UNIVERSITI PUTRA MALAYSIA

AN ADAPTIVE FACE RECOGNITION UNDER CONSTRAINED ENVIRONMENT FOR SMARTPHONE DATABASE

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By

NOOR AMJED HASSAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

August 2018

DEDICATION

This thesis is dedicated to my beloved parents
(Dr. Amjed Al-Zuhairi & Mrs. Muna Shukur)
For their endless love, encouragement and unconditional support in all my life
And
Especially to my awesome husband, (*Mr. Maytham Saad*)
For his love, patience and great support
And
My lovely daughter (*Joud*)
Love you always and forever.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

AN ADAPTIVE FACE RECOGNITION UNDER CONSTRAINED ENVIRONMENT FOR SMARTPHONE DATABASE

By

NOOR AMJED HASSAN

August 2018

Chairman : Associate Professor Fatimah Khalid, PhD
Faculty : Computer Science and Information Technology

Face recognition is probably one of the most prominent areas of imaging research and has a wide range of real-world applications. Although face recognition has recently achieved advances in identifying people, limitations and challenges remain in face recognition applications in which no restriction is imposed on the conditions of acquired facial videos. This thesis is concerned with face recognition under uncontrolled environments in which the images used for training and testing are collected from the real world using a smartphone camera. For now, publicly available smartphone face databases remain lacking. In addition, existing databases do not address all the challenges of real-world scenarios. One of the crucial problems in the uncontrolled environment of smartphone data is illumination variation, which negatively affects the preservation of image features caused by binary conversion. In addition, using data from smartphone devices introduces a new challenge, namely, different optical zooms. This problem affects the accuracy of face recognition systems when the test and gallery images of the same person differ in terms of face-to-camera distance. Moreover, the performance of recently developed face detection methods is poor under uncontrolled environments, such as those with variations in illumination, complex background and overlapping between face and background colour. In fact, detecting the correct face boundary is insufficient to extract the correct features of the face region, particularly in the presence of occlusion, which affects the feature extraction operation and decreases the accuracy of face recognition. Finally, increasing the accuracy of a face recognition method under the complex environment of a smartphone face database remains a considerable challenge among researchers.

The first objective of this study is to construct a smartphone face video database that closely reflects real-world videos. The next objective is to enhance the appearance of face features under various illumination conditions by converting an image into a

binary image using a new columnar binary conversion method considering the robustness and strong discriminative power of binary features. In addition, this study aims to improve the performance of the face recognition method under the effect of different optical zooms by detecting the normalised facial feature region using the proposed facial feature region normalisation method. The next objective is to accurately detect the face region under a complex background and varying illumination conditions using the proposed geometric skin colour method. Furthermore, this thesis aims to solve the problem of unintentional occlusion by detecting the correct non-occluded area using the non-occluded facial area detection method. Finally, this study aims to obtain high-accuracy face recognition performance under the uncontrolled environment of a smartphone database based on the proposed adaptive face recognition method that combines two new face recognition algorithms. The proposed method works by adapting to the environment of the input image and uses multiple facial features to increase the reliability and efficiency of the recognition process. Experimental results showed that the recognition rate achieved 100% under different environment conditions.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ADAPTIF PENGECAMAN WAJAH DALAM PERSEKITARAN TERKAWAL BAGI PANGKALAN DATA TELEFON PINTAR

