Doctoral Dissertation

Development of Robust High Performance Face Detector under Different Environmental Conditions

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Dedicated to my Family, Teachers and all of my supporters

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5. Conclusions and future research

Abstract

The expressive three dimensional objects can be known as a face. Every human being has their own face. Face represents a physiological biometric identifier that is widely used in person recognition. Nowadays, the face detection process has become very common in computer vision systems. The process of locating the position of the face in an image is known as face detection.

The process is performed either by using still or video images. In this thesis, still images have been treated for face detection. There seems to be a lot of applications and systems applied for face detection, but developing a system that will increase the face detection rate based on the static position of the face on an image will help to make the face detection system more advanced and crucial.

A lot of face detection algorithms have been developed till now, but the face detection rate haven't reached to 100%. It is due to the presence of the different environmental conditions in an image. The environmental conditions are image noise, illumination variant images, occlusion, pose, rotation, variation of the facial skin color etc. The aim of this research is to clear all the environmental conditions and increase the face detection rate, which will play an important role in developing a robust face detection system. In the thesis, the novel ideas are presented for clearing the above mentioned environmental conditions by modifying, combining and developing the algorithms by using various process with the best results compared to the other related works.

The thesis consists of five chapters.

Chapter 1, introduction, includes the introductory part of the face detection systems, i.e., the background, face detection problem and their importance's, related works and organization of the thesis.

Chapter 2, high performance face detector using UKF, concerns with a high performance algorithm for human face detection in still image. The algorithm has been developed for increasing the face detection rate under different environmental

conditions. In this chapter, the skin color detector is modified by combining with the low pass filter, Sobel edge detector and the modified Viola Jones eye detector. The Haar cascade classifier is modified by using the clustering algorithm. The modified algorithms are then combined together with the Unscented Kalman filter (UKF) in the face detector. The use of the UKF in case of the face detection algorithm simply reflects the novelty of the detector. The UKF is used for removing the film grain noises from the still image. Film grain noises can be removed only by using the UKF. To clarify the effectiveness of our proposed algorithm, it is compared with other face detection algorithms through the benchmark tests using different facial databases and the ROC curves are drawn. Especially, the noisy image problem has been solved by an application of UKF. Then, the proposed algorithm has the highest face detection rate compared with the other detection systems.

Chapter 3, robust face detector for illumination variant images, includes a novel approach of the implementation of the stochastic resonance (SR) for the very first time in the field of face detection. In this chapter, a proposed algorithm has been designed by using the SR for image enhancement. To increase the visibility of the images taken in a dark environment and images taken under different illumination variant conditions, the SR has been modified and an image enhancement system has been developed using the modified SR. The enhanced images are then passed to the face detector developed in the first chapter and checks the presence of the face in the given illumination variant images. To bring the robustness in the face detection system to overcome with image noises and illumination variant at a time, image enhancement process has been combined with the face detector proposed in the previous chapter. The application of the modified SR gives the excellent result on face detection for illumination variant images.

Chapter 4, face detection algorithm for occluded facial images, includes the novel approach for detecting faces and facial features from the occluded images. .geometrical approach for detecting the presence of the facial components and the face from the given occluded images. The geometrical approach of three triangle method is used for locating the presence of the hidden facial features in an occluded image. In this chapter, a system has been developed that detects the presence of the facial features and the faces from the still images even the facial components are occluded. In this system, the geometrical position of the facial components is calculated by using the facial geometry which calculates the distance and the location of the facial features and the width of the face. The system first extracts the eyes, nose and mouth also known as the facial features by using the skin color model and the Haar cascades. The geometrical model is then applied to the extracted features using the three triangle method that calculates the height, width, distance and the position of the extracted features. Then, the proposed face detector detects the presence of a face in an image even with an occlusion. The combination of the three triangle method with UKF and the modified Haar cascade classifier represents the novelty of this proposed system. Experiments on various images under different conditions have been performed, using different facial databases to clarify the effectiveness of the proposed method. Thus, high performance of the face detector has been upgraded.

Chapter 5, overall discussion and conclusions, includes the overall discussion on the effectiveness of this research, also present the pros and cons of the research.

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Chapter 1

Introduction

1.1 Background

The expressive three dimensional objects can be known as a face. Every human being has their own face. The process of locating the position of the face in an image is known as face detection. It detects facial features and ignores anything else. The process is performed either by using still or video images. In this research, the still images are used for face detection. The system detects the face by the skin color region of the face and the shape of the head along with the presence of the facial features like eyes, nose and mouth. In case of the grayscale images, the Haar features are calculated to find the facial features.

There seems to be a lot of applications and systems applied for face detection, but developing a system that will increase the face detection rate based on the static position of the face on an image will help to make the face detection system more advanced and crucial. A lot of face detection algorithms [1-1] have been developed till now, but the face detection rate haven't reached to the 100%. It is due to the present of different environmental conditions in an image.

The environmental conditions in an image are image noise, illumination variant images, partially occluded images, rotated images, pose, expression etc. To increase the face detection rate, these conditions have to be cleared. In this research, a novel face detection algorithm that works on these environmental conditions of image noise,

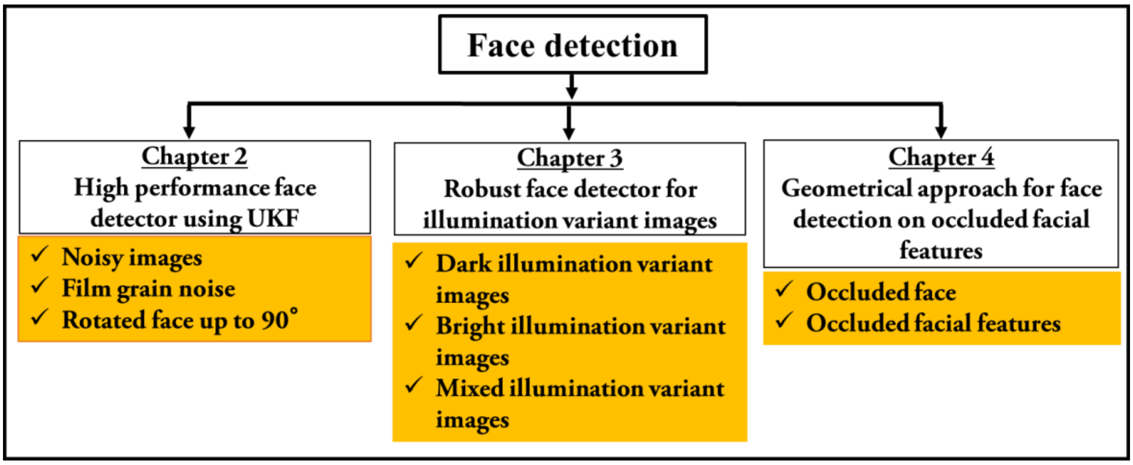


Fig.1.1. Diagrammatic representation of my thesis status

illumination variant images and occluded facial features is developed for increasing the face detection rate. The diagrammatic representation of the thesis status is shown in figure 1.1.

As a first approach, a face detection system [1-2] is developed by combining and modifying the different face detection algorithms such as Haar cascade classifier [1-3], skin color detector [1-4] and Viola Jones eye detector [1-5] along with the image processing tools. To solve the problem of the noisy images especially the film grain noises [1-6], the "Unscented Kalman filter process" [1-7] is used in the system. The use of the Unscented Kalman Filter (UKF) process in the face detector reflects the novelty of the first approach.

Similarly, as a second approach, a system is developed to detect the face from the illumination variant images. The Stochastic Resonance (SR) [1-8] is modified and applied it to the face detector [1-2]. This process first enhances the illumination variant images, extract the image candidates and detect the presence of the face in an image. This idea is developed from the idea of SR without tuning by Collins et al. [1-9].

The modified SR technique for image enhancement idea [1-10] is a new approach as a pre-processing for face detection. The use of stochastic resonance in the face detection process is being implemented by us for the first time. These two points really reflects the novelty of the second approach. The images after being enhanced and made visible are sent to the high performance face detector for detecting the presence of the faces in an image. The effectiveness of this approach is clarified by preforming several experiments.

As a third approach, a system is developed for detecting the presence of the facial features and the face from the partially occluded facial images. The three triangles geometrical model [1-11] for locating the position of the facial features is being used. Different from the other process of geometrical model [1-12], the generation of three triangles by using the detected eyes and nose as the first, detected nose and the mouth as the second and detected eyes and mouth as a third triangle.

The formation of these three triangles is fruitful for obtaining the position of the facial features, so whenever a single triangle can be developed from the extracted facial features, the face can be detected even in different conditions of occlusion. The three triangle method combined with the UKF, modified Haar cascade classifier and modified skin color detector reflects the novelty of the third approach.

The changes, modifications and the differences between the proposed algorithm and the related researches are mentioned in this thesis clearly. Finally, the effectiveness of the proposed algorithm is clarified through the benchmarking process using face databases of CMU-MIT [1-13], INRIA Graz-01 [1-14], MIT training sets [1-15], and FDDB datasets [1-16].

1.2 Face detection problems and their importance

Face detection is the process of determining whether or not a sub-window of an image belongs to the set of images of a face. Thus, anything that increases the complexity of the decision boundary for the set of images of the faces will increase the difficulty of the problem, and possibly increase the number of errors the detector will make.

There are many sources of variability in the face detection problem. These sources are outlined below. The problems or the environmental conditions associated with the face detection are already mentioned above. The three main environmental conditions being solved through the current research can be attributed to the following factors: (1) Image noise, (2) Illumination variant image and (3) Occluded facial feature.

Image noise**:** The photos taken with digital cameras are the random pixels scattered all over the photo which are the unwanted variations in the image. It is very much similar to the film grain effect in the film photography. The image noise usually occurs when the picture is taken in a low light or very slow shutter speeds or very high sensitivity modes are used.

There are several noises in image, among them, film grain noise, Gaussian noise, salt and pepper noise, shot noise, quantization noise, antistrophic noise are often seen in still images. These noises are the main factor for face detection from the image. Especially, the film grain noise [1-6] is one of the most complicated type of noise in the image, which degrades the quality and the visibility of the image. As, film grain noise is one of the complex type of noise, the Unscented Kalman Filter (UKF) [1-17] is used for removing the film grain noise from the image because other noise filters are not able to clear the film grain noise. The example of the film grain noise image is shown in figure 1.2.

It is necessary to remove these types of noise from the image, because noise causes a wrong conclusion in the identification of the images in authentication and also in the pattern recognition process. The noise embed in to an image document affect the performance of the face recognition algorithms in real. To detect the various features of the face from the image, the removal of noise should be the first step. If the problem of the face detection from the noisy image is solved in the still images, it can be applied in the video images and the face recognition system as well.

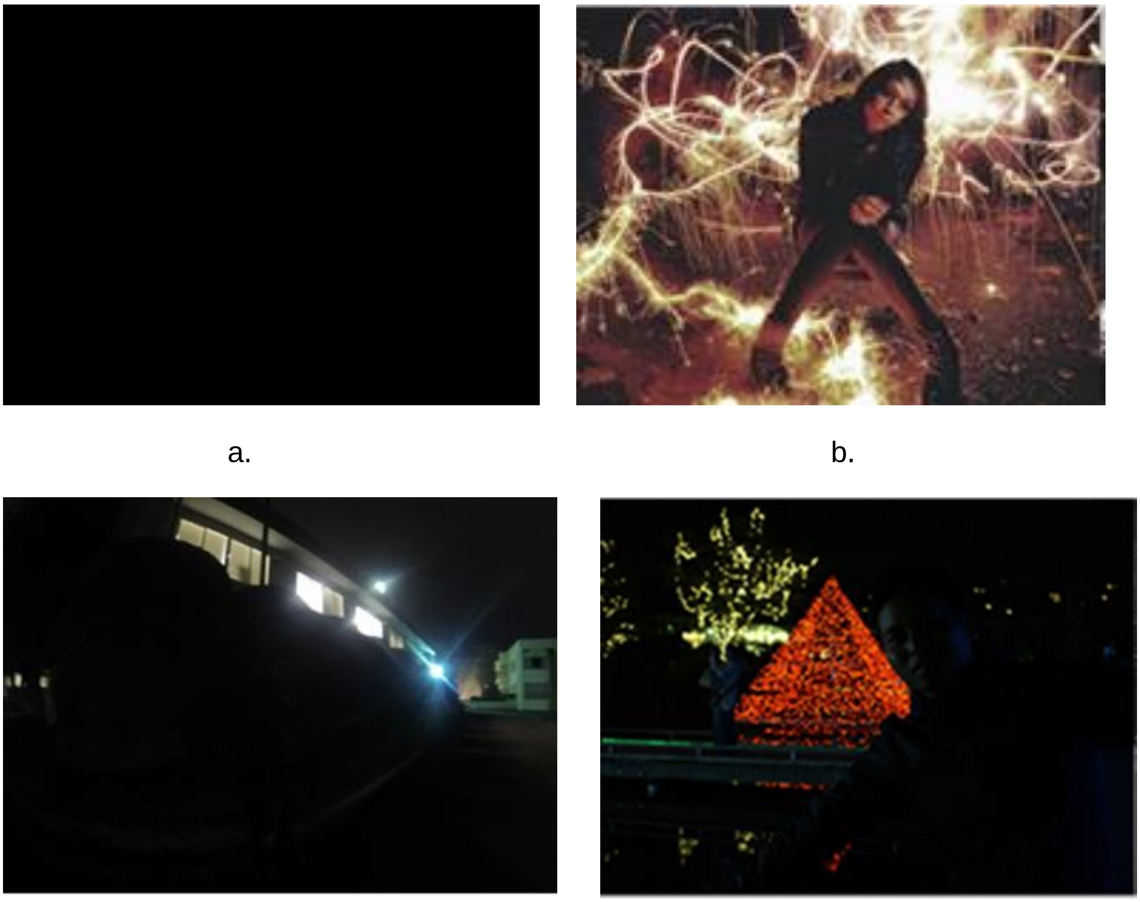
Fig.1.2. Images showing the presence of the film grain noise in an image.

Illumination variant images**:** The images taken under different illumination variants. These types of images can be the dark images or the brightest images. The images taken in a dark environment without any lights are considered as the dark image whereas, the images taken under the high beam of light are considered as the bright image. If both the dark and the bright portion are included in the image, they are called mixed illumination variant image.

