School of Electrical, Electronic and Computer Engineering

EEE8094: Individual Project Literature Review

Facial Recognition

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Acronyms

ARG:	Attributed Relational Graph
FLD:	Fisher Linear Discriminant
HMM:	Hidden Markov Model
ICA:	Independent Component Analysis
KL:	Karhunen-Loeve
LDA:	Linear Discriminant Analysis
PCA:	Principle Component Analysis
WoS:	Web of Science
2DPCA:	Two-Dimensional Principle Component Analysis

Literature Review

Title: Facial Recognition

Abstract

Biometric security technology is becoming a widespread utility in many applications. This phenomenon has somehow spurred the quest for an efficient, robust and reliable biometric verification exploiting the unique features of human being. This literature review briefly describes different type of biometric security in its actual context in providing trusted security to users.

Special attention was given to facial recognition due to the fact that face is the main body part that man can effortlessly distinguish one person to another. Inspiring by this remarkable human vision capability and the demand for face recognition in many areas, there exist different form 'machine vision' approaches of facial recognition; some are explained in this paper highlighting their specific features, recognition performance and specialties in tackling face image variation such as under various illumination, facial expression, occlusion etc. One popular approach is Principal Component Analysis (PCA) which has widespread application and in some way had influenced and ignited numerous facial recognition researches. Based on the same reason and considering its simplicity yet able to provide reliable recognition performance, PCA was chosen as the main algorithm in this Facial Recognition MSc project. The features and algorithm of PCA is described in great detail in this paper with aim to provide comprehension and strong support for starting the project.

1.0 Introduction

In our daily lives we meet different people every now and then without realising that we can always recognise and differentiate them with no major mistake even after long separation. We might distinguish them mostly by face but certainly face is not the only unique feature of human being. Our physical body, eyes, skin, voice, manner are all different. Thus it is not too much to say that every single human is different from one to another regardless of their nationals, races, family members or even a pair of identical twin! This remarkable uniqueness of human being gives rise to a scientific study of recognising individuals - which is termed biometrics.

Biometrics recognition measures the uniqueness of individuals by defining certain features of human that are unique to only one person - no other person shares similar features. One of the most common biometric which had a widespread application nowadays is thumb print or fingerprint [1], [2]. Other recognition biometric which is still in active research is iris [3] and facial recognition. New biometric study which are just begin to enter biometric study is keystroke dynamic [4] and voice recognition [5]. All of these human features are proved to be unique from one person to another and therefore have a huge potential to be developed as biometric recognition for security.

Among those biometrics, facial recognition appear to be the most prominent feature for personal identification as it comes in natural way in our daily lives to differentiate people by their faces. Evidence had shown that photo of faces are needed for various occasion – in passport, driving licence, personal identity card, university registration, crime record etc. The purpose for those photos is none other than for personal identification. With that in mind, there comes the challenge to build one facial recognition system that can recognise one particular person by using only their facial image.

Apart from personal identification, facial recognition could be used for system authentication as well as for security purposes. Bearing these applications, the need for authentic facial recognition is becoming widespread necessities and especially after the incident of September 11 major countries such as America have strict up their border access control and aims at build up a system for personal identification and security-related database.

In majority of cases, biometric security works in the same way as the traditional username and password scheme. However unlike username and password that are forgettable, biometric remain with the users throughout their life time, except for major accident. The main advantages relies on its permanent and trusted nature that no body are able to impersonate or steal the unique features. Nonetheless, this permanent nature will introduce another fatal security problem that will be briefly discussed in the next chapter.

1.1 Aims and Objectives

The primary aim of this report is to provide sufficient background knowledge on biometric security technology especially facial recognition that are currently under development and might as well being used in many security-based applications before the actual MSc project is carried out.

List of objectives of MSc project and generally this literature review are details as follows:

- To comprehend and appreciate the fundamental concept of biometric technologies currently existed in providing trusted and robust security in security-based applications in relation to traditional user id – password authentication.

- To provide insights of the historical development to current working and research progress of biometric realm especially in facial recognition, including their salient achievements.

- To discover the algorithms existed in facial recognition and their relation to each other, before deciding on a particular algorithm to be used in the project.

