ENHANCED FACE DETECTION FRAMEWORK BASED ON SKIN COLOR AND FALSE ALARM REJECTION

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Dedicated to my beloved parents and family, whom without their love and support this research would have never been completed.

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ABSTRACT

Fast and precise face detection is a challenging task in computer vision. Human face detection plays an essential role in the first stage of face processing applications such as recognition tracking, and image database management. In the applications, face objects often come from an inconsequential part of images that contain variations namely different illumination, pose, and occlusion. These variations can decrease face detection rate noticeably. Besides that, detection time is an important factor, especially in real time systems. Most existing face detection approaches are not accurate as they have not been able to resolve unstructured images due to large appearance variations and can only detect human face under one particular variation. Existing frameworks of face detection need enhancement to detect human face under the stated variations to improve detection rate and reduce detection time. In this study, an enhanced face detection framework was proposed to improve detection rate based on skin color and provide a validity process. A preliminary segmentation of input images based on skin color can significantly reduce search space and accelerate the procedure of human face detection. The main detection process is based on Haar-like features and Adaboost algorithm. A validity process is introduced to reject non-face objects, which may be selected during a face detection process. The validity process is based on a two-stage Extended Local Binary Patterns. Experimental results on CMU-MIT and Caltech 10000 datasets over a wide range of facial variations in different colors, positions, scales, and lighting conditions indicated a successful face detection rate. As a conclusion, the proposed enhanced face detection framework in color images with the presence of varying lighting conditions and under different poses has resulted in high detection rate and reducing overall detection time.

ABSTRAK

Pengesanan objek dengan cepat dan tepat merupakan tugas yang mencabar dalam visi komputer. Pengecaman muka manusia memainkan peranan penting pada peringkat pertama aplikasi pemprosesan wajah seperti pengesanan pengecaman, dan pengurusan pangkalan data imej muka. Dalam aplikasi tersebut, objek muka sering datang daripada bahagian imej yang tidak penting yang mengandungi variasi seperti pencahayaan, posisi serta halangan pada muka. Variasi ini dapat mengurangkan kadar pengecaman muka dengan ketara. Selain itu, masa pengesanan merupakan faktor penting, terutamanya dalam sistem masa nyata. Kebanyakan pendekatan pengecaman muka yang sedia ada tidak tepat kerana tidak dapat menyelesaikan imej tidak berstruktur ekoran daripada luasnya variasi penampilan dan hanya dapat mengecam muka manusia di bawah variasi tertentu. Kerangka kerja pengecaman muka yang sedia ada memerlukan penambahbaikan untuk mengecam muka manusia di bawah variasi yang dinyatakan untuk meningkatkan kadar pengesanan dan mengurangkan masa pengesanan. Dalam kajian ini, sebuah kerangka kerja pengecaman muka dicadangkan bagi mempertingkatkan kadar pengesanan berdasarkan warna kulit dan menyediakan proses pengesahan. Laporan segmen awal imej input berdasarkan warna kulit dengan nyata boleh mengurangkan ruang carian dan mempercepatkan prosedur pengesanan wajah manusia. Proses pengesanan utama adalah berasaskan kepada ciri-ciri Serupa-Haar dan algoritma Adaboost. Proses pengesahan pula dicadangkan untuk menolak objek bukan muka, yang boleh diwujudkan dalam proses pengecaman muka. Proses pengesahan adalah berdasarkan kepada Corak Binari Tempatan Terperluas dua-pringkat. Dapatan eksperimen set data CMU-MIT dan Caltech 10000 melalui bermacam variasi muka dalam pelbagai warna, kedudukan, skala dan keadaan pencahayaan menunjukkan kadar pengecaman muka yang berjaya. Kesimpulannya, kajian ini mencadangkan pengecaman muka boleh dipertingkatkan dengan kerangka kerja pengesanan menggunakan imej warna dan keadaan pencahayaan yang berbeza-beza dan juga di bawah posisi yang berbeza bagi mendapatkan kadar pengesanan yang tinggi serta mengurangkan masa pengiraan keseluruhan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AdaBoost	-	Adaptive Boosting
ASA	-	American Standards Association
ASM	-	Active Shape Model
CMU	-	Carnegie Mellon University
FLD	-	Fisher's Linear Discriminant
GTAV	-	Audio Visual Technologies Group
GUI	-	Graphical User Interface
HCI	-	Human-Computer Interaction
HSV	-	Color space (Hue, Saturation, and Value)
HMM	-	Hidden Markov Model
JPEG	-	Joint Photographic Experts Group
LBP	-	Local Binary Pattern
MATLAB	-	Matrix Laboratory
MLL	-	Machine Learning Library
MLP	-	Multi Layer Perceptron
NN	-	Neural Network
OpenCV	-	Open Source Computer Vision
PAC	-	Probably Approximation Correct
PBM	-	Portable Bit Map
PCA	-	Principal Component Analysis
RGB	-	color space (Red, Green, and Blue)
ROC	-	Receiver Operating Characteristic
ROI	-	Region of Interest
SOM	-	Self-Organization Map
RNDA	-	Recursive Non-Parametric Discriminant Analysis
SGLD	-	Space Gray-Level Dependence
SVM	-	Support Vector Machine