In these type of images, it is very hard to detect the presence of the face, because the faces or image candidates are not seen properly, which means the face detector cannot detect the properties of the face required for face detection. In such cases, the image have to be enhanced at first. The stochastic resonance [1-8] is used for image enhancement.

The figure showing the illumination variant images is shown in figure 1.3 a, b, c and d. The images in figure 1.3 a, c and d are the original images taken for this research and the 2b image is downloaded from the internet from the author permission.

If the problem of face detection from the illumination variant images can be solved, this system can be used in the security or surveillance cameras, applied in the movies without the light effects and can be used in the vehicles for preventing the road accidents at dark nights.



a. b.

c. d. .

(a). Dark image

(b). Bright image

(c). & (d). Mixed illumination variant images

Fig. 1.3. Illumination variant images

***Occluded facial features*:** The partial visibility of the face or the facial features in a facial image is known as occlusion. A face is occluded, if some area of the face is hidden behind an object like a mask, sunglass, beard, hand or we can say the face is partially visible.

Facial occlusions can degrade the performance of the face detection system. If any part of the face is invisible then it is very hard to locate the presence of the other facial features and the face in an image.

a. b. c.

(a). Face occluded by mask

(b). Mouth occluded by hand

(c). face occluded by head and object

Fig.1.4. Occluded facial images (b, c are the images from FDDB database.)

The geometrical approach [1-10] is used for detecting the presence of face in an image. The image showing the examples of occluded facial features is shown in figure 1.4.

If the problem of occluded facial feature detection is solved, it can be used in the area of securities, as well as for the person's identification and recognition. Several applications like surveillance or robotics, a real-time system which rely on face detectors will be fast and accurate as well as have low memory overhead.

1.3. Related works

In the current thesis, a high performance face detector is developed for clearing the problems of image noise, illumination variant images and the occluded facial features. Many novel face detection methods have been proposed till now being based on these problems, but they still lacks the accuracy and the true positives. A detailed review over works in the face detection related to the first approach can be found in Ref. [1-18] and

[1-19]. Yang [1-18] provided an approach combining multiple color models for stable color based face detection.

Several researches have been done regarding the success of Viola Jones algorithm [1-20] which describes about the Haar feature calculation for face detection. The process of detecting and aligning faces by image retrieval process and landmark localization [1-21] shows the face detection process performed under different environmental conditions of occlusion, facial appearances, and pose estimation.

The LAB features [1-22] have been developed from the inspiration of Haar feature and local binary pattern [1-23] for face detection, these process hold a good result for face detection but still lacks the highest face detection rate. Erdem et al. [1-24] combined the Haar cascade classifier and skin color detector, but were limited in these two processes only.

Luo [1-25] proposed a face tracking system using modified Viola-Jones method combined with the Kalman filter. However, these studies are applications of the Kalman filter for tracking. Kovesi [1-26] have suggested the image de-noising process but is focused on video images and it doesn't work on film grain noise.

In order to overcome with the environmental difficulties of illumination variant images, the contrast adjustment process has been applied by T. Sim and T. Kanade [1-27] for the different illuminating examples, whereas S. Hayashi and O. Hasegawa worked on the low resolution image [1-28]. These processes work properly on some images, but still there are some illumination variant conditions which are not satisfied with these methods.

The current approach is different from the state of the art of SR based techniques used in case of image enhancement. A large number of techniques [1-29] [1-30] have focused on the enhancement of gray level images in the spatial domain which includes histogram equalization, gamma correction, high pass filtering, low pass filtering etc.
R.K. Jha et al [1-31] proposed two SR based techniques for enhancement of low contrast images by using Dynamic stochastic resonance technique in DWT domain for enhancing the images that are dark, grayscale and colored perception for the improvement of the input signal through the addition of external noise.

Peng et al. [1-32], used non dynamic stochastic resonance for improving the system performance of adaptive histogram equalization by using SR in medical images. The intrinsic noise of image for contrast adjustment is used in their technique which is capable of enhancing the image without spot artifacts, blocking and ringing. The images used in this process are the dark images that are made dark by the contrast adjustment, totally different from the original images taken in a dark or bright environment.

Similarly, to overcome up with the environmental conditions of occluded facial features, face detection approaches have been classified into knowledge-based [1-33], feature invariant [1-34], template matching [1-35] and appearance-based [1-36] methods as a global approach. In recent years, the component based approaches have produced better results than global approaches. The component based approaches can be used to construct detectors that can handle partial occlusions [1-37].

Similarly, Naser and Soderstrom [1-38] have used Principal Component Analysis (PCA) [1-39] for occluded image reconstruction. The geometric based approaches [1-40] uses width, length and angle information of the facial points for face detection. Classic approaches to 2D alignment include deformable templates [1-41], Active Appearance Models (AAMs) [1-42], [1-43], [1-44] and elastic graph matching [1-45].

Alignment with full 3D models provides even richer information at the cost of additional computation [1-46], [1-47]. A key difficulty in most of these approaches is the dependence on iterative and local search techniques for optimizing model alignment with a query image. This typically results in high computational cost and the concern that local minima may undermine system performance.

1.4. Organization of the thesis

The current thesis is divided into five chapters.

Chapter 1 is the introduction, where the introduction and background along with the types of problems related to face detection are explained. The environmental conditions, which affects the face detection are described along with the problems handled in this thesis.

Chapter 2 of the thesis is related to the “High performance face detector using UKF” concerns with a high performance algorithm for human face detection in still image. The algorithm has been developed for increasing the face detection rate under different environmental conditions. In this thesis, the skin color detector is modified by combining with the low pass filter, Sobel edge detector and the modified Viola Jones eye detector.

The Haar cascade classifier is modified by using the clustering algorithm. The modified algorithms are then combined together with the UKF in this process. The use of the UKF in case of the face detection algorithm simply reflects the novelty of the current process. The UKF is used for removing the film grain noise from the still image. The film grain noise can be removed only by using the UKF.

To clarify the effectiveness of the proposed algorithm, it is compared with other face detection algorithms through the benchmark tests using different facial databases and draw the Receiver Operating Characteristic (ROC) curve. The ROC curve along with the experimental results and the process will be presented in this chapter. The paper related to this chapter is published in the "International Journal of Information and Electronics Engineering (IJIEE) [1-2].

Chapter 3 of the thesis is related to the "Robust face detector for illumination variant images" includes a novel approach of the implementation of the stochastic resonance for the very first time in the field of face detection. In this chapter, the algorithm is designed by using the Stochastic Resonance (SR) for image enhancement.

To increase the visibility of the images taken in a dark environment and images taken under different illumination variant conditions, the stochastic resonance is modified to develop an image enhancement system. The enhanced images are then passed to the face detector, developed in the second chapter and check the presence of the face in the given illumination variant images.

To bring the robustness in the face detection system to overcome with the image noise and the illumination variant images at a time, these two process of image enhancement and face detector are combined together. The process along with the experimental results and the calculated processing time will be presented in this chapter. The paper related to this chapter is published in the "Journal of the Institute of Industrial Application Engineers" (JIIAE) [1-10] and "ACM Digital Library" [1-48].

Chapter 4 of the thesis, “Face detection algorithm for occluded facial images” includes the novel geometrical approach for detecting the face and facial features from the occluded images. The geometrical approach of three triangle method is used for locating the presence of the hidden facial features in an occluded image.

In this chapter, a system is developed, which detects the presence of the facial features and the face from the still images even the facial components are occluded. In this system, the geometrical position of the facial components are calculated by using the facial geometry which calculates the distance and the location of the facial features and the width of the face. The system first extracts the eyes, nose and mouth also known as the facial features by using the skin color model and the Haar cascades.

The geometrical model is then applied to the extracted features using the three triangle method that calculates the height, width, distance and the position of the extracted features. The proposed face detector then detects the presence of the face in an image even with an occlusion. The combination of the three triangle method with UKF and modified Haar cascade classifier represents the novelty of our proposed system. The paper related to this chapter is published in the “Journal of the Institute of Industrial Application Engineers” (JIIAE) [1-11].

Chapter 5 of the thesis is related to the “Overall Discussion and Conclusions” includes the overall discussion of the thesis, where the pros and cons of the research are presented. The discussion on the computational time and the effectiveness of this research compared to the related works will be included in this chapter.

Chapter 2

High performance face detector using UKF

2.1. Introduction

This chapter concerns with a high performance algorithm for detecting human faces in a still image. The process of locating the position of the face in an image is known as face detection. The process is performed either by using still or video images. This research uses still images for face detection.

The research combines and modifies the different types of algorithm in this chapter. Nowadays, the face detection process has become very common in computer vision systems. There seems to be a lot of applications and systems applied for face detection, but developing a system that will increase the face detection rate based on the static position of the face on an image will help to make the face detection system more advanced and crucial.

A new algorithm is developed by using the different face detection algorithms and face detection process in a different manner. The algorithm is developed in such a way that it combines the skin color detector [2-1], the Haar cascade classifier [2-2], the Viola Jones eye detector [2-3] and the Unscented Kalman Filter (UKF) process [2-4] for detecting the faces in an image.

The skin color detector is slightly modified by adding the low pass filter [2-5] for removing noise from an image. The Sobel edge detector [2-6] operates the edges of a face. Moreover, by selecting the skin color region of the face a facial candidate is detected. The detected facial candidate is then passed to an eye detector [2-7] for checking the presence of eyes in a face. The Haar cascade classifier is modified by combining with the clustering algorithm [2-8]. It even helps in increasing the accuracy of the face detection rate.

After combining these major face detection algorithms, a good face detection rate was obtained, but still some high frequency Gaussian noises [2-9] and film grain noises were found in the images. So the UKF [2-10] was used to remove these noises from a detected image, the UKF remove the noise from the images at first and then passes the noise filtered images to the modified Haar cascade classifier [2-11].

The modified Haar cascade classifier is used for detecting and verifying the face in an image under the different environmental conditions such as scale, the absence of the structural component, occlusion, illumination variation, color region, multiple face detection and so on.

In this chapter, the applied process are positioned in a proper way. The reason related to the positioning of the different process is mentioned in this paper. The reason for using a low pass filter and the Unscented Kalman Filter (UKF) process instead of using the Extended Kalman Filter (EKF) process [2-12] are also mentioned in this thesis.

The applied process is slightly different from the other face detection algorithms implemented yet. The changes, modifications and the differences between the proposed algorithm and the others are mentioned in this thesis clearly. As for evaluation metrics, the Receiver Operating Characteristic (ROC) curve [2-13] is used. Finally, the effectiveness of this proposed algorithm is clarified by benchmarking using image databases of CMU-MIT [2-14], INRIA Graz-01 [2-15], MIT training set [2-16], and FDDB datasets [2-17].

In the area of face detection, many novel methods have been implemented. Yang [2-18] provided an approach combining multiple color models for stable color based face detection. Several researches have been done regarding the success of Viola Jones algorithms [2-2] which describes about the Haar feature calculation for face detection.

The process of detecting and aligning faces by image retrieval process [2-19] and Landmark localization [2-20] shows the face detection process performed under different environmental conditions of occlusion, facial appearances, clutter and pose estimation. The LAB features [2-21] have been developed from the inspiration of Haar features and Local binary pattern [2-22] for face detection, which holds a good result for face detection but still lacks the highest face detection rate.

2.2. Proposed algorithm using UKF

2.2.1. Structure of the proposed algorithm using UKF

The structure of the proposed algorithm is reflected by the flow diagram shown in figure 2.1. The concept of this algorithm is to show the combination process of different face detection algorithms for developing one best face detection algorithm that includes different features of face detection process. From the survey and researches on face detection process, the concept of the face detection algorithm has been developed by modifying the face detection algorithms in a better way for obtaining the best result.

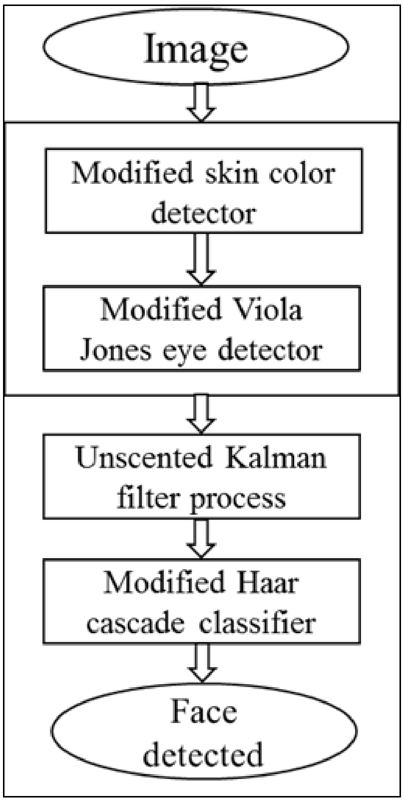


Fig.2.1. Proposed algorithm for face detection using UKF

The still image is sent to the modified skin color detector [2-11] and then the modified eye detector as the first process. The skin color detector helps to locate the skin skin color region of a face and gives color information of the image. The modified Viola Viola Jones eye detector is adapted to detect the eye from the image of the detected facial region obtained from the skin color detector.

Similarly, the image is sent to the Unscented Kalman filter process (UKF) for removing the noises from the image. The UKF is basically used for removing the film grain noise from the image. Then, the image is passed to the modified Haar cascade classifier for classifying the facial image into black and white region and then calculating the facial region of the image by using integral sum method [2-23].

Moreover, Viola Jones eye detector [2-2] is used in order to verify detected faces obtained from Haar cascade classifier. The Haar cascade classifier is modified by combining with the clustering algorithm.

2.2.2. Modified skin color detector

In this thesis, a modified skin color detector is developed by combining the basic skin color detector with the low pass filter, Sobel edge detector and the color region detector as shown in figure 2.2.