- To study in depth and comprehend the selected algorithm feasible for the facial recognition which is expected to provide strong platform to carry out the project.

2.0 Literature Review

2.1 Facial recognition

The study of facial recognition is still active although it has been nearly about 25 years of extensive study and researches [6]. Extensive research has been conducted to study various aspects of face recognition from different approaches covering psychology and neural face analysis to features extraction and statistical analysis of face images. Even though the works has dated back from 1970, a significant development of facial recognition emerged in 1990 attributing to interest in commercial face recognition research project to fulfil the need of various hardware and software application such as for surveillance cameras, border access control and personal identification to fight against terrorist activities.

With further biometric development, it is discovered that there are some security problems surfacing from current biometric technologies. One concern is that the biometric data is not securely protected and once compromised it will lost forever and can not be used again. This is due to its permanent nature. Some studies were carried out to address this problem while improving the security suggesting the use of cancellable template to reproduce an intentionally distorted biometric data once it is compromised [1], [7], [8]. Other serious security concern relates to identity theft and data privacy which were addressed by using biometric hashing [3], [9], [10] and cryptographic keys [2], [4], [5].

In the essence of facial recognition, there are basics performance metrics that determined the effectiveness of a particular approach. They are listed out as follows:

- Recognition rate – number of correct recognition over total number of samples under test.

- Computational complexity – describe the processing power of computational activities to run a particular algorithm of facial recognition.

Recognition rate is somehow determined by the characteristic of the facial images. This is due to the fact that image of one person is not always the same for all captured images. They are dependent on various conditions such as lighting, image position, age, mood etc that affect the accuracy of identifying persons. These variations are referred to as the challenges faced by researches in facial recognition realm. There are a lot of works that have been done to minimise this effect in order to result in an optimum performance. Those works will be discussed in detail later in this section.

Due to the complexity and multidimensional of human faces, it is particularly difficult to develop a reliable facial recognition system. Bierderman and Kalocsai [11] discussed a number of behavioural phenomena that distinguish the recognition of faces and object from neural, perceptual and cognitive viewpoints. Objects and faces were differentiates through various behavioural and neural differences. They eventually concluded that face

recognition requires holistic representation and fine matrix variation of face surface whereas object recognition can be expressed in term of arrangement and structural parts and description.

Generally, the classification of facial recognition can be categorised into two different methods which is feature-based and image-based [6], [7]. Feature-based describe person according the common face features such as eyes, nose, mouth, head outlines and other physicals by describing their relation to each other. A novel line feature-based face recognition was proposed by Park *et al.* in [12] which discussed that the geometric and the structural information of face can be encoded in an Attributed Relational Graph (ARG) structure. His proposed algorithms demonstrated an excellent recognition of face image in the presence of occlusions, various expression changes and illumination variations by using only one face image. Although the time of processing image was negligible, the ARG-matching required most of the processing time and thus, indicates a relatively high computational complexity. Samaria and Harter [13] take the advantage of natural order of face features using top-bottom scanning to identify persons. Their work is based on Hidden Markov Model (HMM) and literally examines the effect of different parameters used in the model on identification rates with no specific measure on the ability of the model to recognise face images relative to other methods. A study on surface information of 3-D face was carried out by Liu *et al.* in [14]. This study discussed how texture gradient provide information about surface discontinuity, orientation and occluding edges of face features. Various experiments were conducted to ultimately reveal the ability of texture gradient to recover face geometry of complex objects including faces.

Despite the fact that this feature-based facial recognition approach remains the most popular approach in computer vision literature, research in human strategies of face recognition shown that facial features and their relationships provides inadequate information to account for the ability to recognise a particular person [15].

Meanwhile image-based facial recognition is based on the statistical analysis of the actual image itself. Its working principal is based on complex analysis on mathematical theory which proved to provide high recognition accuracy as compared to feature-based technique. One approach of recognising face using image-based is Principal Component Analysis (PCA) or commonly called eigenfaces method or Karhunen-Loeve(KL). Since Turk and Pentland published their papers [15], [16], the eigenfaces approach have been used extensively in different recognition systems for various conditions. It was described that the eigenfaces approaches works by capturing the variation of a collection of face images, encode those variation and recognise a new image by comparing it to those variation. This approach has proved to be computationally efficient while maintaining a high degree of accuracy. The drawback lies in the fact that it is poor at recognising face image under different illumination and facial expression because under these variations it retains unwanted variations occurring [17].

