algorithm and Fast fixed-point type (FastICA) algorithm are the common functions of this method. In this work, the FastICA algorithm is used to implement the ICA method for the estimation of the independent components. The ICA in face recognition system performs under one of two distinct architectures, Architecture I and Architecture II [35,40,43]. The whitening step is involved in the FastICA algorithm during the estimation process of ICs by ICA technique. Figure 18 illustrates the main processes of ICA technique in this project. More details about the whitening process can be found in [56]. Firstly, PCA treatment based on the subspace scheme is applied to constructing the eigenfaces. Then, the approximate Newton iterative is applied in the FastICA algorithm, a mixed matrix is generated and finally independent components of ICA are obtained [40]. The theoretical analysis of ICA processes and its baseline mathematics is illustrated as follows [43]:

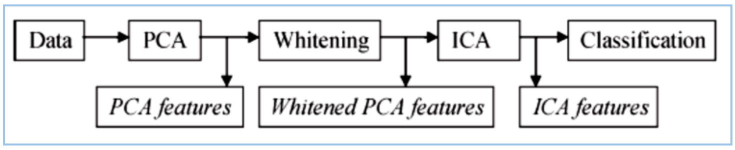

Figure 18. Block diagram of ICA method in face recognition system

Suppose that given n linear random observed variables $x_1, x_2, x_3 \ldots, x_n$, these n mixture variables are the ICs [39,40,46]. As written in the equation below:

$$X = (x_1, x_2 \ldots, x_n) \tag{7}$$

The n independent components are obtained from the n independent non-Gaussian variables as $S=(s_1, s_2, \ldots, s_n)$ [39,40,46]. So, the observed data vector X_i which is based on linear combination of the original variables S_n can be calculated as written in the equation below:

$$X_i = a_{i1}S_1 + a_{i2}S_2 + \ldots + a_{in}S_n \tag{8}$$

Where $i = 1,2,\ldots,n$, a_i are the random coefficients or independent components. The above formula can be also derived from the below equation:

$$X = As \tag{9}$$

By considering the linear combination of X_i as an estimating for one of the independent components as $y=b^T X$, where b is the uncertain vector [39,40]. Therefore, the relation $y=b^TX$ can be derived in another way using the equation 9 when an assumption of $q= b^TA$, then:

$$Y = b^TX = q^T S \tag{10}$$

In Figure 19 shows samples of the independent components that are generated by ICA.

Figure 19. Samples of independent components generated by ICA method

However, in the face identification system each image is represented as a column of feature vectors. By giving n training set and n observation vector, X can be derived

[40]. So, in order to obtain m basis images based on ICA method as written in the equation below, where W is the mixed matrix:

$$U = WX \qquad (11)$$

In order to calculate the face feature vector of given a test image, *y* is being bleached and centered, then the test image *y* will be projected into the basis images *m* [40].

$$Z = Uy \qquad (12)$$

Figure 20. Sample of mean face calculated by ICA method

Figure 19 shows a plot of the mean face that is obtained by ICA method in this research. Also, Figures 21, 22 and 23 illustrate the data variance and the intensity of the mean face, the mean adjusted images and the covariance matrix that are generated by ICA technique in the proposed face recognition system of this project consecutively.