Oleh

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Sistem pengecaman wajah merupakan salah satu bidang yang kian mendapat perhatian dalam bidang penyelidikan pengimejan dan mempunyai pelbagai aplikasi dunia nyata. Walaupun sistem pengecaman wajah dewasa ini telah mencapai kemajuan dalam mengenal pasti individu, namun masih terdapat kekurangan dan cabaran dalam aplikasi pengecaman wajah di mana tidak terhad terhadap keadaan video wajah yang diperolehi. Kajian ini adalah berkaitan dengan pengecaman wajah dalam persekitaran yang tidak terkawal di mana imej yang digunakan untuk latihan dan pengujian didapati daripada dunia sebenar menggunakan kamera telefon pintar. Buat masa ini, pangkalan data yang mengandungi wajah bagi telefon pintar yang tersedia untuk kegunaan umum masih kurang. Tambahan pula, pangkalan data yang digunakan sekarang tidak mengambil kira cabaran-cabaran yang dihadapi dalam senario sebenar. Salah satu masalah yang penting dalam persekitaran data telefon pintar yang tidak terbatas ialah variasi pencahayaan yang memberikan kesan negatif terhadap prestasi sistem pengecaman wajah memandangkan ciri-ciri raut wajah bergantung sepenuhnya kepada pencahayaan sekeliling. Di samping itu, penggunaan data daripada peranti telefon pintar memberikan cabaran yang baru seperti zoom optik yang berbeza. Masalah ini mempengaruhi ketepatan sistem pengecaman wajah apabila imej pengujian dan imej galeri bagi individu yang sama tetapi berbeza dari segi jarak wajah dengan kamera. Selain itu, prestasi kaedah pengesanan wajah yang dibangunkan terkini adalah kurang memuaskan dalam persekitaran yang tidak terkawal, seperti mempunyai variasi dalam pencahayaan, latarbelakang yang kompleks dan pertindihan antara wajah dan latarbelakang berwarna. Malah, pengesanan sempadan wajah yang tepat adalah tidak mencukupi untuk mengekstrak ciri-ciri kawasan wajah yang sebenar terutama sekali dengan kehadiran oklusi yang mana memberikan kesan kepada operasi mengekstrak ciri dan ketepatan pengesanan wajah berkurangan. Akhirnya, meningkatkan ketepatan kaedah pengecaman wajah dalam persekitaran yang sukar

dari pangkalan data wajah telefon pintar masih merupakan cabaran yang besar buat para penyelidik.

Objektif pertama kajian ini adalah untuk membina suatu pangkalan data video telefon pintar yang mencerminkan video dunia nyata. Objektif seterusnya adalah untuk meningkatkan penampilan ciri-ciri wajah dalam keadaan pencahayaan yang berbeza dengan menukarkan suatu imej kepada imej binari dengan menggunakan kaedah penukaran binari kolumnar yang baru dengan mengambilkira kekukuhan dan kuasa diskriminatif ciri-ciri binari yang kuat. Di samping itu, kajian ini bertujuan untuk meningkatkan prestasi kaedah pengecaman wajah di bawah kesan pembesaran optik yang berbeza dengan mengesan rantau ciri-ciri wajah yang dinormalisasikan menggunakan kaedah normalisasi rantau ciri-ciri wajah yang dicadangkan. Objektif seterusnya adalah untuk mengesan dengan tepat rantau wajah dengan latarbelakang yang kompleks dan pelbagai keadaan pencahayaan menggunakan kaedah warna kulit geometri yang telah dicadangkan. Tambahan pula, tesis ini bertujuan untuk menyelesaikan masalah oklusi yang tidak dijangka dengan mengesan kawasan yang tidak terhalang menggunakan kaedah pengesanan kawasan wajah yang tidak terhalang. Akhirnya, kajian ini bertujuan untuk mendapatkan prestasi pengecaman wajah yang berketepatan tinggi dalam persekitaran yang tidak terkawal bagi pangkalan data telefon pintar berdasarkan adaptasi kaedah pengecaman wajah yang dicadangkan yang menggabungkan dua algoritma pengecaman wajah yang baru. Kaedah yang dicadangkan berfungsi dengan penyesuaian persekitaran imej input dan penggunaan pelbagai ciri-ciri wajah untuk meningkatkan kebergantungan dan kecekapan proses pengecaman tersebut. Keputusan eksperimen menunjukkan bahawa kadar pengecaman mencapai 100% di bawah keadaan persekitaran yang berbeza dansistem ini lebih baik berbanding beberapa kaedah lain yang mana keputusan yang diperolehi amat memberansangkan.