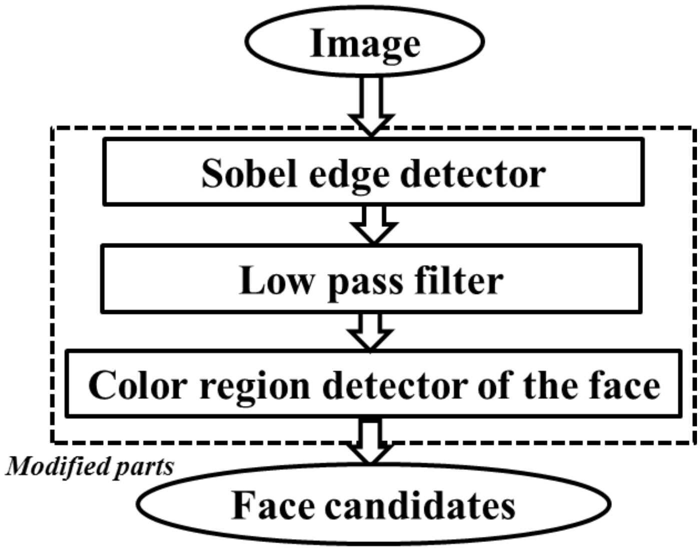
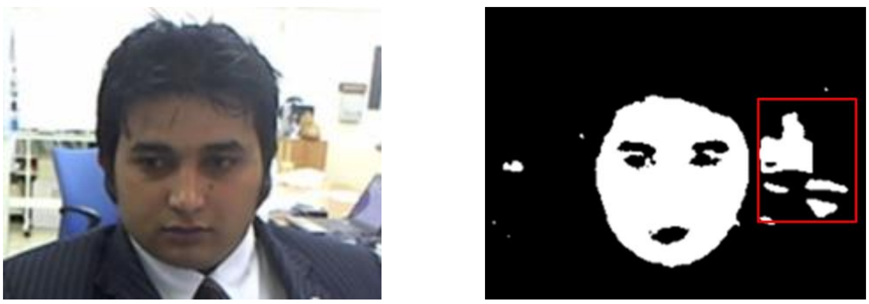


Fig.2.2. Modified skin color detector

Skin color region detector: The skin color region detector in figure 2.2 is an algorithm that automatically recognizes skin tone and detects a face image. This detector detects the color region of the face which is similar to the color of skin.

The pseudo-code for the skin color detector is shown below.

procedure Skin color detection
//texelIn is a sample texture region
begin
   for each pixel and each channel of texelIn **do**
      Compute blending_texel value using texelIn
   Compute each distance class based on each pixel position in blending_texel
   for each channel of blending texel **do**
      for each distance class of blending_texel **do**
         Compute mean and standard deviation values;
         Compute SVC of distance class;
      end for;
      Compute SVC of the color channel;
   end for;
   return (SVC_R, SVC_G SVC_B) for each channel in RGB space
end



(a) Original image (b) Detected skin color region

Fig.2.3. Example executing skin color region detector

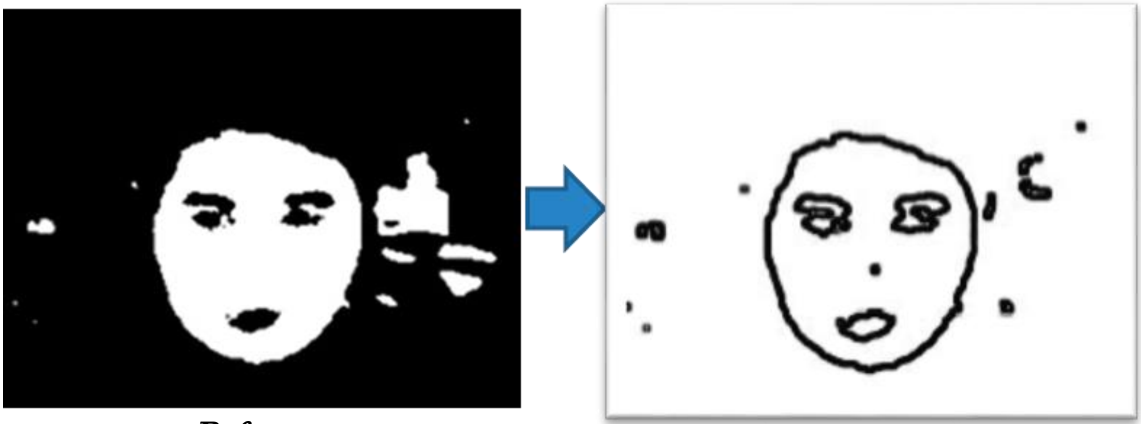
An applied example of the skin color region detector along with the example image is shown in figure 2.3. Although the skin color region is detected in this figure, there are still some pixels, which are detected as skin pixels but actually are not skin pixels, they are only similar to the color of the skin. These pixels are actually called noise or the false skin color region.

Sobel operator: In case of the edge detection process, Sobel operator is simply used to perform and quickly to compute 2-D spatial gradient measurements on an image. The Sobel operator performs a 2-D spatial gradient measurement on an image and so emphasizes regions of high spatial frequency that correspond to edges.

This process helps us to detect the greatest regions that have the shape of face in terms of roundness and proportion. The image showing the edge detection by using Sobel operator is shown in figure 2.4, the before and after image reflects the effect of Sobel operator. The edge of the detected skin color region is detected in the after image.

The algorithm of the Sobel operator can be described as:

Input: A sample image.
Output: detected edges.
Step 1: Accept the input image.
Step 2: Apply mask *Gx* , *Gy* to the input image.
Step 3: Apply Sobel edge detection algorithm and the gradient.
Step 4: Masks manipulation of *Gx* , *Gy* separately on the input image.
Step 5: Results combined to find the absolute magnitude of the gradient.
Step 6: The absolute magnitude is the output edges.



Before *After*

Fig. 2.4 Before and after effects of the Sobel operator

Noise filter: In order to remove high frequency noise, a low pass filter by a 5 x 5 mask is implemented in our system. A low-pass filter, also called a "blurring" or "smoothing" filter, averages out rapid changes in intensity. The simplest low-pass filter just calculates the average of a pixel and all of its eight immediate neighbors. The process is repeated for every pixel in the image.

Every pixel of the block is set to white, if the number of white pixels is more than half of total pixels in that block; else, this block is transformed to complete black block. This process is used to filter the high frequency noise from the detected skin color region. A result of the low pass filter execution is shown in figure 2.5 (b).

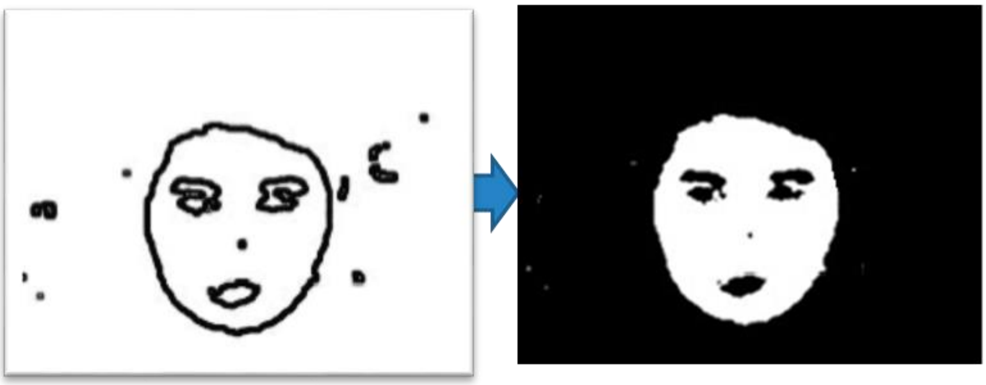
The algorithm of the 5 x 5 low pass filter can be described as:

Step 1 Consider a 5×5 block in the image of size $H \times W$.

Step 2 Count total number of 1's in the block.
Let the count value be S.

Step 3 If $S > 20$ then
convert every pixel of the block to 1,
else
convert every pixel of the block to 0.

Step 4 Move to step 1.



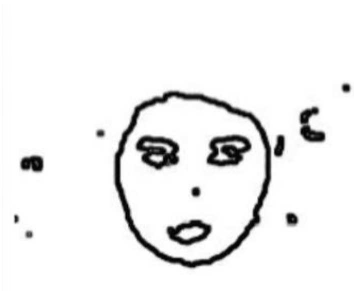
(a) Result of Sobel operator (b) Execution of low pass filter

Fig.2.5. Effect of low pass filter

Color region detector: After the greatest region of a facial shape is detected, the color region of the face is calculated. Once again and then a facial image is obtained with respect to the color space of the face. Finally the face is spotted and the facial candidates are detected. This process uses the skin color detector process but after filtering the noise from the extracted facial image and detecting the edge of the face. This can be known as the post process of our system. The figure 2.4 (c) reflects the color region detection of our process.

In this thesis, the above mentioned process are combined to develop the modified skin color detector. The high frequency noises are cleared by using the low pass filter, the edges of the face have been created and detected by using the Sobel edge detector, the skin color region is detected by using the color region detector and then the facial candidates are detected by our process.

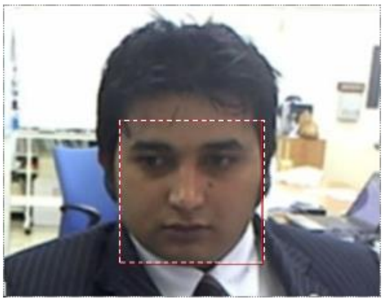
An execution example for our modified skin color detector is shown in figure 2.6. Figure 2.6 (a) is a the detected edge of a face using Sobel edge detector, , figure 2.6 (b) is noise filtered face image using low pass filter, figure 2.6 (c) is the detected color region of the face using color region detector and figure 2.6 (d) is a detected face candidate. The noises and errors detected from basic skin color detector is cleared by using the modified skin color detector.



(a). Face edge detection

(b). Noise filtered region

(c). Color region detection



(d). Face detected

Fig.2.6. Execution processes of modified skin color detector

Then, the skin color region detector is modified by combining with the Sobel operator, low pass filter and color region detector. The differences between the skin color region detector and the modified skin color detector is the removal of the high intensity noise that are similar to the skin pixels as shown in figure 2.6(b), and the facial edges can be calculated for the proper facial candidates. The error in figure 2.3(b) or 2.4(a) occurred by using the skin color region detector is cleared by using the modified skin color detector.

2.2.3. Modified Viola Jones eye detector

The eye detector is the process of detecting the region of the eyes in a face. To give a continuity to the proposed high performance face detector and accuracy to the modified skin color detector, we are using the eye detector in the current process. There are many eye detection algorithms [2-3] developed till now. In this system, the Viola Jones eye detector is slightly modified as shown in figure 2.7 to make the algorithm work with the modified skin color detector. The geometrical test process is applied for modifying the eye detector.

The Viola Jones eye detectors detect the presence of either of the eye in a face, but the modified eye detector algorithm checks the presence of two eyes in a face as shown in figure 2.8. The geometrical test includes the eyes-center distance test, the eye pair distance test and the eye shape test. The eye center distance test is used for calculating the distance of eyes from the center of the face. The eye pair distance test is used for checking the distance between the eye pair and the eye center distance. The eye shape test is used to check the eyes shape.

The suggested algorithm is composed of iterative thresholding and geometrical tests. The thresholding ratio is set being based on maximum pixel value in the facial image. Experimental results demonstrate that selecting too high thresholding ratio is not proper and sometimes it is dangerous to start with it. We found out “0.7*maximum value” is the best to start with.

The geometrical tests are then applied on eye candidates obtained after thresholding. If two regions found that satisfy all the tests, they considered as eyes and algorithm finishes, else algorithm restarts by lowering the threshold ratio. The next ratio is obtained by previous minus 0.1 (ratio = previous ratio - 0.1). This iterative task would be continued till both eyes are detected by algorithm.

The geometrical tests satisfies the presence of two eyes in a face and in case, if two eyes are not detected, the threshold of the detected eye is made to decrease and once again the process is repeated for getting the two eyes in a face. The performance of the modified eye detector is 99.9% in case of frontal face image, but the problem of occlusion occurs when both of the eyes are not visible in a face.

The algorithm for the modified Viola Jones eye detector is shown in figure 2.7. In comparison to the Viola Jones eye detector, the modified Viola Jones eye detector detects the presence of the two eyes in a face which is helpful for increasing the accuracy of the face detection, as shown in figure 2.8.

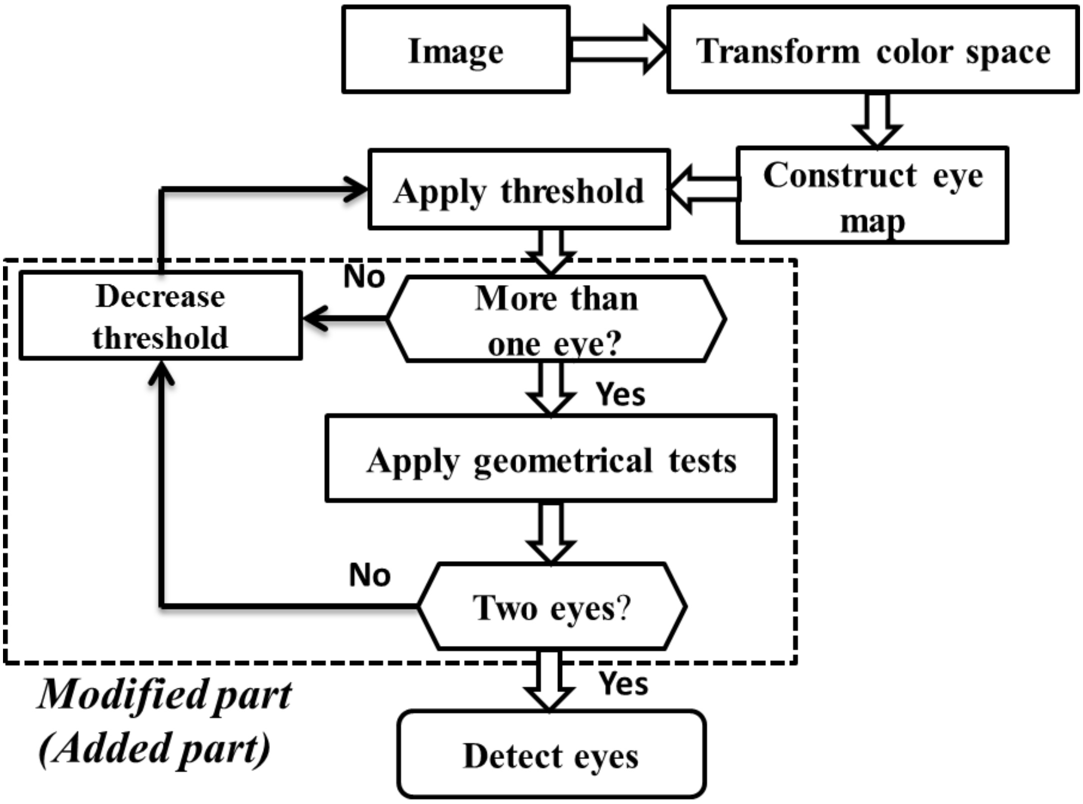
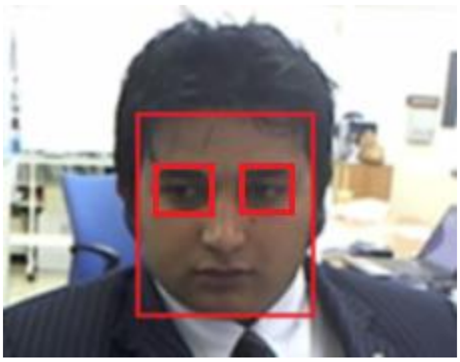


Fig. 2.7. Modified Viola Jones eye detector

Before (original V-J eye detector)



After (modified V-J eye detector)

Fig.2.8. Execution example of modified Viola Jones eye detector

2.2.4. Modified Haar cascade classifier

Haar cascade classifier is a feature-based algorithm that trains a classifier using many images of specific objects. The face detection algorithm proposed by Viola and Jones [2-23] is used as the base of our design. The face detection algorithm looks for specific Haar-like features of a human face. Haar features are digital imaging features used in object recognition as shown in figure 2.9. They owe their name to their intuitive similarity with Haar wavelets and were used in the first real-time face detector.