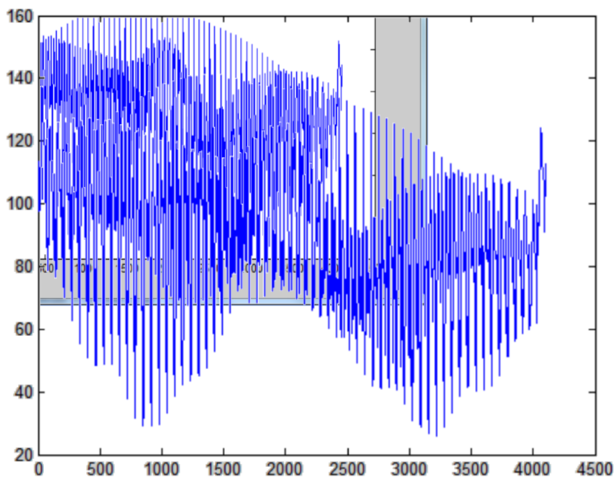

Figure 21. Data variance of the mean face calculated by the ICA method

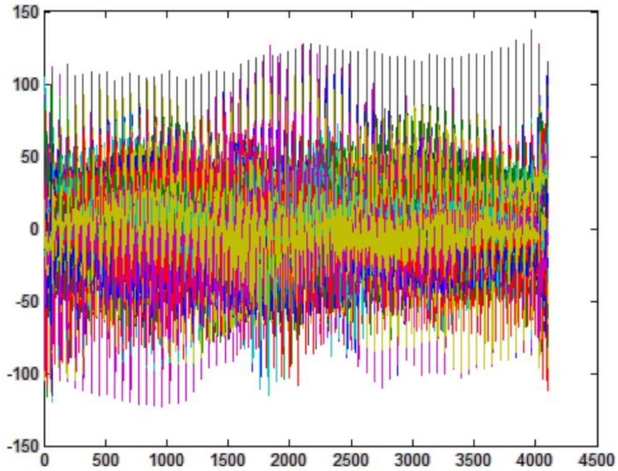

Figure 22. Data intensity of the mean adjusted images of the ICA method

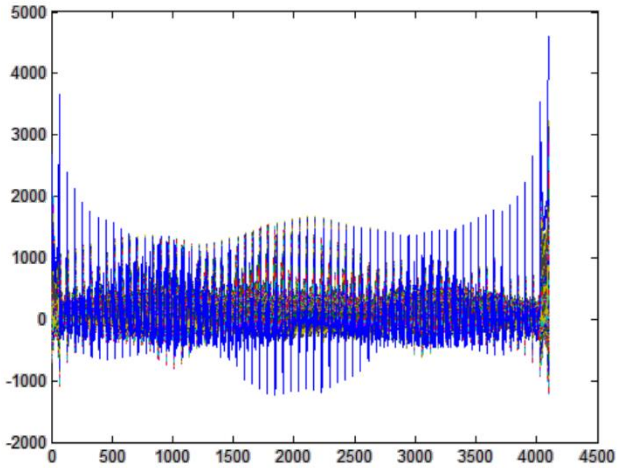

Figure 23. Data intensity of the covariance matrix of the ICA method

11.3 Introduction to Euclidean Distance Mathematical Implementation

ED classifier from the images classification point of view is considered as a popular technique for the images distance measure due to its simplicity in terms of the classification of different patterns. In this project, ED is used for the identity classification of a set of unknown face images. The general theory of ED classifier in the face classification is explained as follows:

By assuming that *x,y* are two *M by N* images. When $x = (x^1,x^2,...xMN)$ and $y = (y^1,y^2,...,yMN)$, where *xKN*+1, *yKN*+1 are gray level points at the location (*K,1*) [50]. Then, the Euclidean Distance *dE(x,y)* can be calculated by the following formula:

$$d_E^2(x,y) = \sum_{k=1}^{MN}(x^k - y^k)^2 \qquad (13)$$

In order to implement ED classifier based the MATLAB libraries, the following scenario was applied as explained below:

Firstly, a set of input test images in both the PCA and the ICA methods are read and stored in the MATLAB matrix. Then, the mean face that is calculated by PCA will be subtracted from the test images matrix in order to generate the feature vector. The projected features that are generated by the PCA and the ICA will be used in the classification task. Hence, the ED classifier will measure the distance with the highest similarity between each input test image with the projected feature vectors of the input training images. Distance measurement of the ED is implemented using a function called (*arrayfun*) when the feature vector of each test image will be matched with those feature vectors of training face images.

12. Results Discussion

Set of experiments are carried out to study the robustness of the two subspace methods the PCA and the ICA against a variation in noise conditions. In this chapter, the experimental results are discussed. The face recognition system is implemented using two dimensionality reduction techniques are the PCA and the ICA and one classifier is the ED for the face classification process. All the experiments are performed for the performance comparison of the PCA and the ICA using ED as an implementation of the face recognition system. Different noise levels are applied on the input test images of the FEI face database. The quality of the test images was amended as an evaluation of the system robustness against a set of face images with low resolution. Both of the testing and training images datasets were pre-processed in order to increase the computational speed of the PCA and the ICA methods and to improve the accuracy of the classification performance.