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I certify that a Thesis Examination Committee has met on 8 August 2018 to conduct the final examination of Noor Amjed Hassan on her thesis entitled "An Adaptive Face Recognition under Constrained Environment for Smartphone Database" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS

PIN	Personal Identification Numbers
FRS	Face Recognition System
HFR	Hybrid Face Recognition
ASM	Active Shape Model
PCA	Principal Components Analysis
LBP	Local Binary Pattern
SVM	Support Vector Machine
SFV	Smartphone Face Video
GUI	Graphical User Interface
CBC	Columnar Binary Conversion
SSIM	Structural Similarity Index Measure
CHT	Circular Hough Transform
RMSE	Root Mean Square Error
CFFBPNN	Custom Feed Forward Backpropagation Neural Network
CNN	Custom Neural Network
ROI	Region Of Interest
FBA	Face Boundary Area
PSNR	Peak Signal to Noise Ratio
GSC	Geometric Skin Colour
NOFAD	Non-Occluded Facial Area Detection
FFRN	Facial Feature Region Normalization

CHAPTER 1

INTRODUCTION

1.1 Background

Face is a significant natural characteristic through which humans are recognised based on their facial features and expressions. Face recognition systems (FRS), such as logging on a computer using facial verification as a password, gaming, people tagging, security and commercial and law enforcement areas, are widely used in the modern world (Haji & Varol, 2016). Recently, researchers have investigated face recognition in uncontrolled environments to coincide with the development of real-world scenarios. Collected images from the Internet or smartphone cameras have complex backgrounds, partial occlusions and large variations in lighting and views. Current FRS in the market have many limitations, such as reliability problems, reduced recognition accuracies in certain environments, complicated feature extraction, high setup costs and performance issues. These environment problems and obtaining high accuracy performance remain a challenge for most current face recognition algorithms (Fu, 2015; Vazquez-Fernandez et al., 2011). Thus, a precise FRS should be developed to fulfil the development of face recognition algorithms in uncontrolled environments.

According to last statistics and updates upon information concerning the social media and phone users, (McCool et al., 2012) show that people are now consider social media and phones as a part of their daily life. More likely, increasing in the number of phone users and the utilization of photos with different social media applications can be used as a helpful tool for security purpose and face recognition systems. Nevertheless, there is a lack in the existed database in terms of variations of illumination, sites, background, races, occlusion, cameras and views (Fathy et al., 2015; McCool et al., 2012; Raja et al., 2015).

Illumination variation is a major challenge for face recognition. Illumination variation affects the appearance of facial features in images and the performance of feature extraction (Nagaraju et al., 2011). Moreover, the effect of illumination variation on facial features is increased with the data obtained by smartphone cameras (Olivares-Mercado et al., 2017). A binary image is a significant means to present the features because it plays an important role in generating unique features to distinguish several classes of pattern recognition (Atmaja et al., 2016). A local adaptive thresholding technique is a popular technique for binary conversion process and is a common solution for illumination variation because different threshold values are computed for each pixel in the image. Many studies have used the local adaptive thresholding technique based on illumination variation. Pai et al. (2010) proposed an adaptive thresholding approach that combined the advantages of local and global thresholding methods based on intelligent block size detection and performed thresholding based on each block of degraded image. Khan et al.,(2017) proposed an iterative region-

based Otsu (IRO) thresholding as an improvement on Otsu's and iterative Otsu's threshold method by Cai et al, (2014) in varying illumination environments. The IRO method computed the threshold value by using the statistics of greyscale intensities and regional distribution of illumination noises. Although many studies have been conducted in this field, their algorithms have limitations under conditions of extreme illumination variation.