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The latest evolution in computer science and the existing technologies have advanced the machinery world, where human life is improved by taking advantage of the artificial intelligence. In fact, the trend has encouraged an active improvement in machine intelligence. For instance, computer vision systems have been used in particular everyday jobs such as performing boring and tedious tasks. The current development in computer vision is moving forward to be more generalized vision applications including face recognition and summarizing video surveillance systems. In addition, the main and primary step of these kinds of applications is to find and locate human face.

Over the last decades, human face detection has been researched widely due to the recent advances of its applications such as video surveillance system, security access control, information retrieval in many unstructured multimedia database, and advanced Human Computer Interaction (HCI). The input images can be captured via several devices such as cameras and they can be manipulated by various computer vision methods (Jaimes and Sebe, 2007). In addition, most of the biometric and HCI applications include computing some analysis on human faces such as in face alignment, recognition, verification, and authentication purposes. Indeed, human face must be detected before any such analysis can occur in these images (Hemalatha and Sumathi, 2014). In other words, face detection is one of the most important steps in many image-processing applications, especially in face recognition and summarization of video-surveillance, systems due to they have to locate face first to recognize and summarize information about the given frame in real-time applications. However, human face detection from input image is a challenging issue due to the high degree of spatial variability in location, pose (frontal, profile, rotated), and scale. Human face detection is part of computer vision and aims to locate human face in digital images or video frame (in real-time applications) in order to ignore the background of images (Ban *et al.*, 2014). The background of images may contain of some other objects, which is not human face such as building, road, tree, and car.

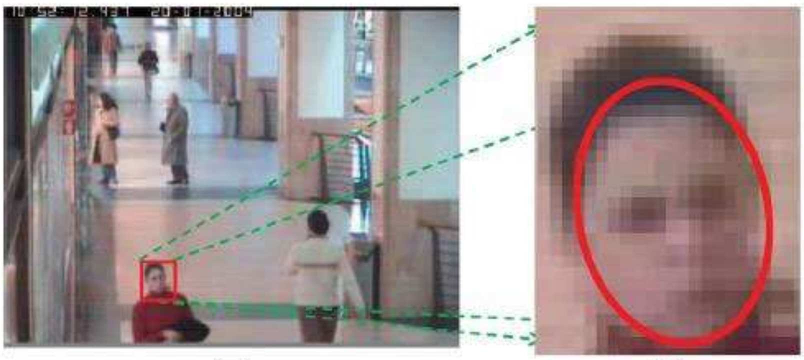
In the literature, different frameworks of face detection are provided and among them Viola and Jones have proposed one of the superb approach which is commonly used in most of the existing face detection methods or with the combination of some other methods in order to increase its accuracy (Yang *et al*., 2010). In addition, the proposed approach by them also have some limitations such as difficulty in training and creations of high false alarms and the late proposed methods have aimed to decrease the number of false alarms (Zakaria and Suandi, 2011). The description of this method is available in literature review of this study.