The algorithm for the Haar cascade classifier is shown below.

Input: a 24×24 image with zero mean and unit variance

Output: a $d \times 1$ scalar vector with its feature index f ranging from 1 to d

Set the feature index $f \leftarrow 0$

Compute feature type

for all (i, j) such that $1 \leq i \leq 24$ and $1 \leq j \leq 24$ **do**

  for all (w, h) such that $i + h - 1 \leq 24$ and $j + 2w - 1 \leq 24$ **do**

    Compute the sum S_1 of the pixels in $[i, i + h - 1] \times [j, j + w - 1]$

    Compute the sum S_2 of the pixels in $[i, i + h - 1] \times [j + w, j + 2w - 1]$

    Record this feature parametrized by $(1, i, j, w, h)$: $S_1 - S_2$

    $f \leftarrow f + 1$

  end for

end for

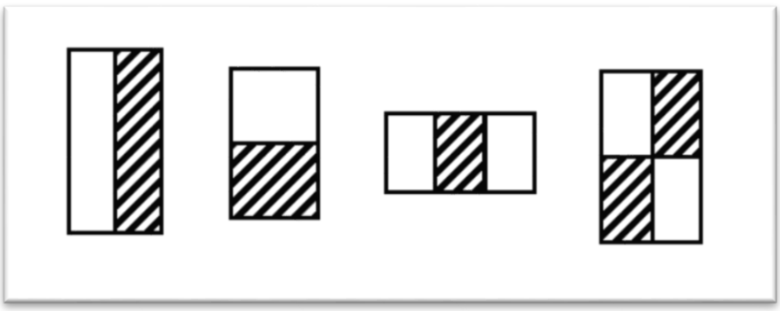


Fig.2.9. Haar Features

A Haar-like feature considers adjacent rectangular regions at a specific location in a detecting window, sums up the pixel intensities in each region and calculates the difference between these sums. Haar features are based on Haar wavelets, which are functions that consist of a brief positive impulse followed of a brief negative impulse. In image processing, a Haar feature is the difference between the sums of all pixels in two or more regions.

In the proposed high performance face detector, the Haar cascade classifier is used for detecting the multiple faces in an image, but sometimes the false face detections, no face detection and multiple detection in a face occurs. In order to overcome up with this problem, we think of modifying the Haar cascade classifier.

The Haar cascade classifier is modified by combining it with the clustering algorithm for the proposed system as shown in figure 2.10, because this algorithm can be used for basic pixel level to feature level for the classification of facial images. This process helps to reduce a cluster of many squares whose center points are very close (distance lesser than a tunable threshold) to one square. This reduces the false positive rates.

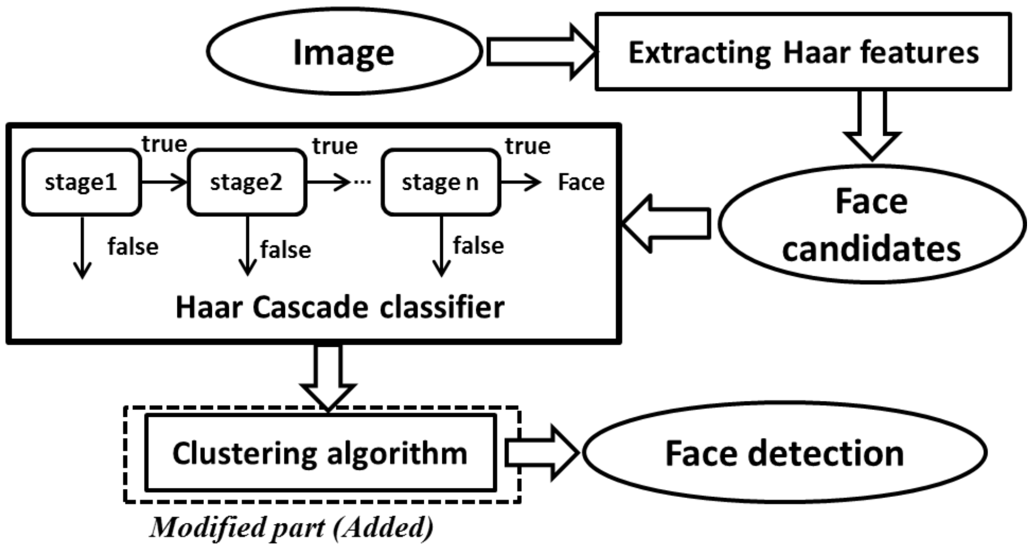
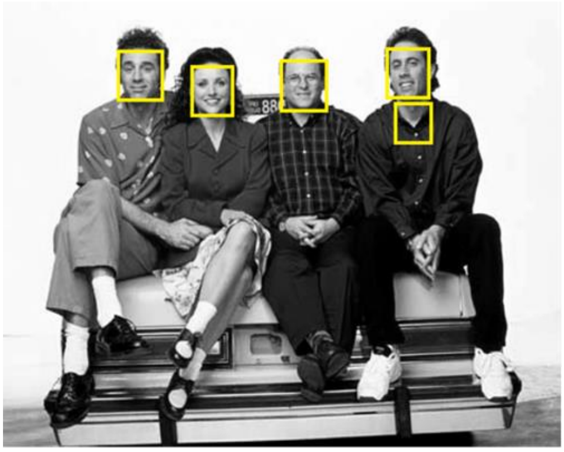
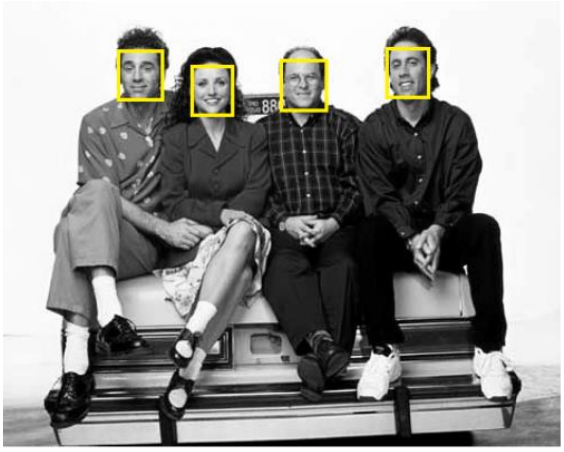


Fig.2.10. Modified Haar cascade classifier algorithm



Before (original Haar cascade classifier)



After (modified Haar cascade classifier)

Fig. 2.11. Execution examples of modified Haar cascade classifier

The number of squares that were "duplicates" of the reduced square per face is then called the "genuineness" of that face. The execution examples for correct face detection using the clustering algorithm together with some experimental results for Haar cascade classifier is shown in figure 2.11. The images used in this figure are taken from CMU-MIT database. The before and after images clearly reflects the effectiveness of the modified Haar cascade classifier.

The algorithm for the modified Haar cascade classifier is shown in appendix 6. In comparison to the Haar cascade classifier with the modified Haar cascade classifier, the modified Haar cascade classifier avoids the false face detection in the group face image as shown in the figure 2.11.

2.2.5. The Unscented Kalman Filter (UKF) process

The UKF is used for estimation of the film grain noise from the image and removing the film grain noise from the image. The film grain noises are present in the photographic film, where the film density is related linearly to the logarithm of the exposure. Film grain noise manifests itself as multiplicative non-Gaussian noise in the exposure domain, which results to the false face detection.

In case of the Image processing, the film grain noises that are not removed by the other noise filters can be removed by the use of UKF. The removal of noises in the images causes a drastic change in the face detection from an image. The regular noises can be filtered by using the other filters too, but the film grain noises are very hard to filter because the film grain noises are hard to identify as well.

There has been an excellent success in one dimensional (1D) nonlinear filtering by employing the UKF. Applying two dimensional (2D) Kalman filter to image noise reduction have begun by Woods [2-24], here the resulting filter is a general 2D recursive filter. They suggest that it is able to use to remove noises from still images. Therefore, we have used the UKF process in our algorithm for removing the noise from an image in our process.

The image prior is modeled as non-Gaussian and is incorporated within the UKF frame work using importance sampling. Image estimation based on the traditional autoregressive (AR) model often results in smoothed edges. A discontinuity adaptive Markov random field model is adopted to encode the statistical dependence among the neighboring pixels but with edge preserving capability. We employ importance sampling to estimate the statistics of this non-Gaussian prior and propagate them to the update stage of the UKF.

The Unscented Transformation (UT) [2-26] is a method for calculating the statistics of a random variable which undergoes a nonlinear transformation. The two dimensional UKF for image restoration [2-10] is used in this process. Film grain noise in an image is determined by the least squares method using the state equation and the measurement equation. The image is scanned by using the non-symmetric half plane (NSHP) model.

The image is scanned from the top left pixel, and scan the first column from top to the bottom. This process is applied for eight times and can achieve a better result with the noise filtered image. This process is the 2D UKF method [2-10] for clearing noises in a static image. A noise filtered image helps to increase the face detection rate. The before and the after effects of the UKF process is shown in Figure 2.12. The false positive are cleared after applying the UKF.

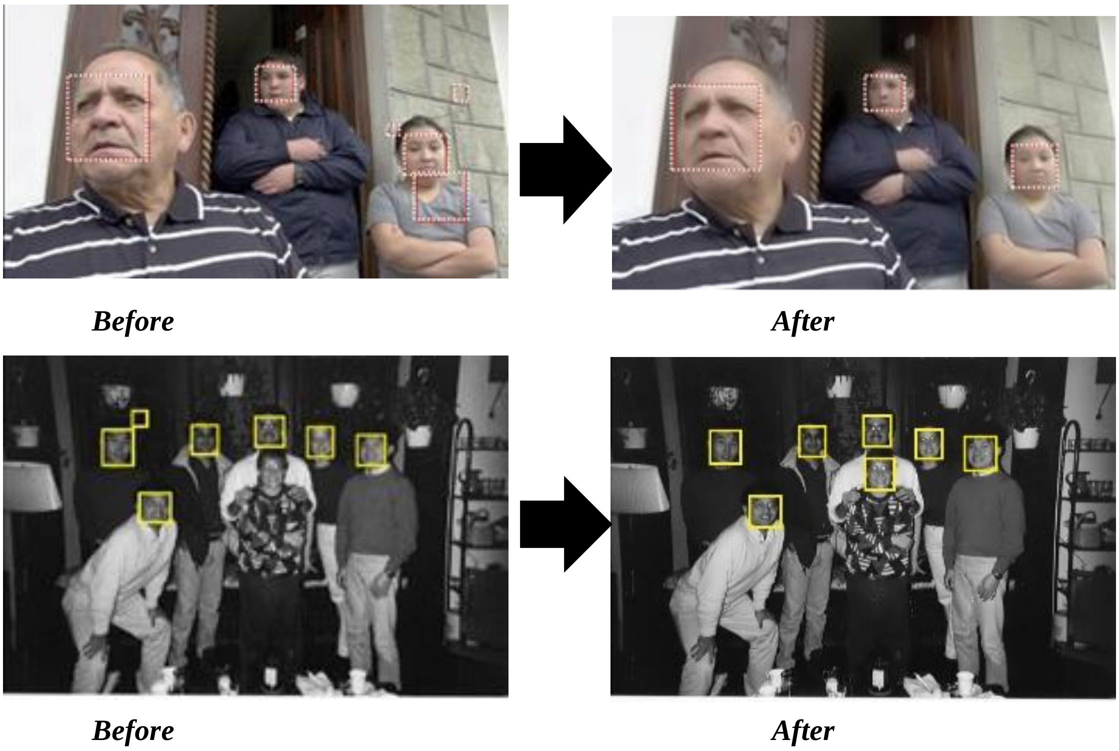


Figure 2.12. Effects of the UKF:

Comparing “Before” (without UFK) and “After” (using UKF)

The algorithm of the UKF process can be described as follows.

1. Initialize state vector and state covariance matrix: $\boldsymbol{x_0}$ **and** $\boldsymbol{P_0}$
2. Choose the sigma points: $\boldsymbol{x_k}$
3. Time update to estimate covariance: $\boldsymbol{P_{k/k-1}}$
4. Predict measurements: $\boldsymbol{z_{k/k-1}}$
5. Estimate the covariance and cross covariance: $\boldsymbol{P_{(xz)\,k/k-1}}$ $\boldsymbol{P_{(zz)\,k/k-1}}$
6. Calculation gain matrix: $\boldsymbol{K_k}$
7. Measurement update: $\boldsymbol{x_k}$ $\boldsymbol{P_k}$

Where $\boldsymbol{x_k}$ is the sigma points, $\boldsymbol{P_k}$ is Prediction estimates and $\boldsymbol{K_k}$ is the gain matrix. .

In the proposed algorithm, the Unscented Kalman Filter process is used instead of the Extended Kalman Filter (EKF) because the UKF yield performance equivalent to the Kalman filter for linear systems, yet generalizes elegantly to nonlinear systems without the linearization steps required for the EKF. The UKF consistently achieves a better level of accuracy than the EKF in systems with severe nonlinearities.

For comparison, the algorithm of EKF is shown below.

1. Prediction of states
2. Prediction of the covariance matrix of states
3. Kalman gain matrix
4. Update of the state estimation
5. Update of the covariance matrix of states
6. Initialization

EKF was also used for the experimentation and the result obtained was comparatively low than the Unscented Kalman filter's result. The ROC curve for showing the effects of UKF, EKF and without using Kalman filter in the proposed algorithm is shown in figure 2.13. The proposed algorithm using the UKF has comparatively highest face detection rate, so the UKF is used in our process.