The use of a smartphone database called different optical zoom is another challenge, which is produced from the difference of data from one object based on its distance from the camera (Valente & Soatto,2015; Super et al., 2010). Researchers (Noyes, 2016; Bryan et al., 2012; C. H. Liu & Chaudhuri, 2003; C. H. Liu & Ward, 2006) investigated the influence of this problem in viewing human faces at different distances from the camera, and the results showed that facial recognition was difficult when viewed under different levels of optical zoom. Few studies have investigated the performance of face recognition algorithms on different optical zoom images. Valente & Soatto, (2015) investigated the effect of captured faces in different distances on the performance of automatic face recognition algorithms. They compared the performance of several face recognition algorithms on captured test images with the same distance as training images and different distances. They showed that the effect was large scale when applied to the same personal video chat contexts or "selfie" mobile videos/images in different distances that cannot be more than an arm's length.

Face detection is a major step in face recognition systems. The results of all other steps are dependent on accurate face detection results. Face detection is a difficult task because face images frequently appear differently in terms of illumination conditions, occlusions and complex backgrounds (S. Lee & Lee, 2016). Face detection methods have been classified into four categories, namely, knowledge-based, characteristic-based, template matching and appearance-based methods. The characteristic-based method includes a colour-based method and uses structural characteristics that are valuable for face detection under uncontrolled environment conditions. Skin colour is a characteristic-based method and an essential feature of images for detecting human faces (Hsieh et al., 2008; Conseil et al., 2007). Fundamentally, various important methods are used to segment or detect skin colours. These methods are classified into three categories, namely, statistical colour model, generic skin colour model and unsupervised learning approaches (Han et al., 2009). The performance of these methods is limited under uncontrolled environments (Mahmoodi & Sayedi, 2016). To overcome these problems, considerable studies have combined skin colour with geometric features, including the regional characteristics of two eyes, nose, mouth, contour and shapes, to increase face detection accuracy. Verma et al.,(2014) proposed a face detection method based on skin colour segmentation and geometric features. A Gaussian model was used to extract the skin colour in CbCr colour space and a binary mask was created by using a likelihood ratio method. Best ellipse searching was used to detect facial contours. Yadav & Nain, (2016) detected the faces in an image by combining skin segmentation and geometric features. The segmented face regions were classified by using a set of facial features, such as eye-mouth hole detection, bounding box and eccentricity ratio. However, the performance of these methods was

limited under illumination variation conditions and the overlapping of skin colour with background colour.

Occlusion is another challenge in uncontrolled environments. Occlusion reduces the performance of face recognition on missing information represented by invisible face parts (Dhamecha et al., 2014; Khadatkar et al., 2016) Face recognition methods that overcome facial occlusions are classified into two categories. The first category is part-based methods that deal with occlusions by separating the images into parts and classifying these parts as non-occluded and occluded. Then, the features of non-occluded parts are used in the recognition process. Venkat et al., (2013) proposed an approach called psychophysically inspired similarity mapping (PISIMA) to recognise occluded faces. This approach processed local facial components by using a Bayesian network model to determine whether they were occluded parts or not. Dhamecha et al., (2014) divided face images into parts, computed the intensity histogram and Local Binary Pattern (LBP) as a texture descriptor for all patches and classified them using support vector machine (SVM). Khadatkar et al., (2016) proposed a face recognition method for occluded face images by classifying face patches using an SVM classifier and recognised other non-occluded regions of images. The second category is feature-based methods that detect occluded parts from the local features of images. Kumar et al. (2012) detected occlusions based on skin colour by using an SVM classifier. Gao et al. (2014) proposed a mean face image obtained from train images. The mean face was subtracted by test face to form an error face image. The occlusion area of the test image was obtained by using the error face image based on an image segmentation technique. Le et al., (2017) presented an automatic and semi self-training system to simultaneously detect and segment facial beard/moustache from facial images. A classifier was built from random ferns and SVM with two models, namely, self-trained and pre-trained models. The two aforementioned algorithms employed statistical approaches with complicated mechanisms in detecting the occluded regions of faces. Moreover, occluded parts were difficult to model by using a limited training database due to various occlusion accessories or hair face features. In addition, these techniques were time consuming because they were required to classify each part as valuable or occluded parts.