1.2 Problem Background

Innately, integrating information from various visual cues, such as texture, stereo disparity, and image motion, have better improvement in performance on perceptual tasks, such as face detection. On the other hand, the additional determination required to extract and signify information from additional cues may increase computational complexity. The automatic face detection is known as one of the complex problems in image processing. Several approaches are proposed to solve this problem including template matching, knowledge based, Adaboost learning based, Neural Networks, SVM algorithms. However, the success is accomplished with each face detection method with varying degrees and complexities.

Face detection is the first and primary step in most of the face processing systems, such as localization, face recognition, video surveillance systems, face tracking. The problem of all the stated applications is all about face detection. This is a fact that seems inexplicable to new researchers in this area. However, before face recognition is possible, one must be able to discover a face and its landmarks. This is essentially a segmentation problem and in practical systems, most of the effort goes into solving this task. Indeed, the actual recognition based on features extracted from these facial landmarks is only a minor last step.

There are two different types in face detection problem including face detection in static image and detection in real time. Most of the face detection frameworks try to extract a portion of the whole face, thus eliminating most of the background. Real-time face detection involves detection of a face from a series of frames from a video capturing device. Although the hardware necessities for such a system are far more inflexible, from a computer vision standpoint, real-time face detection is actually a far simpler process than detecting a face in a static image. This is due to the face that unlike most of our surrounding environment, people are frequently moving. Therefore, face detection has an outstanding importance and plays a critical role in most of the face processing systems and the performance of this step has direct impact on the overall performance of the systems (Xiaoning *et al*., 2010). Figure 1.1 depicts a video frame in a real time surveillance system, which face recognition systems as the second stage can be applied to identify the face from the video.



(a) (b)

Figure 1.1 : Capturing a face from a surveillance video (a) Surveillance system. (b) Detected facial region (Zou *et al*., 2012).

The processing of human face is one of the active areas of research in machine vision fields (Wang *et al*., 2008). The researchers, which are interested in this area, have aimed to propose and design intellectual systems to detect and recognize human faces from input images. In addition, face detection is one of the high applicable instances of the object recognition system, which deals with detecting and recognizing appearances of human faces in digital images or video frames (Sugimoto *et al.*, 2005). In addition, biometric systems use appearance of user's face and they can identify persons for security issues from video surveillance systems (Tsalakanidou *et al*., 2007). In addition, as another application of the face recognition it can be pointed that people can search in their own digital photography archives for all the images of particular people. These scenarios have become feasible today with getting advantage of face detection as well as recognition methods.

Face processing can be divided into several fields including face detection, face recognition, face verification, face tracking and facial expression which face detection is the first step in any of these face-processing systems (Sharma *et al.*, 2009). The main aim of face detection is to detect and locate the places in the given image or video frame which consist of human face. Furthermore, feature extraction is responsible to detect the presence of features in human face such as nose, eyes, ears, mouth etc. This step is widely used in most of the face detection approaches especially for those which work based on the features of the face. In fact, face recognition systems include a database, which compares the detected face and the faces in database. The process continues until the system finds an occurrence of matching. In addition, facial expression, occlusion, and lighting conditions can change the overall appearance of face and can effect on the mentioned applications. In the next sections, several variations that can make significant effect of the face processing systems are described.

The main and general approach of face detection contains of three main modules, which are preprocessing, feature extraction, and classification (Bagherian *et al.*, 2008). In the preprocessing stage, several enhancements can be performed to increase the quality of input image such as normalization and changing in illumination to make it easier for next stages to extract facial features that exist in images (Ming *et al.*, 2008). In the feature extraction stage, the input image is divided into sub windows and then features can be extracted from the sub-windows in order to grab those features, which are related to human face such as eye, lip, nose, forehead etc. The last step is responsible to classify faces from non-face objects.