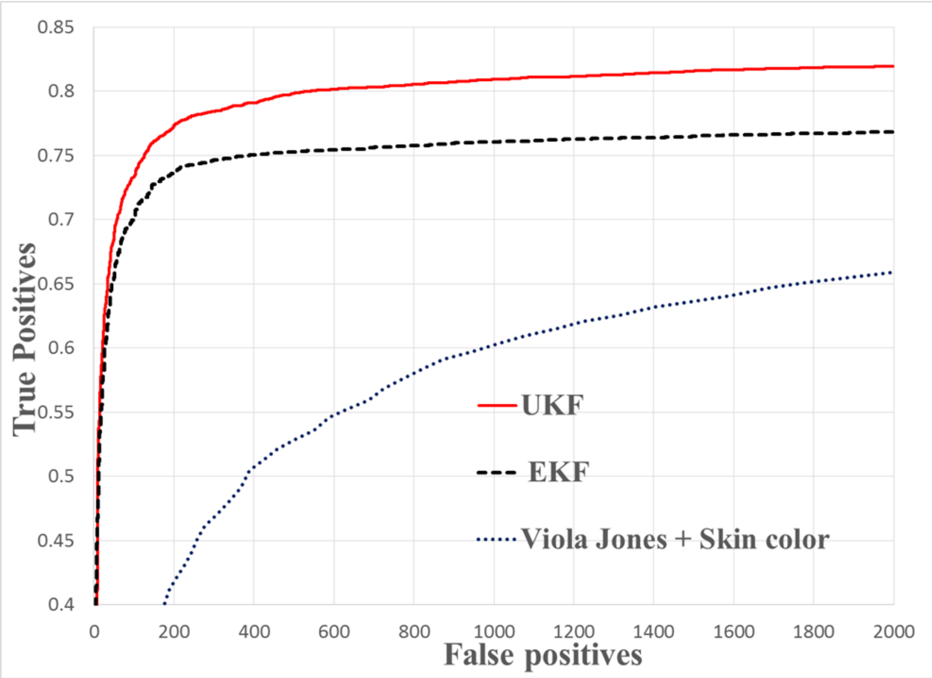


Fig.2.13. Comparison of EKF and UKF using DB3

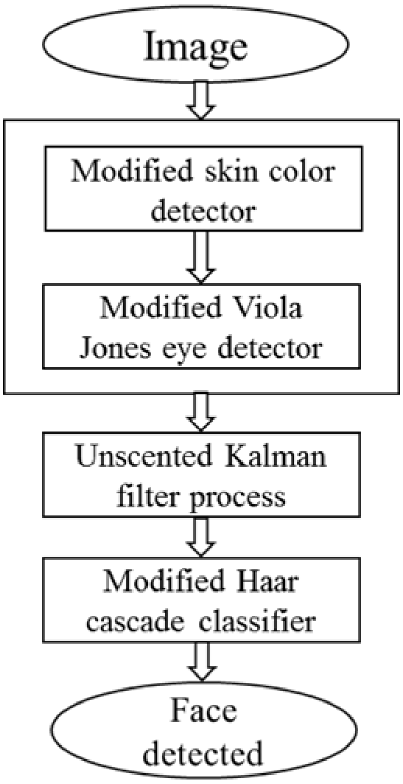


Fig.2.1. Proposed algorithm for face detection using UKFR (repeated)

2.2.6. Position or order of the applied process

The position or the order of the applied process in an algorithm plays a vital role. In the current process, the UKF is positioned after the modified skin color detector and before the modified Haar cascade classifier as shown in figure 2.1. In the modified skin color detector, the Low pass filter is used at the very beginning for filtering the high Gaussian noises from the images because it is easy to detect or create an edge from the noise filtered image.

After modified skin color detector, the images are once again passed towards the UKF for clearing the film grain noises that are still not being removed by the low pass filter. Those film grain noises takes part in the false detection of a face. We also tried to use the UKF before the modified skin color detector, but when the UKF is applied, the images becomes little blur, which means the modified skin color detector will results to a lot of false detections.

In case of the modified Haar cascade classifier, the Haar features are classified by using the Haar cascade classifier, which is also used for the face detection, but due to the duplication of the clusters in a group image, the clustering algorithm is used with the Haar cascade classifier, which results in the proper face detection with the true positives. The order of the different algorithms gives us a perfect result.

2.3. Experimental results and evaluation

2.3.1. Tools and databases used

The system was developed by using Visual studio 2010 and Open CV. The experiments are performed using the PC (i7-2600 CPU, 4GB main memory and Windows7 64 bit) and 1080M pixel web camera. The system detects the faces and eyes in a red square box. The detected region either correct or false is spotted in a red square box. In this paper, the detected region is highlighted by a white square dotted box for making the detected portion clearly visible.

The proposed algorithm is evaluated on four public data sets. The databases used in this research process are CMU-MIT database, MIT training sets, INRIA Graz-01 dataset and FDDB database. The CMU-MIT database, including 507 gray-scale frontal face images is categorized as Database 1 (DB1). Database 2 (DB2) is the combination of three different databases; CMU-MIT Database (DB1), MIT training sets and INRIA Graz-01 datasets. Database3 (DB3) is the FDDB database. The databases are set as follows.

DB1: **CMU + MIT test sets;** gray-scale images, including 507 front faces.

DB2: **CMU-MIT + MIT + INRIA Graz-01;** MIT database includes training set images with 2429 colors and gray-scale images, INRIA Graz-01 database includes 1316 color images with and without faces. The total number of images used DB2 is 507 + 2429 + 1316 = 4252 images. The images are color and gray-scale images taken under different environmental conditions.

DB3: **FDDB database;** including 5171 faces in a set of 2845 images.

2.3.2. Benchmarking: Receiver operating characteristics (ROC) curve

The two benchmarking tests are performed based on the above-mentioned databases, i.e., DB1, DB2 and DB3 to validate our proposed algorithm. For the tests, a benchmark testing support system has been developed. A two-class prediction problem (binary classification) is considered, in which the outcomes are labeled either as positive or negative. ROC curves are used to evaluate the position of the proposed algorithm.

ROC graphs are two-dimensional graphs in which true positive rate is plotted on the *Y* axis and false positive rate is plotted on the *X* axis. An ROC graph depicts relative tradeoffs between benefits (true positives) and costs (false positives). Given a classifier and an instance, there are four possible outcomes. If the instance is positive and it is classified as positive, it is counted as a true positive; if it is classified as negative, it is counted as a false negative. If the instance is negative and it is classified as negative, it is counted as a true negative; if it is classified as positive, it is counted as a false positive.

The true positive rate also known as hit rate and recall of a classifier is estimated as

$$true\ positive\ rate\ (tp) = \frac{\text{Correctly classified}}{\text{Total positives}}$$

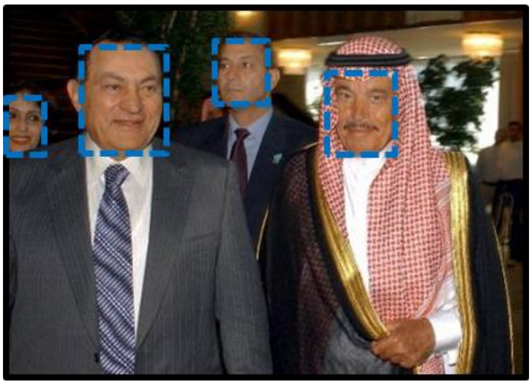
The false positive rate also known as false alarm rate of the classifier is estimated as

$$false\ positive\ rate\ (fp) = \frac{\text{Incorrectly classified}}{\text{Total negatives}}$$

Additional terms associated with ROC curves are

$$Specificity = \frac{1-tp}{fp+tp}$$

In order to validate the proposed algorithm for high performance face detector, we developed a C programming code for performing the benchmarking process of the proposed algorithm. The faces in the images are annotated by drawing the bounding boxes around all the faces. The program counts the true positives and false positives by the detection corresponding to the continuous image region where the detected faces from our system merge or overlaps the annotated region as shown in figure 2.14. The blue dotted box reflects the annotated region and the yellow box reflects the detected facial region.



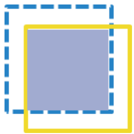
Before (Annotated region)

After (Detected region)

Fig.2.14. Annotated and Detected facial region for counting true and false positives

Each detection corresponds to exactly one entire face, no more, no less. In other words, a detection cannot be considered to detect two faces at once, and two detections cannot be used together to detect a single face. We further argue that if an algorithm detects multiple disjoint parts of a face as separate detections, only one of them should contribute towards a positive detection and the remaining detections should be considered as false positives and the curve is drawn. The curve holding the large area reflects the high detection rate.

To represent the degree of match between a detection *D* and an annotated region *A*, We employ the commonly used ratio of intersected cardinality to joined one:



$$Degree\ of\ match = \text{card}\ (A \cap D)/\text{card}(A \cup D)$$

The algorithm for the generation of ROC curve is shown below.

Construct a graph $G = \{V, E\}$, where V is the set of images, and E are all pairwise edges with weights as the ARG matching scores.

repeat

Compute the Laplacian of G, L_G.

Use the top m eigenvectors of L_G to project each image onto R^m

Cluster the projected data points using mean-shift clustering

Manually label each cluster as either *uniform* or *non-uniform.*

Collapse the *uniform* clusters onto their centroids, and update G.

until none of the clusters can be collapsed.

The system use the correct detection rate as opposed to the true positive for the y-axis of the ROC curve to facilitate comparison with other detectors. The x-axis is the false positive. The curve which holds the large area in both horizontal and vertical axis is regarded to be the best result or high performance. An area of 1.0 represents a perfect test where the true positives and false positive varies but an area of 0.5 represents a worthless test where true positive and false positive rates are quite similar.

2.3.3. Evaluation

A ROC curve shows the performance of our algorithm on DB1, DB2 and DB3 comparing with other face detectors in figure 2.15, 2.16 and 2.17 respectively. First, DB1 database is used for comparing the face detection rate between our proposed algorithm, Viola Jones face detector [2-21] and LAB method [2-21]. The ROC curve is drawn from the result of this test.

The ROC curve is shown in figure 2.15. The ROC curve shows our algorithm having the correct face detection rate higher than that of Viola Jones face detector and LAB methods. The correct face detection rate for Viola Jones face detector is 94.1% [2-21]. The LAB method shows a very good face detection rate that started with 90% to 96% with the constant ratio of face detection. But basically, the true positive rate can reach 1 when the false positive rate is 1, our proposed algorithm shows the face detection rate of 98%.