Although mobile face detection and recognition have emerged, few studies have been conducted on mobile face detection and recognition in uncontrolled environments (Jafri & Arabnia, 2009; C. Zhang & Zhang, 2010). Moreover, the performance of existing FRS is limited under uncontrolled environments. To enhance the recognition performance, recent studies have investigated hybrid face recognition methods. Raja et al., (2015) introduced an authentication system using a smartphone database based on fusing the face, iris and periocular recognition methods. Fathy et al., (2015) combined set-based methods with fiducial-point-based features for a face authentication system. K. Liu & Moon, (2016) also proposed a hybrid face recognition method based on two stages. Firstly, PCA was used to recognise the test image. The recognition process was conducted if the confidence level test was passed. Secondly, high-dimensional local binary patterns (HDLBP) were employed. Gumede et al., (2017) proposed a hybrid component-based strategy for facial recognition. The

proposed algorithm detected facial components (eyes, mouth and nose) and extracted textural and shape features. Feature descriptors, Garbo filters and Zernike moments were used for textural and shape features. Unfortunately, most of the abovementioned methods still had limitations under uncontrolled environments. Moreover, they were mostly deployed for constrained and indoor vision applications that did not have hard illumination variation of outdoor environments and without different capturing distances and noises caused by a moving mobile camera.

1.2 Research Problem

Existing smartphones face databases were not addressed for all challenges such as varying illumination of different indoor and outdoor sites, background, cameras and different face to camera distances. McCool et al. (2012), Raja et al. (2015) and Fathy et al. (2015) proposed a smartphone face databases that cutter the challenges as different illumination conditions of indoor sites, person appearance variation and different races. More details will be explained in section 3.4, table 2.1.

The preservation of image features caused by binary conversion is a difficult task under the effect of illumination variation conditions. Several binary conversion methods have used an adaptive thresholding technique to improve their performance under illumination variation conditions because it provides more robustness to these conditions. Khan et al., (2017) proposed an IRO thresholding as an improvement on iterative Otsu's threshold method by Cai et al. (2014) in varying illumination environments. The IRO method computed the threshold value by using the statistics of greyscale intensities and regional distribution of illumination noises. However, the performance of existing methods was still limited under high differences illumination conditions specially for uncontrolled lighting sources and directions of the indoor and outdoor environments.

Apart from the aforementioned problems, the different of close distance between face and camera (different optical zoom) is a crucial problem in the recognition of smartphone data either from front or rear camera. Such problem occurs when the input image is different from the gallery images of the same person (Super et al., 2010; Flores et al., 2013; Perona, 2013; Valente & Soatto, 2015).

Skin colour segmentation is a popular method used in face detection, but the performance of this method is reduced under uncontrolled environments. Therefore, several studies have combined skin colour with geometric features to improve the performance of face detection. Yadav & Nain, (2016) detected the faces in an image by combining skin segmentation and geometric features. The segmented face regions were classified by using a set of facial features, such as eye-mouth hole detection, bounding box and eccentricity ratio. Ramesh et al., (2017) proposed a skin detection algorithm that used a particle swarm search method in determining the fitness of a region and its likelihood as skin. In addition, they used the boundary of the face area

by using an active contour model called gradient vector flow snake to obtain the face boundary region of interest. However, the variation of illumination and complicated background with same skin colour will reduce the performance of the algorithms discussed.

The extraction of correct facial features is a challenging task, especially with the presence of occlusions. Most of the occluded face recognition algorithms based on learning techniques have detected the facial occluded regions. Dhamecha et al., (2014) divided the face image into parts, computed the intensity histogram and LBP as a texture descriptor for all patches and classified them using SVM. Khadatkar et al., (2016) proposed a face recognition method for occluded face images by classifying the face patches using SVM classifier and recognised other non-occluded regions of images. Le et al., (2017) presented an automatic and semi self-training system to simultaneously detect and segment facial beard/moustache from facial images. However, using learning techniques to classify the occluded and non-occluded parts is difficult to apply due to the variety of occlusion types or the variety of hair face features. Therefore, occluded parts are difficult to model using a limited training database which affect the accuracy of FRS. Moreover, these techniques considered as time consuming because it need to classify each part as a useful or occluded part.