Many extensions to PCA have been conducted to improve the recognition performance at various events. Yang *et al.* [18] described two-dimensional PCA (2DPCA) and shown

that their technique resulted in higher recognition rate and computationally more efficient as compared to original PCA approach. 2DPCA were also being used in [7], [8] to complement the technique of cancellable biometric aimed at proving more secure authentication system. Accuracy was shown to increase by up to 3% from the original data. With similar aim, Ngo *et al.* proposed robust extraction of bits strings from raw input biometric features in [10]. His technique to improve biometric security was applied to facial recognitions methods including PCA and demonstrated high recognition rate compared to using only the raw methods. Integration of PCA with correlation filter as in [19] works well in recognising face images under various illumination and even occluding faces, better than other face recognition algorithms. The occluding faces in eigenfaces was also minimised in [20] by different approach of features extraction apart from the original eigenfaces' called hypothesis-and-test paradigm. The approach works well but at the expense of computational power gain.

Apart from being extended to numerous different techniques, many works have used PCA as a standard base line for comparative measures [10], [17], [18], [21], [22], [23]. A work conducted by Belhumeur [22] compare the performance of fisherfaces under low-dimensional subspace with eigenfaces technique. The experiments demonstrated that fisherfaces technique produced lower error rates for images under large variation in lighting and facial expression.

Other recent image-based methods include Independent Component Analysis (ICA) and Fisher Linear Discriminant (FLD). As compared to PCA, ICA technique lies on the idea that better basis images may be found by method sensitive to high order relationship among pixels in a set of images [23] c.f. pairwise relationship between pixels in PCA. The aim of ICA is to decompose an observed signal into a linear combination of several unknown independent signal which in particular related to blind source separation problem [17]. The ICA basis images are believed to capture more possibilities that later being used for better classification. Many literatures have proven that ICA outperforms PCA in image representation and recognising faces [24]. The main drawback of ICA is that it requires high computational complexity. Similar to PCA, there have been many enhancements to ICA to improve its performance to cater specific recognition problems. One example is the work by Kwak and Pedrycz [17] that integrates ICA with FLD to create well separated classes in low-dimension subspace and is insensitive to extreme variation of expression changes and illumination.

In contrast with PCA and ICA, FLD [22] works in a manner that maximise the ratio of between-class scatter and within-class scatter to classify relevant information used for facial recognition. It is one of the linear discriminant analysis (LDA) techniques that obtain feature representation by using classification ability [21]. As discussed before, [22] describe how fisherfaces address the problem relating identifying images under extreme lighting and facial expression variation. Enhanced FLD was carried out by Liu and Wechsler [25] to enhance generalization ability of the standard FLD-based classifer and simultaneously overcome problem associated with overfitting of data.

In summary, it is not an overstatement to say that PCA, ICA and FLD are the most prominent image-based recognition algorithms under particular interest by facial recognition researchers nowadays. Being presented with ideas following each method, PCA seems to be the most suitable algorithm to be carried out in this MSc project. The particular reasons lie in the advantages of the PCA technique itself which can be summarised as follows:

- Provide fundamental knowledge of facial recognition in statistical image analysis.
- Being extensively used applied in many researches – [16] has been heavily cited, 2130 by SCOPUS, 1004 by WoS [26] at time of this writing.
- Due to its simplicity and less complex computational power.
- High recognition rate.
- Low dimensional subspace that brings efficiency.

In this project, the facial recognition technique will be developed to analyst its recognition performance for static facial image as well as in various image conditions such as under different illumination and facial expression using face databases that will be decided later. It is also aimed to develop another facial recognition algorithm such as FLD so that detail comparison on both performances could be measured and studied. The next section describes PCA in a greater detail.