Face detection is a significant challenge due to its applications such as face tracking, face recognition etc. and practically it must be accurate and fast enough in practical applications to avoid any interruption in the systems. For instance, Figure 1.2 illustrates two types of images which a face detection approach has to struggle with. Figure 1.2 (a) shows an image that contains a face and it is easy to be detected, meanwhile Figure 1.2 (b) depicts an image which is not easy to detect by a face detector due to several variations such as low contrast, profile-view, complex background and this type of images make several limitation and challenging issues.

(a) (b)

Figure 1.2 : Sample image from Caltech 10000. (a) Image that is easy to detect face. (b) Image that creates challenges for face detectors.

Most of the face detection algorithms are able to locate the face in Figure 1.2 (a), due to this image is taken in frontal view, without occlusion, centered, and in a good condition of illumination. Hence, to locate such this kind of images there is not much challenging issues. The challenges start when a face detector has to struggle with the second type of images (Figure 1.2 (b)), which creates all the mentioned limitations that is called unstructured settings. The unstructured settings in images may contain several variations such as complex backgrounds, different lighting conditions, poses, races, skin colors, age, gender, face occlusion and etc. (Kemelmacher-Shlizerman and Seitz, 2011). Figure 1.3 also illustrates some samples of images from Labeled Faces in the Wild (LFW) face database which are taken under unstructured settings.

Figure 1.3 : Sample of unstructured images from LFW face database.

There are number of challenges and difficulties which cause to decrease the performance and accuracy of face detection systems including noise, complex texture, complex background, pose variation, illumination condition, occlusion (Alabbasi and Moldoveanu, 2014). Generally, some of the main reasons, which make it difficult for machines to detect human faces, are categorized as following:

i. Different poses such as frontal or profile and upside down.
ii. Different illumination conditions.
iii. Presence or absence of glasses, beards, mustache, etc.
iv. Complex background/ texture.
v. Different face size.
vi. Computation time in real time applications.

First challenging issue occurs due to the different position of face in images and changing in plane rotation, and some facial features such as nose or lips may become occluded partly or completely.

Second problem is known as different illumination conditions. The issue occurs when the image is formed; factors such as lighting (spectra, source distribution and intensity) and camera characteristics (sensor response, lenses) affect the appearance of a face and since face images possess a 3-D shape, under lighting in different directions, illumination variations is one of the most important factors. (Goel and Agarwal, 2012).

The next issue is occlusion, that means human face(s) in images may be occluded partially or completely by other objects. For example, one object may partially occludes the face of other people.

Fourth challenging issue is related to the background image which some objects can have same features as human face and wrongly detected by face detector, which is called false positive. A face detection system must be able to detect faces in different sizes due to not all of faces in an image have the same size.

The fifth issue is related to the different scale of face objects. This factor can be achieved using some methods such as scaling the input of image or changing in object model (Goldmann *et al.*, 2007). However, different size of objects commonly make challenges for face detectors in order to obtain the small size of faces are more difficult than obtaining the large ones. Figure 1.4 shows an image from CMU database, which contains different face scales.

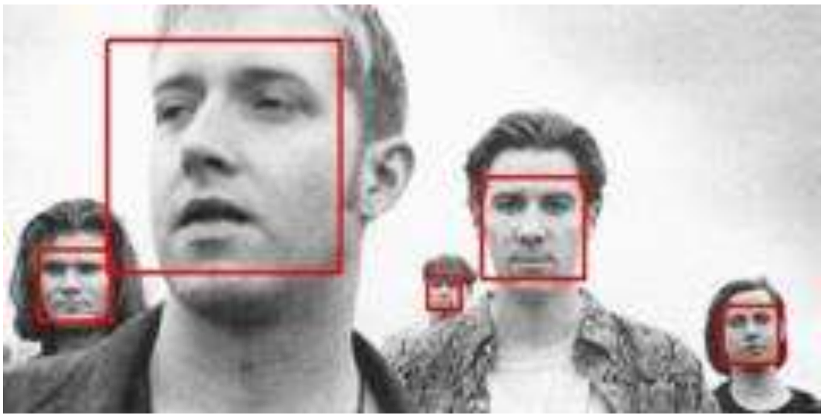


Figure 1.4 : Sample image includes faces with different scales from CMU database.