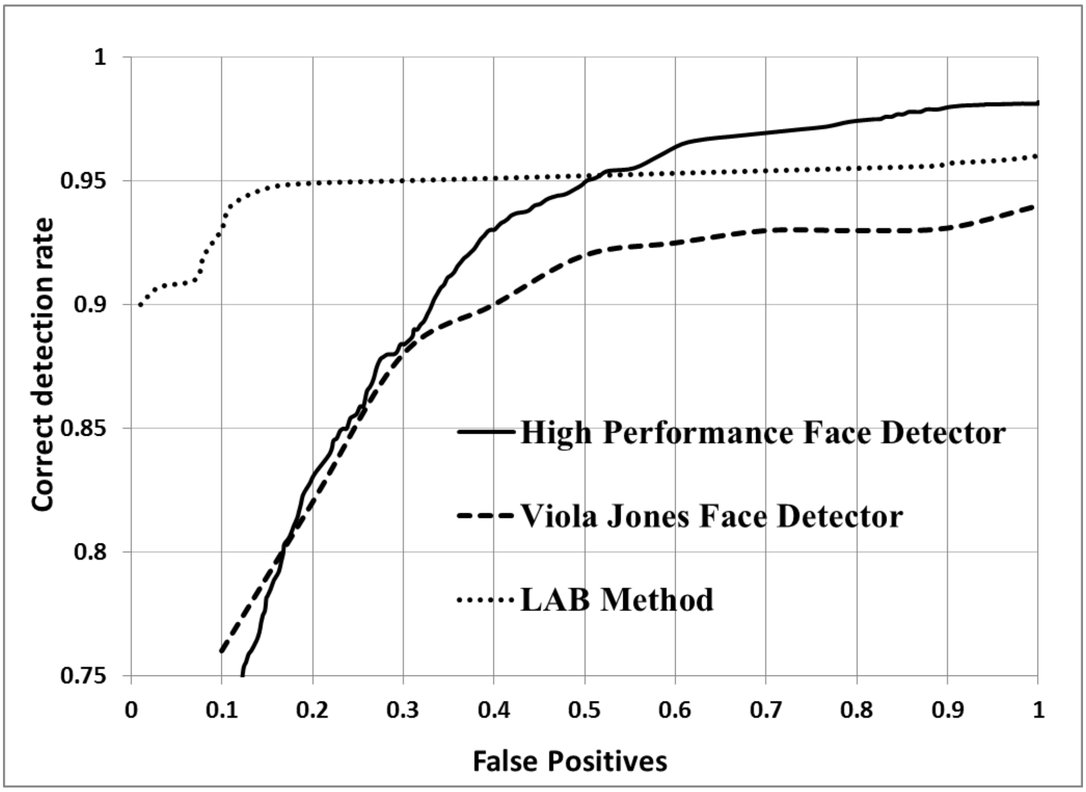


Fig. 2.15. Result of benchmark test for DB1

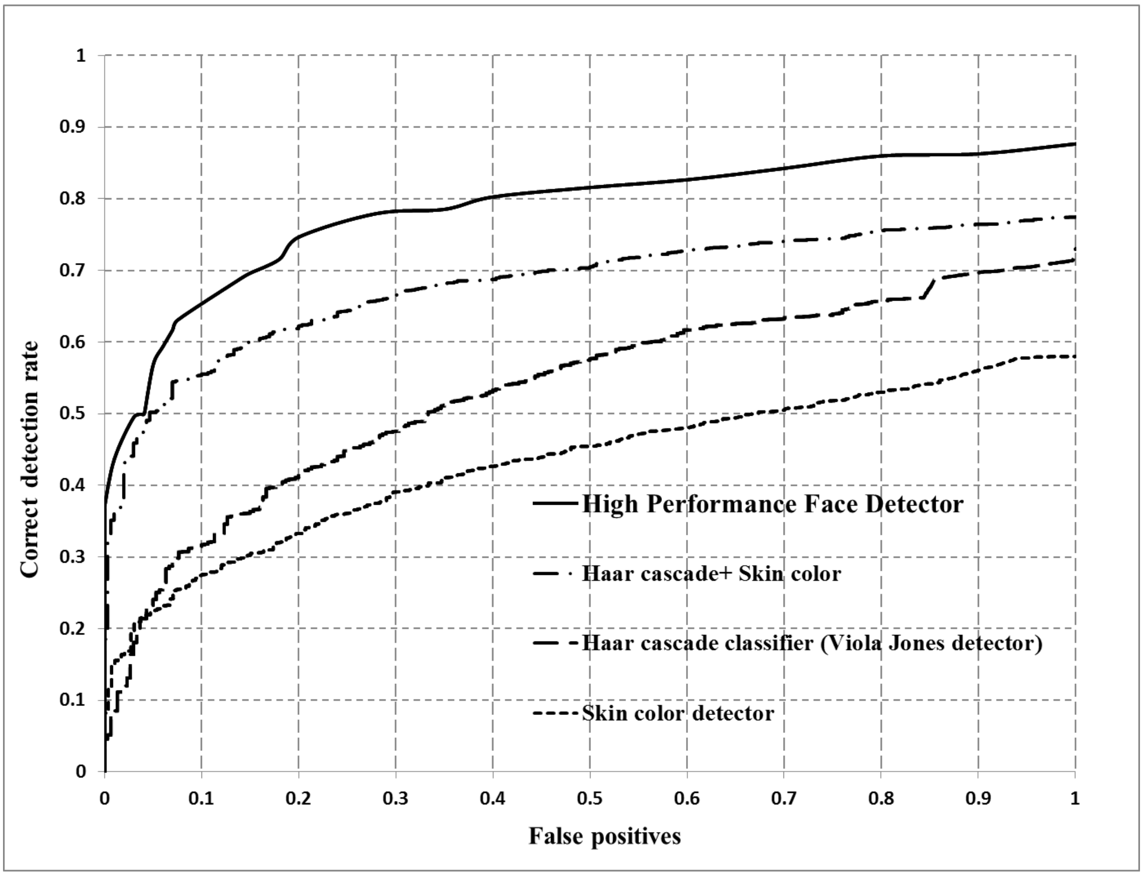


Fig. 2.16. Result of benchmark test for DB2

Second, DB2 is used for comparing the participation of the face detectors used in our proposed algorithm. The ROC curves in figure 2.16 shows the results. The "Haar cascade classifier + Skin color detector" also represents the modified algorithm which shows the face detection rate without applying the Unscented Kalman filter process in this system. The ROC curves clearly shows that the proposed algorithm has higher performance for face detection than other ones. This curve is useful for showing the participation of different algorithms in the proposed method.

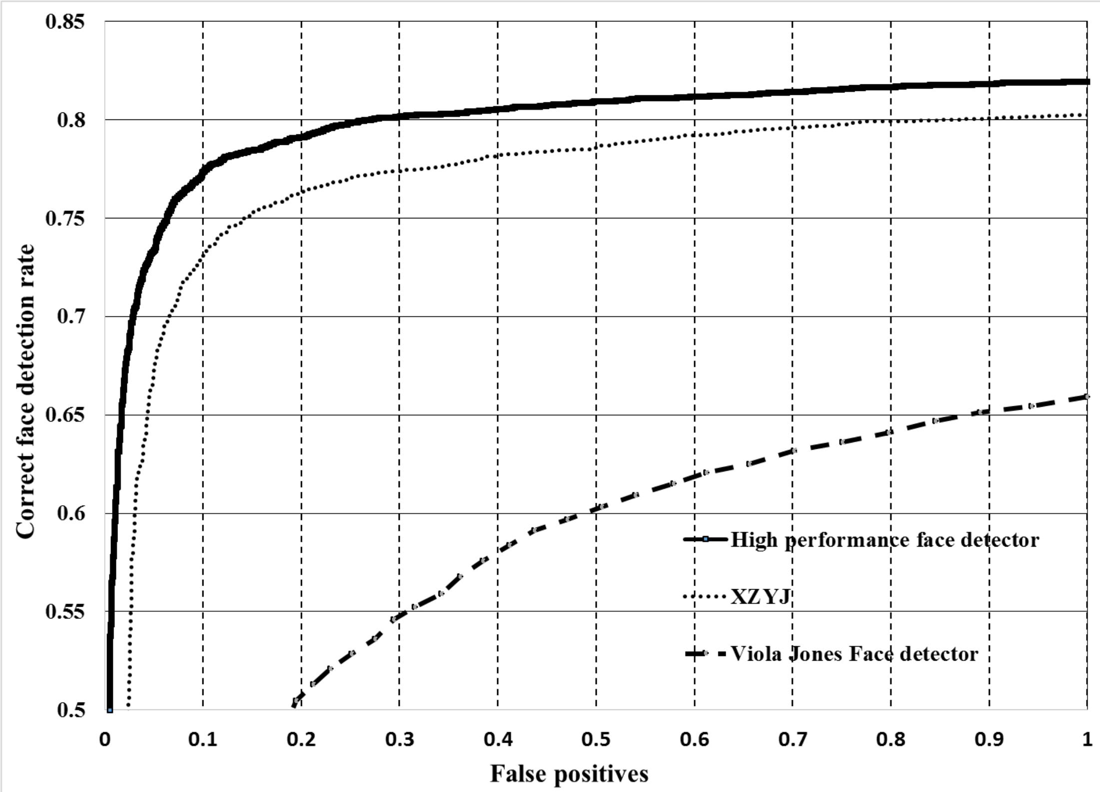


Fig. 2.17. Result of benchmark test for DB3

Finally, DB3 is used for comparing our proposed algorithm with XZYJ method [2-19] and Viola Jones face detector [2-19]. The ROC curve is shown in figure 2.17. The ROC curve is drawn from the first 2000 images by referring the Roc curves shown in [2-19]. The Proposed algorithm shows the highest face detection rate compared to the XZYJ methods and the Viola Jones face detector in case of DB3.

The face detection time of our proposed face detector is 30fps (frame per second) which is equivalent to 33.33ms (millisecond). In the recent studies of face detection, Faceness [2-26] and DP2MFD [2-27] results better face detection rate in-compared to the proposed face detector. These systems are implemented by using CNN and they are experimented in the GPU machine as well. The face detection rate of the Faceness method is 14fps on CPU and 100fps on GPU. The program code was written in MATLAB for this process. Comparing the CPU performance time of this method with ours proposed face detector, our system holds fast runtime in CPU machine, than this process.

The face detection time for DP2MFD method is 23s (second) on average by using 4 cores CPU, 12 GB main memory with 1.6GHz processing speed. This system detects the face in 0.5s by using the Tesla K20 GPU machine. The face detection time of the proposed detector is about 800 times faster than this process while using CPU and even about 17 times faster on GPU machine. We can adopt the idea of CNN and GPU specified by these two face detectors [2-26] [2-27] for making the proposed system more efficient.

2.4. Discussion of this chapter

In this chapter, a high performance algorithm for face detection was presented. The different types of algorithms related to the face detection and image processing were combined together to work under different conditions. The used algorithms were modified by adding different features related to increase the face detection rate.

In this face detector, the faces were detected individually by the two face detectors and verified by two types of eye detectors. The difficult issues on face detection were cleared stepwise with the flow of the proposed algorithm. The algorithm was able to detect both the color and gray-scale images taken under different environmental conditions, using different databases, i.e., DB1 and DB 2 and DB3.

The proposed algorithm while compared with other face detectors algorithms gives higher correct face detection rate. The individual comparison of the proposed algorithm with Viola Jones algorithm and LAB using DB1 also shows higher face detection rate by the proposed algorithm side. The overall comparison of the used algorithm and the proposed algorithm using DB2 also shows the percentage ratio of the participation of different algorithms for the proposed process. The comparison of the algorithm with XZYJ and Viola Jones face detector using DB3 also showed the result by the side of the proposed algorithm. The Unscented Kalman filter was very helpful for filtering noises in images. The noise-filtered images and the images with noises had a great difference in case of face detection.

The high performance face detector using UKF was developed in this chapter. Using the proposed face detector, several experiments and the benchmark tests under various environmental conditions were carried out. The proposed algorithm using UKF can detect faces with different ***scales.*** The ***multi-faces*** condition is being satisfied by the proposed algorithm, the faces present in the ***illumination variant images*** are partially detected, and it needs to be solved properly. The ***occluded facial features*** by beard, mask, glass, etc. or partially occluded facial features are not satisfied. The proposed system detects the face up to 90 degree rotation. The ***image noises with the film grain noise*** are cleared properly by the proposed algorithm, which is the main cause of the high face detection rate.

The face detection rate for the proposed algorithm is 98% by using CMU-MIT database. Similarly, 81.9% on FDDB database. This is the highest face detection rate compared to the other process related to face detection.

Chapter 3

Robust face detector for illumination variant images

3.1. Introduction

This chapter associates the detection of the presence of face on dark and illumination variant images. It is quite difficult to detect the faces from the images taken in a dark environment and under different illumination variant conditions due to the unclear visibility of the image. In this chapter, an algorithm is designed by combining the stochastic resonance [3-1] along with the high performance face detector [3-2] presented previously.

In this chapter, "the modified SR technique for image enhancement" [3-3] have been developed for the enhancement of the image, which extracts the image candidates from the dark and illumination variant images and make them visible. The Gaussian white noise [3-4] is applied to the dark image keeping the threshold value at zero constant. The resultant images are then summed up in a series for extracting the image candidates from the dark images and for making them visible. This technique has been developed from the summing network process [3-5] of the stochastic resonance noise.

The images once enhanced and made visible is applied to our high performance face detector for detecting the presence of the face in an image. The idea of modified SR technique for image enhancement and the use of stochastic resonance in a face detection algorithm for the static dark images clearly reflects the novelty of this thesis. Various experiments on various dark and illumination variant images were performed to confirm the effectiveness of the current research.

In order to overcome this environmental difficulties, the contrast adjustment process has been applied by T. Sim and T. Kanade [3-6] for the different illuminating examples. These processes work properly on some images, but still there are some illumination variant conditions which are not satisfied with these methods.

To overcome the problem of dark and illumination invariant images, Stochastic Resonance (SR) technique is applied on the images that were not satisfied by the contrast adjustment process [3-7]. The SR is used as pre-processing for extracting the face candidates from a dark and illumination variant image. SR is expected to make dark images under various illumination conditions visible and clear. The images after pre-processed is then passed to the high performance face detector for detecting the presence of a face in an image.

The SR is a phenomenon in which a response of a system is enhanced by adding the Gaussian white noise. It can also be known as the counter-intuitive phenomenon where the presence of noise in a non-linear system is essential for optimal system performance.

In this research, the algorithm is tested on three different techniques of SR, one is the threshold phenomenon or the original SR technique [3-1], where the noise is tuned along with a threshold. It is quite difficult to obtain the proper result by using this technique because of the inappropriate tuning as auto-tuning process is difficult.

The second technique is the summing SR technique or SR without tuning by Collins et al. [3-5]. This technique is probably being used in signal processing, but in this chapter, the technique is slightly modified for application to image processing.

The third technique is modified SR technique for image enhancement, developed from the idea of SR without tuning by Collins et al. The Gaussian white noise is applied on a dark and illumination variant image by keeping the threshold value at constant 0. Then, the resultant images are summed up for several times to get the final enhanced image. This makes the system possible to protect the image from losing the special features which are necessary to detect faces in an image.

The modified SR technique for image enhancement is a new approach to pre-processing for face detection. The use of stochastic resonance in the face detection process is being implemented by us for the first time. These two points really reflects the novelty of this thesis. The images after being enhanced and made visible are sent to our high performance face detector for detecting the presence of the faces in an image. The effectiveness of the current technique is clarified by several experiments.

3.2. Image enhancement for illumination variant images using SR.

A development of a robust system being based on the idea of stochastic resonance theory [3-8] for electronic signal processing is presented in this chapter. Actually, there are two types of stochastic resonance techniques being used in the field of signal processing, they are "threshold phenomenon" or "Original SR technique" [3-8] and the "SR without tuning" [3-5]. In case of image processing, we have developed "modified SR technique for image processing" from the idea of the SR without tuning.

Both of the techniques are applied in the current research and were able to get different types of results due to which, modified stochastic resonance technique for image processing was developed. The pixel series of the image is calculated, instead of calculating the time series of the signal for applying the stochastic resonance in the field of image processing.

3.2.1. Original SR technique

SR was first presented by Benzi [3-1]. The process of the original SR technique is shown in figure 3.1. In this figure, the process of signal processing is modified to the process of image processing. A Gaussian white noise is added to the input image and then the threshold is applied to the image. The threshold value has to be tuned along with the proper noise level for getting the appropriate result. In this process, the noise and the threshold value have to be tuned manually, which is quite a complicated task and leads to the very low face detection rate.

The experiment performed on a dark image by using this process is shown in the figure 3. 2 and the matrix showing the face detection under different noise level and the threshold value is shown in table 1. In table 3.1, "○" represents the true face detection, "×" represents the false and "Δ" represents only one face out of two faces is detected.

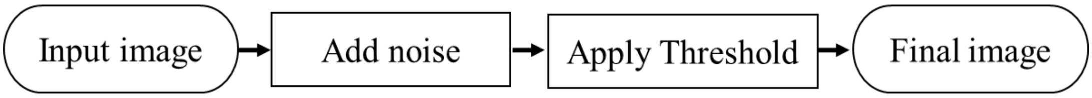
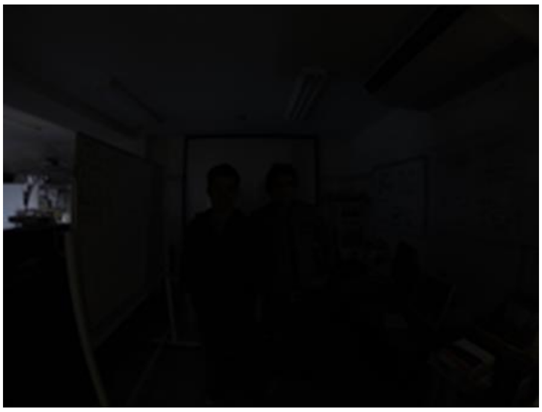


Fig. 3.1. Original SR technique



Original dark image

Noise level=1, Threshold value=1

Noise level=2, Threshold value=2

Noise level=4, Threshold value=4

Fig.3.2. Example of images improved by the original SR.