The pre-processing steps have included reducing the size of the training and testing face images from 640 by 480 pixels into 64 by 64 pixels. Also, the located face area was cropped and converted from RGB images (Red, Green, and Blue) into grayscale images (black and white) in order to reduce the computations that are generated from the large dimensions of the data. The Euclidean distance classifier was used to classify the test images. In each experiment there was an increment on the number of the principal components that are generated by the PCA and the ICA.

The number of projected images was gradually increased in each experiment starting from 20, 30, and 40 till 50. This increment in the number of PCs has improved the performance of the PCA method in all the experiments. On the other hand, the ICA method showed a decreased performance while increasing the number of the ICs. In general, the ICA was highly affected by the noise effects when the number of the independent components was more than 30. In all the experiments, a very small deviation is recorded of the PCA performance against all the applied noise conditions whereas FastICA showed a very large deviation in the test cases. When the number of the projected images is 20, the PCA showed its lowest performance in Experiment 5 in which 82% accuracy rate was achieved. In contrast with the experiments 1, 3, 6 and 9, the PCA achieved the highest level of accuracy with 100% successful recognition when the number of the PCs was 20.

When a slight increment was added while generating the PCs to 30 basis images, PCA obtained better results with 90% success rate in comparison to its achievements when the number of PCs was 20. PCA performance was obviously improved in which 92 % accurate results were recorded when the number of the projected images was increased to 40 and 50. The PCA performed 100% success rate which is the highest level of performance when 40 and 50 PCs were efficiently projected from the initial face images. In this research, the PCA as a dimensionality reduction method has efficiently performed in most of the experiments.

An average of the recognition performance is taken for the best three achievements of the PCA and the ED classifier. In the experiments number 1, 2 and 9, 98.6 % accuracy rate was attained by the PCA technique in comparison with the ICA performance. According to the ICA performance in this project, an obvious deviation was recorded of this method due to ICA being highly affected by the applied noise levels in which the ICA could not generate better basis images. The minimum performance of the ICA method was recorded in experiment 8 when the number of the independent components was 20 due to the noise effect that was applied on the test classes. There are two main reasons behind this decreased performance of the ICA method. First, the FastICA library, with its whitening process that is involved in the implementation of the ICA method, has affected the projection of the independent components by the ICA [43].

The second reason in which the ICA showed marked decrement in the performance is that the increments on the number of projected images have raised the loss of the most significant information in the facial features. In other words, the ICA generated the ICs with insignificant facial features information. Therefore, the ICA performed lower than PCA in some of the test cases especially in experiment number 3, 5, 6 and 8 while increasing the number of the projected images. The best three achievements of the ICA were recorded in the experiments number 1, 2 and 9. Therefore, an average performance of the ICA was recorded with 87.0% recognition rate. However, extensive experiments have reported that the PCA outperformed the ICA in some cases while other studies concluded that the ICA outperformed the PCA based on the above scenario [43].

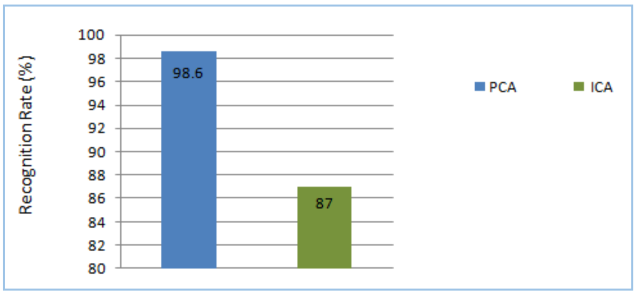

Figure 24. Experimental results comparison of PCA and ICA using ED classifier

In addition, PCA performed with less computational cost than the ICA. Due to the large number of iterations and the whitening process that are applied while generating the basic features of the ICA method. The time consumed by ICA processes was more than in the PCA method. Therefore, the PCA generated the principal components faster than ICA. The proposed work in [58] introduced an efficient approach of face recognition using the PCA for features extraction and the Minimum Distance Classifier (MDC) for face classification. The research in [58], a number of experiments were carried out on a subset of face images that are selected from AT&T face database for evaluating the introduced system performance. They provided many samples with different facial expressions for each individual class or subject in the training dataset. Their proposed method achieved a 96.7% success rate. An optimal fusion of different subspace methods such as PCA, LDA, LPP and ICA1 (Architecture I) was suggested by the researchers in [59].