The final factor is computation time; is speed of computation, which controls the speed of face detection systems, this is another important factor especially for real time purposes that needs to be improved.

In spite of all these difficulties, tremendous progress has been made in the last decade and many systems have shown impressive real-time performance to detect human face under different variations. There are many researches, which had been conducted in order to improve the performance of face detection systems as stated in the list of challenges and they aimed to improve one specific problem. However, these researches are unable to detect face in other images, which contain other challenging issues (Haider *et al*., 2014). For example, several studies in face detection are proposed to detect faces under different illumination conditions, but the same algorithm is not be able to detect face under different poses or the false positive/negative rate is high under the other mentioned challenging issues. Although, many methods have been proposed by scholars aim to improve the performance of face detection, but none of methods can solve all the problems and challenges in face detection in a single algorithm. Omaima (Omaima, 2014) has presented recently result of some face detection systems and is reported a detection rate is vary between 77.9% and 97.3%, which the false positive rate is between 0.5% and 5%. This concluded that face detection systems still need to be improved.

To evaluate the performance of face detection methods, some factors have been defined including "true positive", "false positive", "true negative", "false negative", "false alarm", "detection rate", and "computation time" (Omaima, 2014). The "true positive" is the number of objects (faces) which are detected correctly and the "false positive" is the number of objects, which are detected wrongly. The "true negative" is a term that is used when the objects are rejected correctly in a set of images. The "false negative" is also a term used when the object rejected incorrectly in a set of images. The "false alarm" is named when the detector rejects or selects incorrectly. The "detection rate" is a ratio of the number of true positive (detected correctly) by total number of face(s) in the existing dataset. The last but not least is "computation time" which is one of the important factors especially in practical applications and declared by frame per second.

In addition, the main problem and challenging issue, which are addressed in most of the face detection methods, is “high false alarms”, which some objects are selected incorrectly as human face and some other objects, which are human faces are rejected (Li *et al.*, 2014; Inalou and Kasaei, 2010). For example, in a tracking system, if a face detection algorithm selects a non-face from the video frames of surveillance system, the next stage of tracking will follow an incorrect object and subsequently the whole algorithms will go wrong. In addition, by increasing the face detection rate, the false positive rate also increase accordingly (Li *et al.*, 2014). Researches show that this phenomenon happen in most of the face detection methods and this problem had become worse when some other challenges occur at the same time such as illumination or occlusion in an image (Powar and Jahagirdar, 2012). The problem is illustrated in Figure 1.5, which shows the correct and incorrect selected faces in an image.

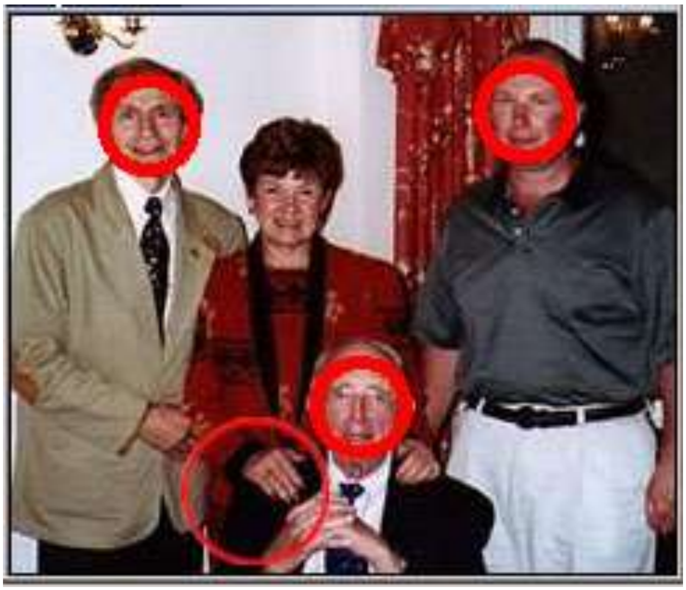


Figure 1.5 : An example of face Detector output with low accuracy.

Figure 1.6 also illustrates an image, which indicated there is no any false detection rates, and all of the human faces are selected correctly.