Table 3.1. Face detection results for Fig.3.2 (a) by the original SR.

Threshold value	Noise Level					
	0	1	2	3	4	5
0	×	×	×	×	×	×
1	×	×	×	×	×	×
2	×	×	△	△	△	△
3	△	△	○	○	○	△
4	○	○	○	○	○	△
5	×	×	△	△	△	△

3.2.2. SR without tuning

The "SR without tuning" or the "summing network" idea was developed by Collins et.al. This idea was first applied as a summing network of the identical excitable units related to the signal interference devices. As, the current research is based on image processing, the PDM (Pulse density modulation) [3-8] is followed in this technique.

Figure 3.3 shows the flow of our adopted SR. One of experiment results performed on dark images by using this technique is shown in figure 3.4. The Gaussian white noise is first applied to an input signal X sequentially. Then a threshold value is applied to each result. Finally, the noise added signals are summed up in a series to obtain the result in terms of $\widehat{\boldsymbol{Y}}$.

In figure 3.4, the "SR without tuning" process have been applied on a dark image and get the final enhanced image as shown in figure 3.4b. In this case, two faces are detected from this image by using the high performance face detector. However, there are some cases that the face detection is not possible by using this technique. The faces are detected in this case but the histogram shows the possibility of the better enhancement of the image.

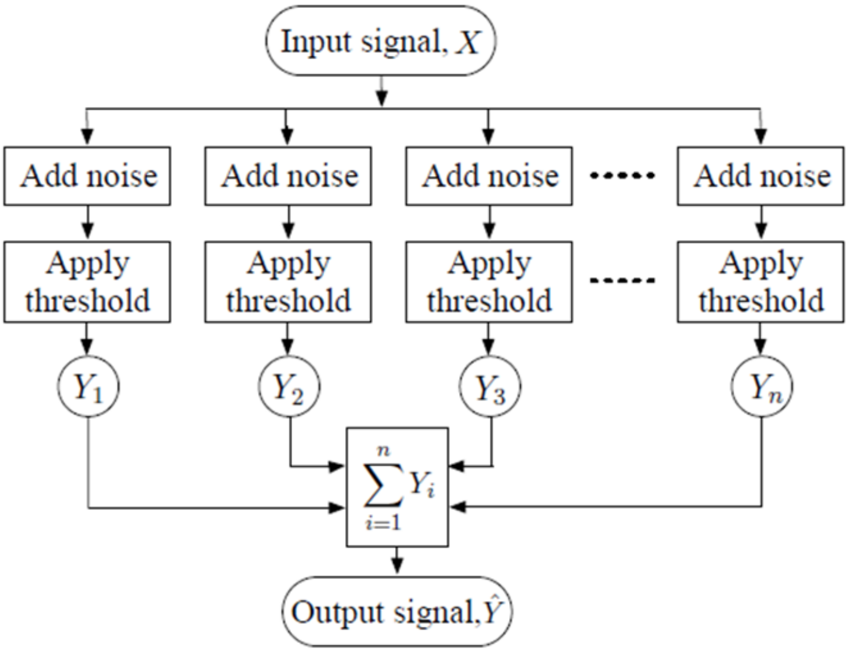
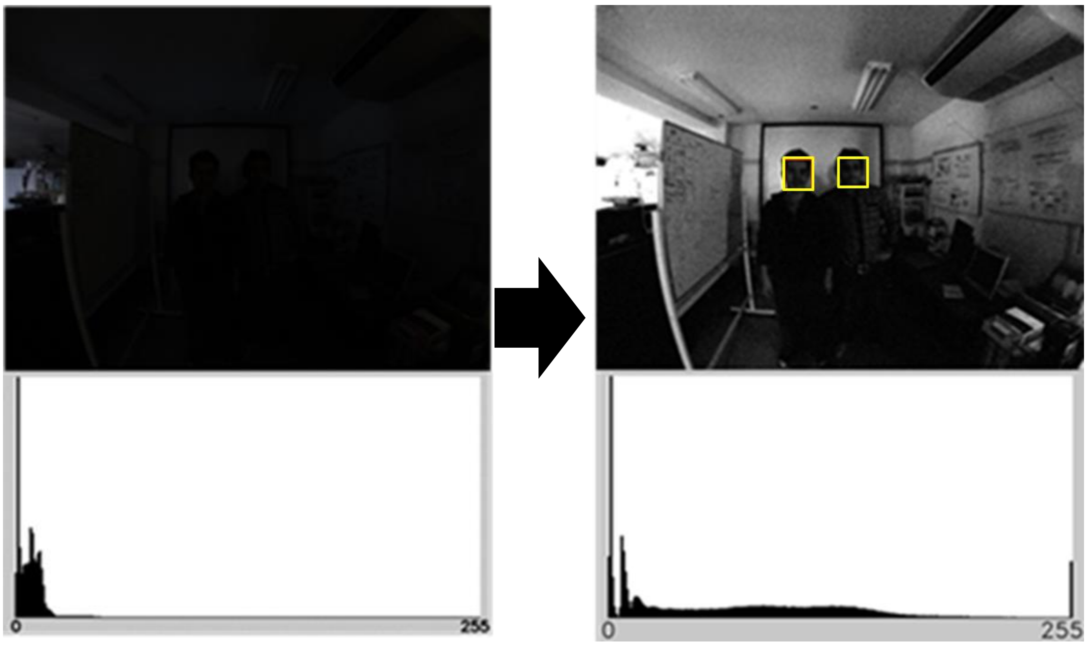


Fig.3.3. SR without tuning (Summing Network)



Original dark image

Enhanced image

Fig.3.4. Example image of SR without tuning

3.2.3. Modified SR technique for image enhancement

This idea is developed from the “SR without tuning” by Collin et al. The algorithm is shown in figure 3.5. The threshold value is kept at constant zero in this process. In the proposed technique, the image is converted to grayscale and we apply the Gaussian white noise randomly in an image, setting the threshold value at constant zero, which means no need to tune the Gaussian white noise and threshold in this process. This point reflects the novelty of the current research and a new approach towards the field of image processing using the stochastic resonance.

In this process, the noise value is normalized from 0-255 range instead of 0-1, because the image is calculated in pixel series instead of time series. Then, the white noise applied images are summed up for several times in a series similar to the super resolution processing [3-9]. When the image with different noises are summed up, the invisible area of the image becomes visible as shown in figure 3.6.

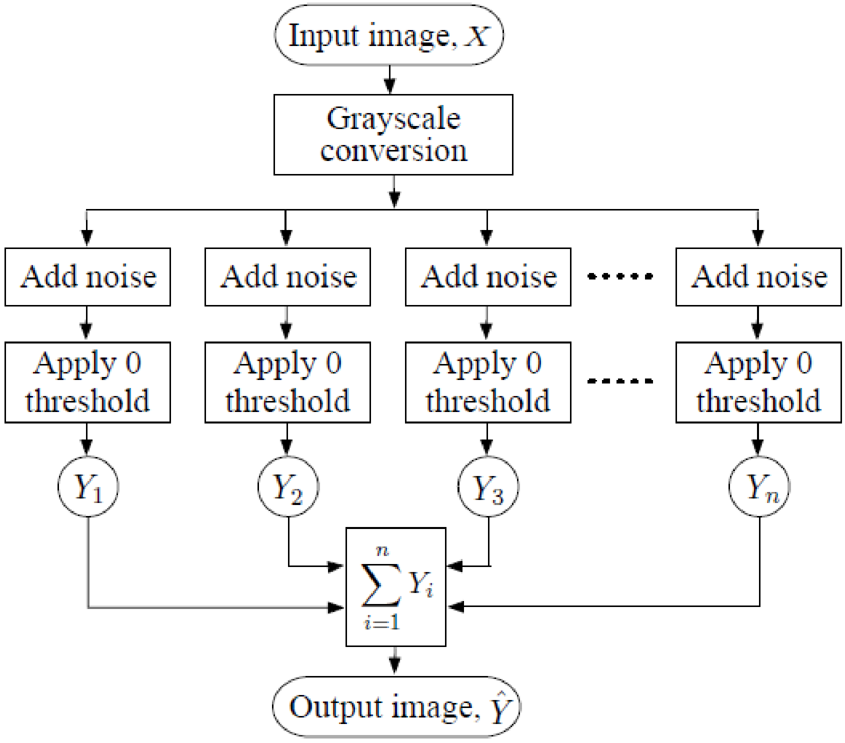


Fig.3.5. Modified SR technique for image enhancement

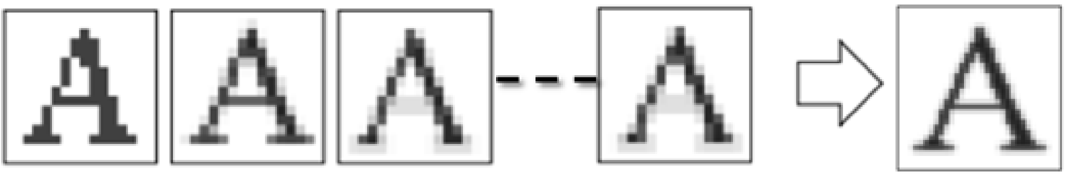
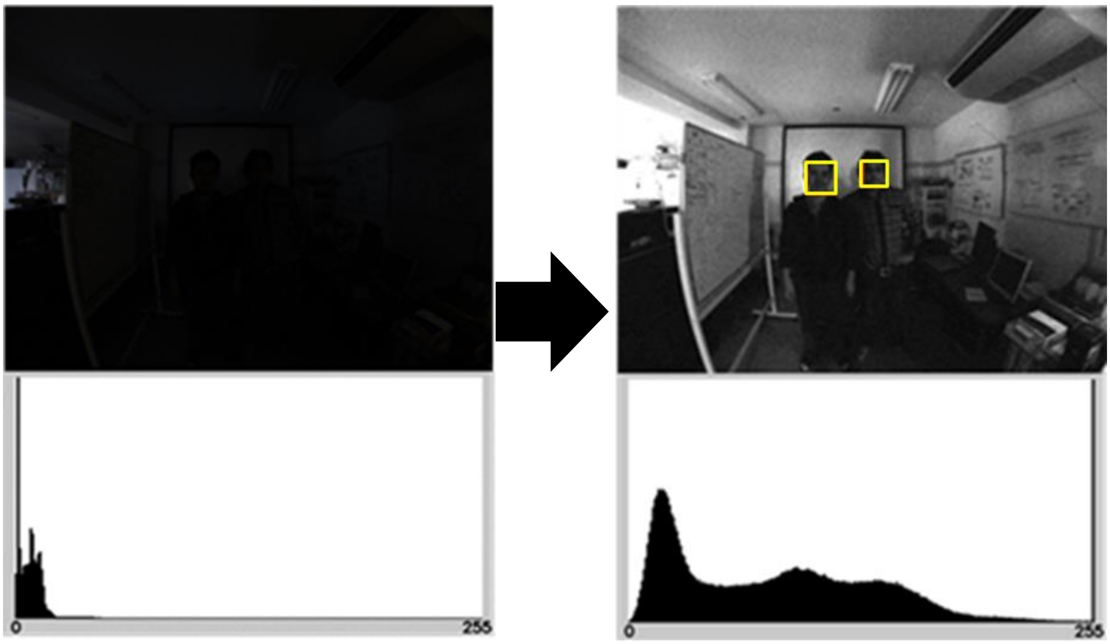


Fig.3.6. Super resolution image processing



Original dark image

Enhanced image

Fig.3.7. Effects of the modified SR technique for image processing

An image showing the experimental result of this technique is shown in figure 3.7 along with the histogram. Comparing the output images from the figure 3.4 b and 3.7 b, the image obtained after applying the current process is clear, standard and acceptable in the field of image processing for image enhancement. The image enhanced properly is best for the face detection.

3.2.4. Why “Modified SR technique for image enhancement”?

In the modified SR technique for image enhancement, a default noise level is applied in a dark image and sum up the noise added image in a series. The threshold value is kept at 0, which means that no need of any tuning of the Gaussian white noise and the threshold in this process. This is the novelty and a new approach in the field of image processing.

In comparison with the “original threshold technique” and the “SR without tuning” process, the modified SR technique gives the best experimental result and is easy to implement. We do not need different noise level and threshold values for developing SR technique in this process. We can just apply a noise value in a single image and then sum up the same image in a series for several times with a threshold value constant 0, which gives a required output image.

In comparison to the “SR without tuning” process, the result is quite similar to the modified proposed algorithm. However, in case of “SR without tuning”, we need to apply the noise levels in an image. It means that the noise has to be tuned in this process, although the threshold value is kept constant but not zero, which may lead to a loss in feature of the face present in the image as shown in the histogram of figure 3.4 b and 3.7 b. The modified SR technique for image enhancement does not lose any pixel data and image characteristics. This method is quite easy and simple to implement SR theory for face detection.

3.3. Robust face detector for illumination variant images

In the current algorithm, the process is divided into two parts. The first part reflects the image enhancement phase and the second part reflects the face detection phase. The structure of the proposed algorithm for robust face detector is shown in figure 3.8. The combination of the image enhancement phase as mentioned in chapter 3.2 and the face detector phase mentioned in chapter 2 represents the robust face detector for illumination variant images.