2.2 PCA for Facial Recognition

Principal component analysis or better known as eigenfaces technique for facial recognition described in this section was developed by Turk and Pentland [16]. Another reference is from Dimitri PISSARENKO webpage [27]

From PCA fundamental theory, the differences in face images lies in the unique characteristic features that differentiate one face to another. One could extract these features and process them in some way that a new face image can be recognised by comparing with a database of models encoded similarly. One way of extracting the unique features contained in an image is by capturing the variation of a set of images. The variation is then used to encode and compare new face images.

In mathematical terms, PCA aims at finding eigenvectors of covariance matrix from a set of face images. The eigenvectors are essentially the principal component of the images. The term ‘eigenfaces’ is originated from the fact that these eigenvectors can be displayed as a sort of ghostly faces. Figure 1 illustrates example of six ghostly images (eigenfaces) calculated from input images. These faces define the face space.

Figure 1: Illustration of six eigenfaces calculated from input images[16].

The process of facial recognition can be described simply by the following diagram:

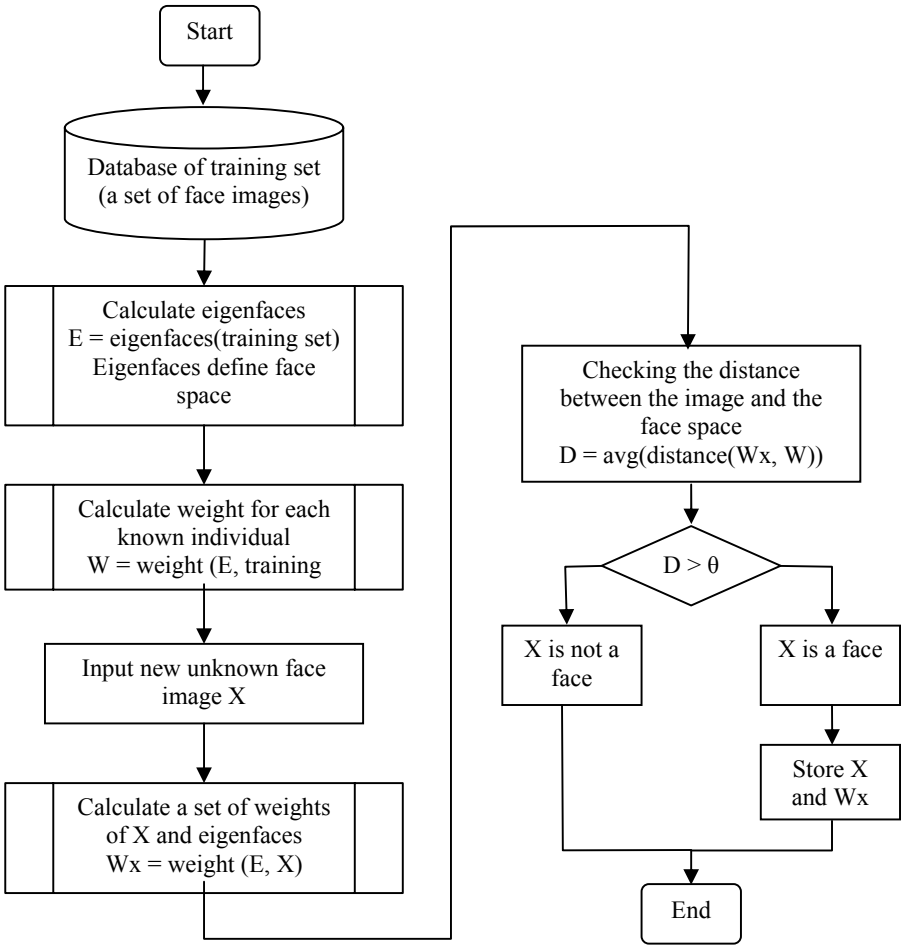

Figure 2: Step by step process of recognising face image using eigenfaces approach

2.2.1 PCA algorithm

Let say a set of face images contains M number of different faces. Each face is denoted as $\Gamma_1, \Gamma_2, \Gamma_3, \ldots, \Gamma_M$.

To set up a face space database, the first step is to calculate the eigenfaces. The following calculations lead to the attainment of eigenfaces.