Figure 1.6 : An example of face detector output with high accuracy.

To evaluate the performance of face detection, there are several metrics including detection rate, false alarm rate, missing rate, etc. Most of the practical applications are able to increase the detection rate, and number of false alarm rate accordingly. This is due to the decision threshold that is learned to distinguish between face and non-face under training data set.

An ROC (Receiver Operating Characteristic) curve is a plot generally used in machine learning and data mining for demonstrating the performance of a classifier under different criteria. Figure 1.7 illustrates the correlation between the detection rate and false alarm rate. A point on ROC curve shows that the trade-off between the achieved true positive detection rate and the accepted positive rate. A good face detector needs to make a balance between detection rate and false alarm rate.

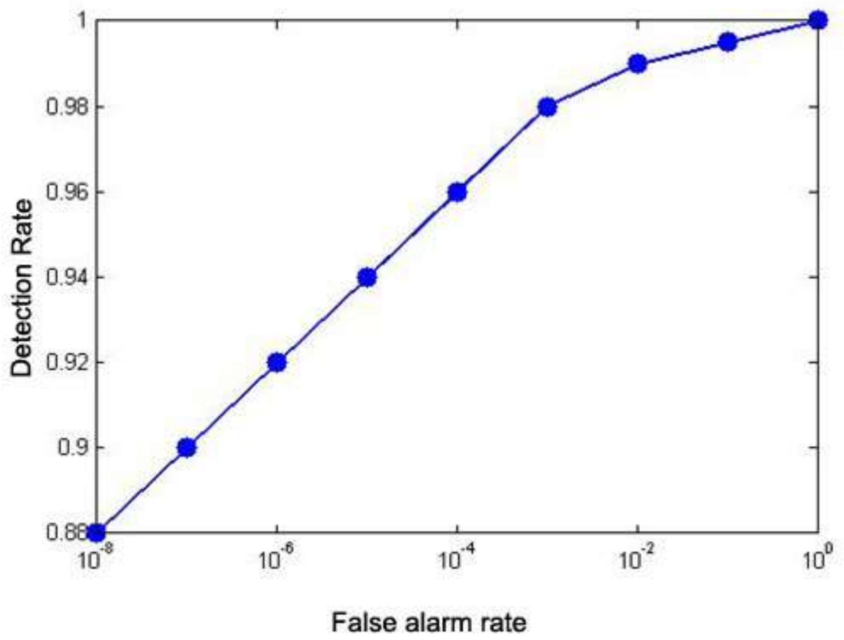


Figure 1.7 : Typical ROC curve for face detection (Li and Jain, 2011).

Although, there is requirement to improve the performance of face detection algorithms just for scientific reasons which triggers the interest of researchers, face detection also has marketable demand to be improved. The commercial significance is raised by the interest of the world's leading camera manufacturers, they interested to include these features in their products (Bakshi and Singhal, 2014).

There are a number of researches associated with face detection problem, which have been conducted in order to provide algorithms to improve the performance of face detection including Template-Based, Feature-Based, Appearance-Based and knowledge-Based methods. Appearance-Based methods are designed as learning based system from the training sets using machine learning and they have shown the most efficient result compare to other methods due to the high performance and ability of handling variations such as different poses, different illumination conditions, and partial occlusion in face images (Zhang and Zhang, 2010). Although, most of the proposed methods have aimed to increase the performance of face detection under different conditions. However, there are other challenges, which are remained such as number of false detection rate and computation time (Omaima, 2014).

The quality assessment of face was firstly introduced by Griffin where a face image is evaluated using some important features of the human face (Griffin *et al*., 2005). Face quality assessment in raw images that has been studied previously. Subasic *et al.*

proposed a method to validate face images for applying in identification documents. These kind of methods are needed to evaluate the performance of face detection systems and allows face recognition systems to be performed successfully (Subasic *et al*., 2005). Generally, the factor of performance in face detection methods is affected by two main components: face/non-face classifier and post processing (Li and Jain, 2011). These two kinds of data set are needed including training set which are used for training classifier and test set which contains normal images to evaluate the performance.