Many researchers focused on the hybrid face recognition methods to enhance the recognition accuracy. Cho et al., (2014) employed dual stages, in which a PCA algorithm was used in the first stage and a local Gabor binary pattern histogram sequence was used in the second stage. K. Liu & Moon, (2016) used PCA in the first stage and HDLBP in the second stage. Meanwhile, Gumede et al., (2017) proposed a hybrid component-based strategy that utilised successfully detected components in recognizing and verifying the person's identity. However, the performance of these methods had low accuracy under uncontrolled environments because they did not have illumination variations of outdoor environments, complex background and different optical zooms.

1.3 Research Objectives

A face recognition method is proposed to solve the issues that addressed in our constructed Smartphone Face Video (SFV) database. This method is designed to achieve the following objectives:

1. To enhance the facial features appearance with varying illumination conditions.
2. To improve the recognition performance under different optical zoom levels.
3. To accurately detect the face area from a complex background and varying illumination conditions.

4. To improve the performance of occluded face recognition algorithms in terms of accuracy and time consumption by detecting non-occluded areas based on facial geometric features.
5. To increase the accuracy of face recognition under the environment of smartphone face database.

1.4 Research Contributions

On the basis of the objectives stated in Section 1.3, the primary contributions are listed as follows:

1. A new binary conversion method called Columnar Binary Conversion (CBC), which is based on an effective thresholding technique, is introduced to enhance the appearance of facial features under the illumination variation conditions.
2. The recognition performance under different optical zoom levels is improved by detecting the face feature bonding box using a Facial Feature Region Normalization (FFRN) method.
3. A robust method named Geometric Skin Colour (GSC) for localizing and detecting the face area is proposed under uncontrolled environments.
4. Important facial features are extracted by detecting the correct non-occluded areas from the face based on the proposed Non-Occluded Facial Area Detection (NOFAD) method.
5. A high-accuracy face recognition performance under uncontrolled environments of smartphone database is obtained using the proposed adaptive face recognition method that combines two new face recognition algorithms.

1.5 Research Scope

The scope of this study is expressed as follow:

- The research cover on uncontrolled illumination conditions in terms of light sources and directions. Where the videos recorded in different indoor and outdoor sites with different lighting sources such as room light, sun light and uncontrolled directions.
- The study focus on the data of frontal face from smartphone camera (rear or front) with different distances based on the person's arm length and the face space respectively.
- The study works on human faces with unintentional occlusion such as bread and moustache.

1.6 Research Outlines

A brief background of the study, its research problem, objectives, contributions and scope are presented in this chapter. The remaining chapters of this thesis are organised as follows:

Chapter 2 introduces a review of the state-of-the-art literature on face recognition methods implemented in previous studies. Then, this chapter presents a brief explanation of the technique used for face detection, feature extraction and face recognition.

Chapter 3 shows the methodology and research framework in detail. This chapter also explains the database collection and several preliminary experiments conducted to determine the optimal parameters for the solution. In addition, the implementation process, software and computer specifications for this study are described comprehensively.

Chapter 4 describes the hybrid face recognition algorithm based on geometric and binary features. This chapter introduces the proposed methodology, implementation, results, discussions and advantages and limitations of the proposed algorithm.

Chapter 5 presents the proposed face recognition algorithm based on colour features. The chapter introduces the proposed methodology, implementation, results, discussions and advantages and limitations of the proposed algorithm.

Chapter 6 concludes the entire research and emphasises the contributions that include the overall evaluation process. This chapter ends by presenting recommendations and directions for future work.

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