Average face,

$$\Psi = \frac{1}{M}\sum_{n=1}^{M}\Gamma_n \tag{1}$$

The difference between face and average face,

$$\Phi_i = \Gamma_i - \Psi \tag{2}$$

Covariance matrix of the set ,

$$\begin{aligned} C &= \frac{1}{M}\sum_{n-1}^{M}\Phi_n\Phi_n^T \\ &= AA^T \qquad\qquad \textit{where matrix } A = \left[\Phi_1\Phi_2\ldots\Phi_M\right] \end{aligned} \tag{3}$$

Eigenvalues, λ_k and eigenvectors u_k are chosen such that the eigenvalue is maximum,

$$\lambda_k = \frac{1}{M}\sum_{n=1}^{M}(u_k^T\Phi_n)^2 \text{ where, } u_l^T u_k = \delta_{lk} = \begin{cases} 1, & \textit{if } l = k \\ 0, & \textit{otherwise} \end{cases} \tag{4}$$

The problem with the algorithm above is that the covariance matrix will result in high dimensionality which is N^2 x N^2 thus will have N^2 number of eigenvectors and eigenvalues. This is computationally not very efficient since only some of the eigenvalues are useful.

The solution proposed by [16] is to calculate matrix based on the number of images, M instead of the dimension of the space, N^2 where $M < N^2$. therefore, instead of solving for 65,536 x 65,536 matrix to calculate 65,536 eigenvalues (for 256 x 256 image), the calculation only need a solution for 16 x 16 matrix (for 16 images in a training set). The calculations are greatly reduced resulted in more efficient computation. The following algorithms describe the calculation of eigenfaces on M by M matrix.

Consider v_i as the eigenvectors of $A^T A$ such that

$$A^T A v_i = \mu_i v_i \tag{5}$$

multiplying by A for both side,

$$AA^T Av_i = \mu_i Av_i \tag{6}$$

This expression shows that Av_i are the eigenvectors of the covariance matrix C since $C = AA^T$. Let L = M x M matrix and for $L = A^T A$ where $L_{mn} = \Phi_m^T \Phi_n$, eigenvectors, v_l of L can be determined, to eventually form the eigenfaces. The eigenfaces, u_l can then be expressed by the following expression:

$$u_l = \sum_{k=1}^{M} v_{lk} \Phi_k \tag{7}$$

2.2.2 Classifying faces

Classifying an unknown face to one of the classes in a face space can be summarised to undergo two consecutive steps such as follows:

1. The new unknown face is transformed into its eigenfaces component. Consider Γ_{new} as a new unknown faces

   $$\omega_k = u_k^T (\Gamma_{new} - \Psi) \tag{8}$$

   for $k = 1, \ldots, M'$, ω_k is the eigenfaces component
   The resulting eigenfaces components form a weight vector $\Omega^T = [\omega_1, \omega_2, \ldots, \omega_{M'}]$

2. To calculate the Euclidian distance, between the weight vector, Ω_i to the predefined face class, Ω_j. If the average distance exceeds some threshold value, θ for all the face class, it is assumed that the new unknown face is not a face at all or optionally can be used to create a new class.

   $$d(\Omega_i, \Omega_j) = \in_k = \sqrt{\left\| (\Omega_i - \Omega_j) \right\|^2} \tag{9}$$

The algorithms presented in the above section will be simulated using MATLAB using face databases that will be decided later. The aim is to analyst the performance of this facial recognition in term of recognition rate and computational complexity under different image conditions.

3.0 Conclusion

This literature review give an insight of biometric security technologies currently existed to fill the need of increasingly demanding security-based applications and its fundamental working principles. A thorough study was specifically allocated on different facial recognition approaches although some were highly related to improving the biometric security. Different approaches of facial recognition was discussed from the feature-based to image-based with an emphasize being put on image-based since it is based on mathematical theory and is the most feasible to carried out in this simulation project.

Some widely used facial recognition algorithms were discovered such as PCA, ICA, FLD, ARG-matching, and their respected enhancement techniques to solve photo variations were comparatively presented. Finally, PCA was chosen for this MSc project due to its simplicity yet able to provide high recognition rates and the fact that it is widely used in facial recognition researches offering strong platform to comprehend other approaches along the way. Working based on its algorithm for the next step in this project, it is hope to measure its practical performance, examining its strength and weaknesses in relation to literature results and other recognition approaches.

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