The present research is mainly concentrates on human face detection problem with the aim of improving the performance of face detection in order to reduce the number of false alarms while keeping high detection rate. According to Omaima (Omaima, 2014), the detection rate is vary between 77.9% and 97.3% which the false positive rate is between 0.5% and 5%. Hence, a face detection framework is proposed to decrease the number of false alarms and subsequently increasing in the detection rate that is the main aim of proposed framework. In addition, the computation time is a main issue in real time application; a skin color segmentation is used to reduce the search space of given image or video's frame.

1.3 Problem Statement

The vast realistic applications of face detection system attracts the attention of researchers in this area of research to improve the detection rate of the face detection system. One of the most challenging issues in the face detection system aims to decrease the number of false alarms. This problem occurred mostly when there are intra-class variations such as illumination, occlusion, and expression. Several researches have been done in the field of face detection, which focused on improving the performance using variations in type and quantity of features and changing in classifier structure. Although, the proposed methods have some improvements in terms of accuracy and computation time, but the high number of false positive rate still addressed as majors issue in face detection and subsequently some other applications which apply the face detection at first stage suffers the lack of performance as well. Few researches addressed face detection with high performance can detect human face under certain criteria such as illumination, pose, and occlusion; however, the result is not 100 % satisfactory in terms of computation time and detection rate, especially when applying the methods in real time applications.

1.4 Research Aim

The main aim of the present research is to propose a new face detection framework for increasing the current accuracy of face detection for human face under different illumination and poses.

1.5 Research Objectives

The main objectives of the present research are described based on the problem statement, as follows:

i. To design a method for reduction of search area using human skin color and morphological operations.
ii. To enhance the current detection process by introducing the validity process for candidate face regions.
iii. To innovate the current face detection framework based on minimized search area and the validity process.

1.6 Research Scope

The research objectives are achieved by identifying the problem scope that covers the following aspects:

i. Proposing a human skin-color segmentation method to remove the background of input image and eliminate the regions, which contains non-skin color objects.

ii. Proposing a validity process based on Local Binary Patterns (LBP) to achieve the rejection of the false positives' occurrences. The validity process has extended the conventional LBP in order to propose an extended LBP (ExLBP) based on two-phase process for training and testing human face objects.

iii. Proposing a face detection framework based on the feature and appearance based approaches by utilizing skin color segmentation and edge detection algorithm as well as morphological operation. Several set of enhanced Haar-like features are applied to extract features from human face and Adaboost algorithm using several weak classifiers to classify the face and non-face objects based on the learning algorithm which be trained with face and non-face objects.

iv. Evaluation of the performance of the proposed face detection framework method, and compare with the recent methods with respect to the related performance criteria.

v. The pose of the face in images is also known as a challenge in face processing. Frontal view, profile and all of the intermediate positions and upside down are samples of different poses which can be exist in input images.

vi. Images can be captured in a variety of illumination conditions. Illumination variation has extremely complex impact on the image of a face. Illumination invariance is one of the most difficult properties to achieve in a face detection system, which is extremely essential if the images are to be taken at an uncontrolled environment.

vii. Analysis on available standard face databases; the experiments are performed on CMU+MIT frontal, CMU profile, GTAV and Caltech 10000 Web Faces test databases due to accessibility, popularity and the diversity of the images in these databases.

viii. All the coding and implementation is performed on Visual Studio 2010 and by taking advantage of OpenCV library to work with the image commands. Moreover, MATLAB is used in order to plot the data on diagram and some preprocessing parts are used this tool as well.

1.7 Significance of Study

As it is described earlier of this chapter, face detection has many applications and they provide lots of motivation for the researchers to improve the accuracy of the existing methods in order to propose new methods, which can increase the detection rate and reduce the false alarm of this system. In the state-of-art of this study, several existing face detectors based on different methods are provided and they have aimed to improve the performance and accuracy of the system. In addition, there are several publications, which addressed the balance between accuracy and number of false alarms is still a challenging issue, and this problem is caused due to the process of decision-making.