The performed experiments in their research were carried out on different face databases such as ORL and YALE databases with different test conditions. They obtained results which showed that PCA achieved a 90% successful recognition rate whereas ICA1 performed 88.12% accuracy rate. An evaluation is conducted by the authors of [60] on the performance of PCA-based face recognition systems in which their research has attained interesting results. In their paper, different experiments with different numbers of subjects were performed using PCA for features extraction and the Nearest Neighbor (NN) approach for classification on the MUCT face database. The obtained results exceeded 97% recognition rate. In Table 3, different results are tabulated of different face recognition systems that are proposed by several researchers as a comparison with the obtained results of this work.

Table 3. Experimental results comparison of different proposed systems

Authors	Methods	Face Database	Recognition Rate (%)
[58]	PCA and MDC	AT&T	96.7
[59]	PCA	ORL	90
[59]	ICA1	ORL	88.12
[60]	PCA and NN	MUCT	97
Proposed system	PCA and ED	FEI	98.6
Proposed system	ICA and ED	FEI	87

As shown below in Figure 25 and Figure 26 the performance comparison between the results of the adopted face recognition system in this work and other systems performances that are proposed by other researchers.

In Figure 25, the PCA performance is compared with three experimental results in which the PCA performance in this research achieved a 98.6 % accurate recognition rate even though the 40 test classes which are chosen as test images have just two samples for each individual class in the training dataset. Other researchers have provided more training samples for each individual subject in order to improve the system performance. In addition, the test images had decreased resolution when different noise levels were applied in order to evaluate the system robustness with low resolution. In regards to the ICA performance, Figure 26 shows experimental results of other researchers that are compared with the ICA results of this research. It illustrates that the ICA has slightly lower performance in comparison with the proposed system performance in which the ICA obtained 87% accuracy rate. Different experiments were carried out in this work with different noise as system robustness evaluation. From the experimental results, an average performance with 98.6% recognition rate was obtained by the PCA and Euclidean distance classifier. On the other hand, the ICA with the ED classifier achieved 87% recognition rate. Table obviously shows that the PCA outperformed the ICA whereas the ICA was more sensitive to the noise conditions than the PCA in which the PCA method was less affected and showed a better capability to perform effectively. This concludes that the system performance highly depends on face image quality. The future progress is suggested to extend the efficiency of the proposed face recognition system. Extensive research will be conducted on increasing the system capability in terms of performing in an uncontrolled environment especially when the face images are taken under different light conditions and illuminations. In addition, other prospective aspects can be approached to maximize the system accuracy. For instance, the nonlinear combination of different face recognition algorithms such as PCA, ICA and LDA. Such a combination of the multi methods in face recognition systems can be considered as challenging. Also, a comprehensive investigation will be exerted on the face classification methods in which more powerful and complex techniques will be studied for the maximum efficiency of the system performance. For example, SVM, Artificial Neural Network (ANN) and Multiclass Neural Network (MNN) can be applied to increase the classification accuracy when an efficient pattern recognition method will be applied.

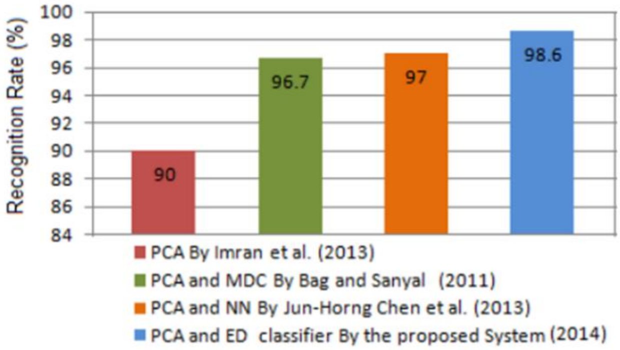

Figure 25. Experimental results comparison of PCA in different proposed systems

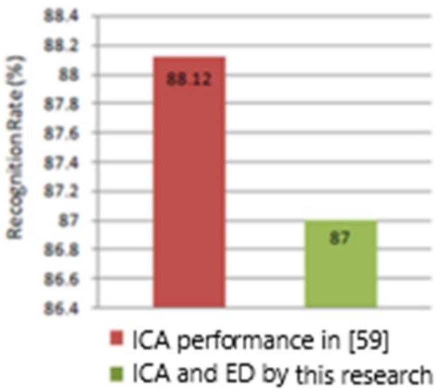

Figure 26. Experimental results comparison of the ICA in different proposed systems

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