The main reason of challenges in this process can be occurred by discrimination function or threshold selection. In addition, most of the proposed methods aimed to increase the detection rate and decrease the false alarms under specific variations, but the method have low detection rate under some other variations. Furthermore, some methods proposed to modify the structure of classifiers or enhancing the discrimination power of face and non-face samples. Although, the proposed methods had some improvements in terms of detection rate and reduction of false alarms, still the detection rate is not satisfactory due to the lack of validity process to verify the whole procedure.

The current study addresses several contributions in digital image processing including image enhancement, skin color segmentation, feature extraction and classification processes to achieve the objectives of the study, which is stated in Section 1.5. Search space reduction is a challenging issues to find and select the regions which consist of skin colors due to the fact that people have different skin colors and it is more apparent when the comparison is between different races which have different skin colors. The segmentation process must be able to eliminate the background of input images and achieve the regions, which contain skin colors. Indeed, the process aims to reduce search space for next process to have much less amount of processing to achieve the features of human face. An appropriate segmentation method can reduce the computation time of face detection process. In addition, most of the segmentation algorithms are semi-automatic. They need some human interactions to initialize and start the process and the result depend of this initial values and human experience. Moreover, the result of existing face detection frameworks are not fully satisfactory, due to the variation which exist in images. Hence, an automatic verification system can help to reduce number of false alarms. Furthermore, the necessity of this system in face processing is crucial especially in face recognition and video summarization systems. This study will be possible to the scientific community to be as base for other methods or the improvement of our proposed method, which concern the detection of human face in real-time applications.

In this study, preprocessing module is employed to remove noise of input image and shrink the search space in order to decrease the computation time for feature extraction and classification procedures. For validation purpose, another post-processing process is applied to confirm or reject the selected candidate faces from previous stage.

The validity process is based on the extended local binary pattern and support vector machine. As a result, the main contribution of this study is to keep the detection rate high as well as decreasing the number of false alarms by applying a 3-stage face detection system, which is done, based on Adaboost algorithm and modified Haar-like features in the main stage and final validity process. The second contribution is to construct a classifier in order to select a small number of critical features.

1.8 Thesis Organization

The present study consists of eight chapters and it is organized as following:

The present chapter presents an overview of the face detection framework, background of research and the existing challenges involve in this process. In addition, it discusses about several recent research contributions in this area specifically concentrating on skin-color segmentation methods and highlights the challenging issues in the existing methods.

Chapter 2 provides materials about literature review on human face detection frameworks, which are closely related to our study. It demonstrates several advantages and disadvantages of each existing face detection framework.

Chapter 3 presents the research methodology of the proposed face detection framework. This chapter also explains all the proposed techniques involved in implementation of proposed framework on skin color segmentation, feature extraction and classification. In addition, the data collection and definition of evaluation of the face detection frameworks are explained in this chapter.

Chapter 4 presents one of the main contributions of study, which describes search space reduction module. It presents the proposed face detection methods to generate less amount of search space for feature extraction process. In this chapter, the methods and improvement of the proposed process in order to reduce the search space of input images are described.

Chapter 5 elaborates the second main contribution of the study. This chapter discusses more about the methods, which are proposed for the final stage of proposed face detection framework. The main methods include feature extraction and classification. The aim of the validity process is to reject or accept the face windows, which are detected by the main face detection module.

Chapter 6 provides the details of the proposed face detection framework consist of main contribution of study, which are reduction in search space, and rejection of the false positive. In this chapter, information about the feature extraction and classification of the main detection process are provided.

Chapter 7 provides the experimental result of detection process, which includes the search space reduction, feature extraction, classification, and validity process. Moreover, several well-known and recent researches in face detection implemented and compared with this work to evaluate the performance and accuracy of this research. This chapter also presents the comparison between proposed framework and other well-known methods in skin color segmentation and final face detection result based on the available online datasets.

Chapter 8 concludes the major achievements drawn this research and future directions are recommend to the researchers which are interested to continue in this field of study. In addition, Appendix A demonstrates existing standard face databases which have been used and Appendix B provides some information about Skin Chromaticity, which is used as one part of the study.

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