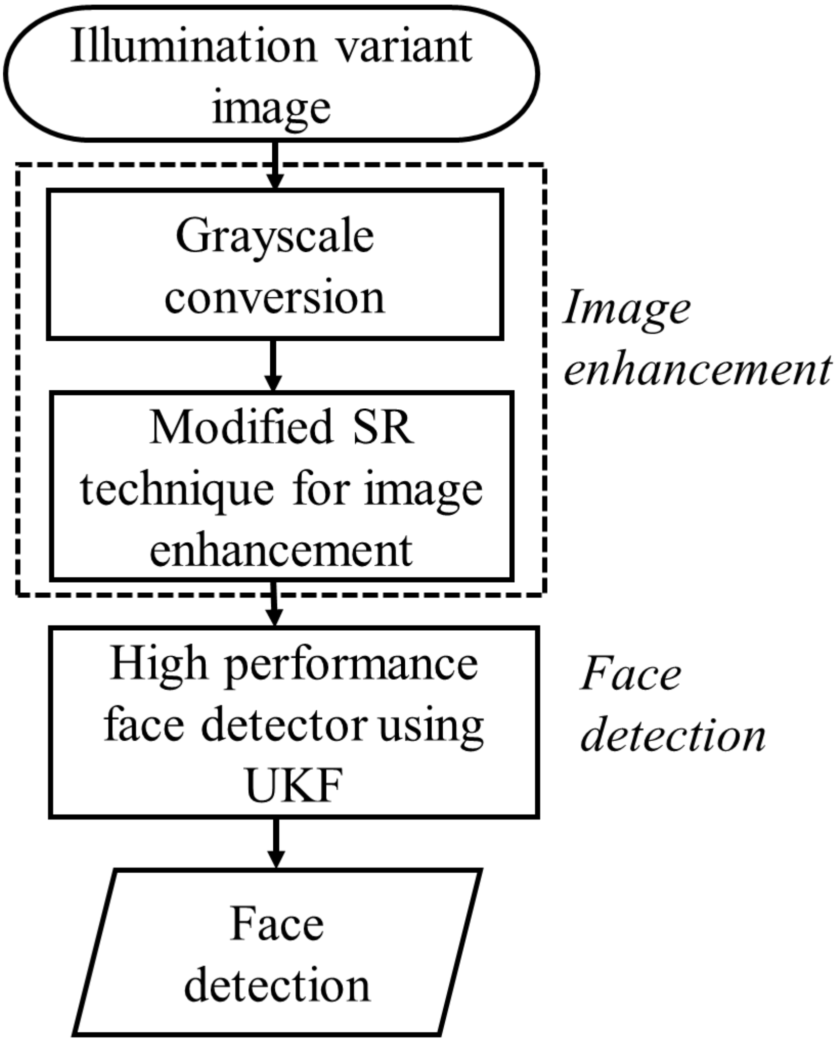


Fig. 3.8. Proposed robust face detector for illumination variant images

3.3.1. Image enhancement phase

The modified SR technique is used for image enhancement in the image enhancement phase. The input image is first converted to a grayscale image in our process because, it is easy to apply SR in grayscale image in compared to the RGB image. The image after converting to grayscale image is then passed to modified SR technique for image enhancement. In this process, the Gaussian white noise is applied to an image with the threshold value at constant 0. The image is then summed up in a series by itself for several times until the image is enhanced and becomes visible as shown in figure 3.9.

In figure 3.9, the enhancement of original dark image continues along with the iteration number n. In case of the dark image shown in figure 3.9, the 10th times iteration of the image gives the best enhanced image required for the face detection. The enhanced image can be checked by using the histogram of the enhanced image.

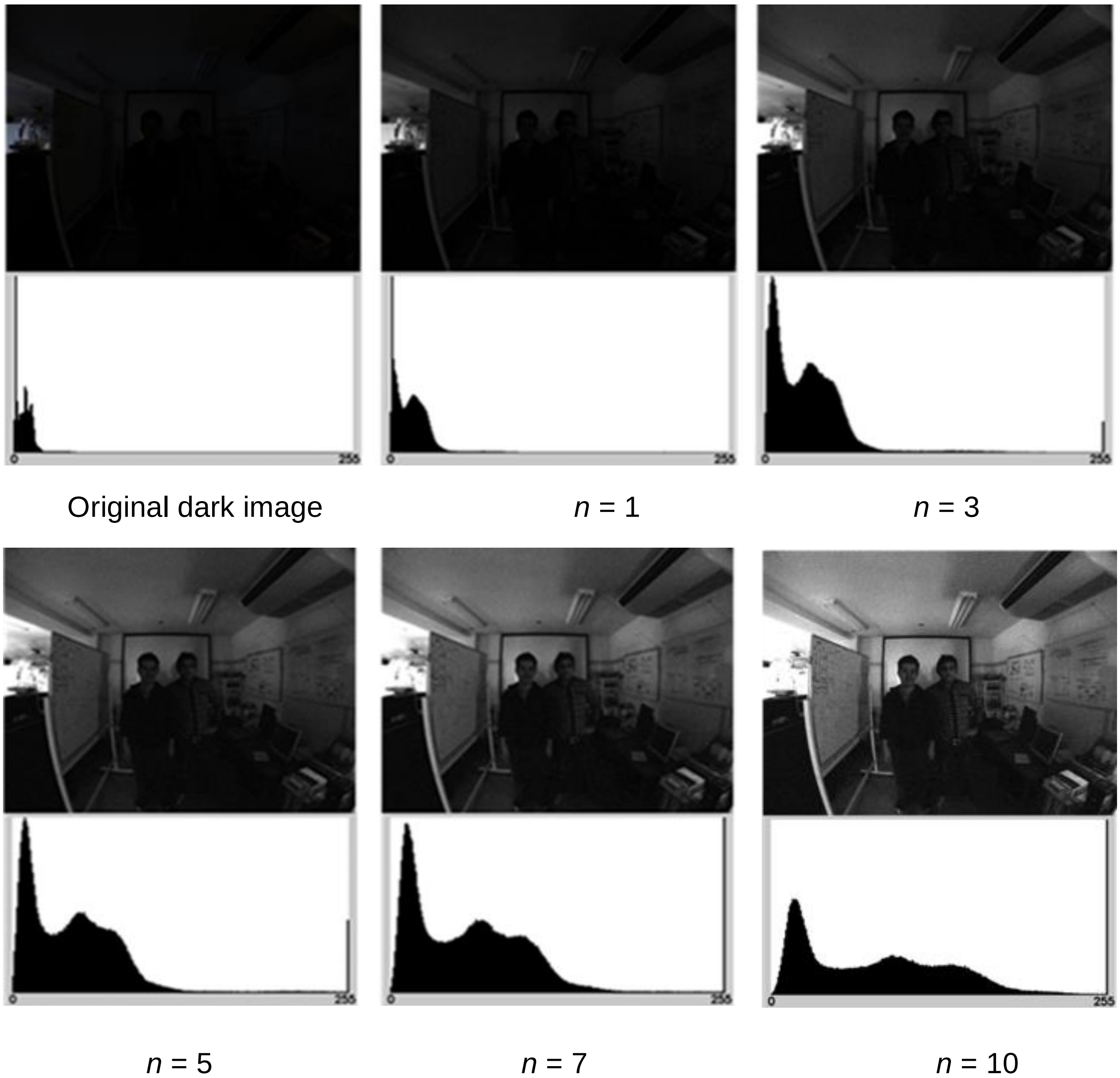


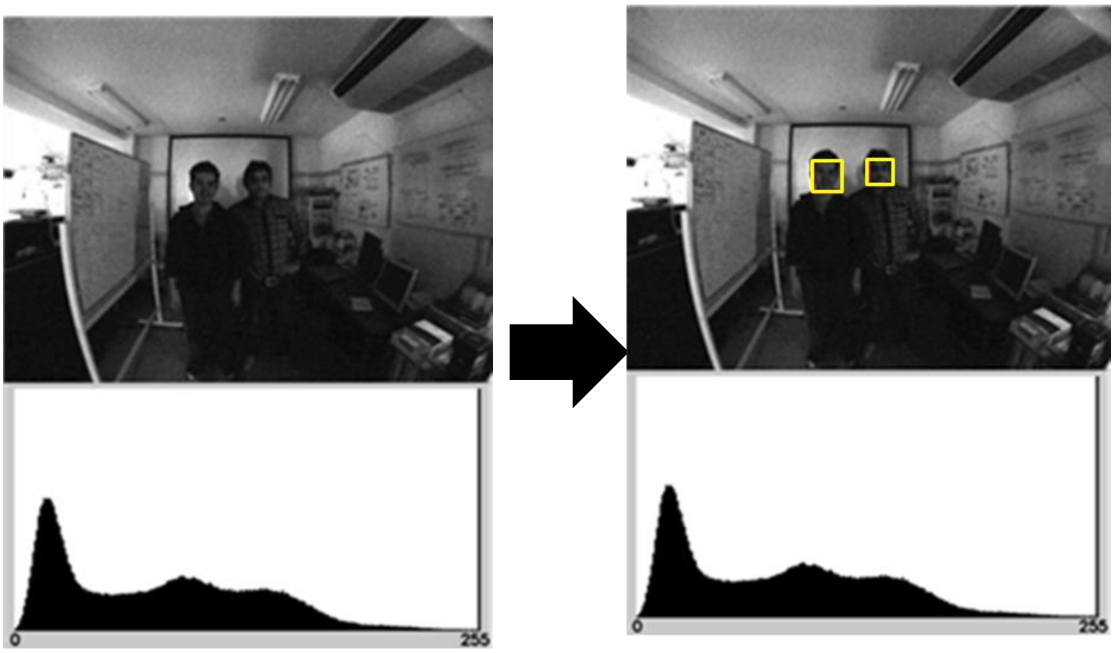
Fig. 3.9. Image enhancement phase of our proposed robust face detector for illumination variant images

3.3.2. Face detection phase

The main target of the current research is the detection of faces on the illumination variant image. For detecting faces from an image we need a face detector. The high performance face detector explained on chapter 2 is used. The high performance face detector detects the faces up to 90 degree rotation. The face detector detects the face under different conditions of noisy images as well. The performance of the high performance face detector is better compared to the other face detection algorithms [3-10].

In the proposed robust face detector for illumination variant images, the high performance face detector is applied after the illumination variant image is enhanced by using the modified SR technique for image enhancement. The face detection phase is applied after the image enhancement phase in this system. Once the image is enhanced by using the current image enhancement process, we are able to apply the high performance face detector using UKF on the enhanced image and we detect the presence of faces from the given image.

The figure 3.10 shows the detected face of the enhanced image for figure 3.9. The two faces are detected from the final enhanced image of figure 3.9. The high intensity noises and the film grain noises if present in the image are also removed by using the high performance face detector. The original dark and invisible image becomes visible and even detects the presence of the faces.



Enhanced image　　　　　　　　　　Face detected image

Fig. 3.10. Face detection phase of our proposed robust face detector for illumination variant images

3.4. Experimental results and evaluation

3.4.1. Tools and databases used

In order to validate the proposed algorithm, some experiments on different dark images under different illumination conditions were carried out. Also, the current process was compared with different types of SR techniques and draw matrix tables like table 3.1.

A C programming code was developed for checking the efficiency of different SR techniques and draw a matrix table showing for the possibility of the face detection on different images. The system was developed by using the Visual studio 2010 and the Open CV library [3-11] on PC (i7-3770, 3.40 GHz, 8GB main memory and Windows 8.1, 64 bit OS).

The current research is performed on dark and illumination variant images under different illumination conditions. It was quite difficult for collecting the data's for such type of images. There aren't any specific databases for our current type of research, so we developed our own database for dark and illumination variant images by taking some pictures under different illumination conditions. Some of the related images were downloaded from the internet with the permission of the author and selected some illumination variant images from the INRIA Graz-01 [3-12] database and FDDB database [3-13].

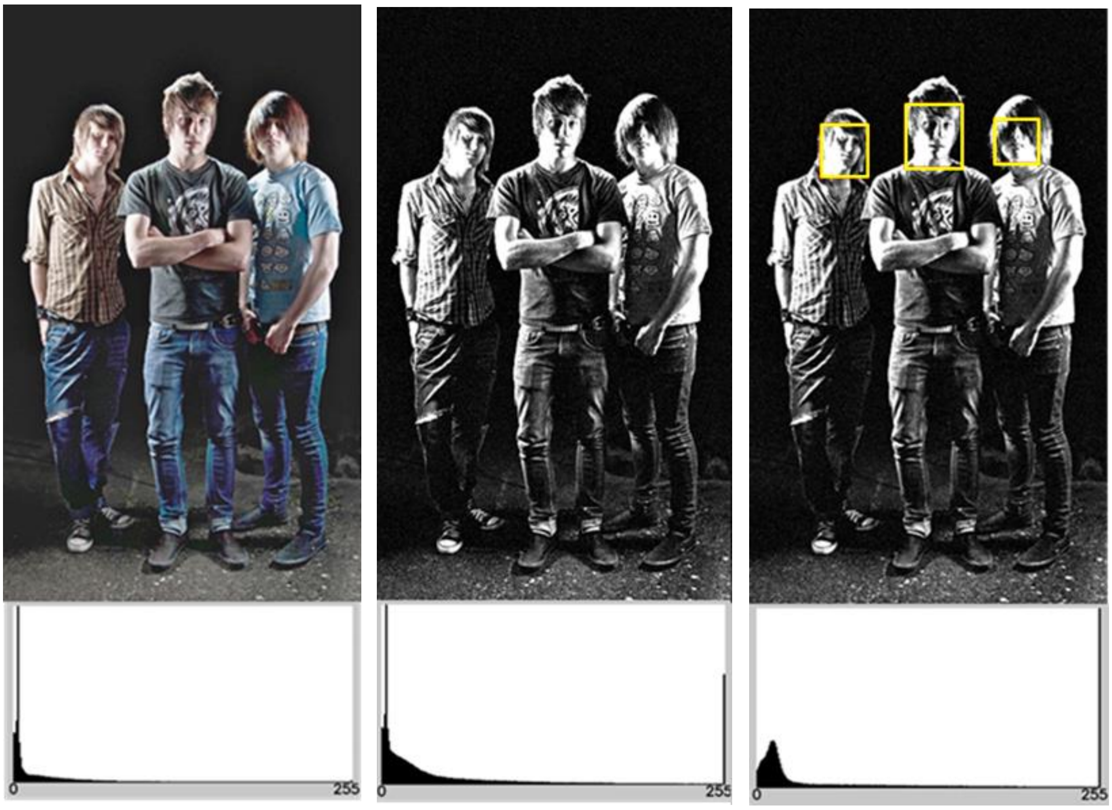
3.4.2. Evaluation of different image cases

The figure showing the implementation of the proposed robust face detector for illumination variant images are shown in the figure 3.11, 3.12, 3.13, 3.14, 3.15 and 3.16 where "*n*" reflects the iteration number of our SR process. We show the five different cases under different illumination conditions being enhanced at first iteration $n = 1$ and the final iteration along with the histogram of the original and enhanced image.

The enhanced image, where the face detection is possible is shown. The noise value is set at 1 for all the five cases. The case 1, 2 and 5 images are downloaded from the internet with the author's permission and the case 3, 4 and 6 images are taken in the lab for the research purpose. These five images are the condition where the face detection is not possible by the contrast adjustment process and other related works.

To show the changes of an image after applying our SR technique, a histogram of an image along with the summed images are shown. The dark area of each image is near to the 0 gradations and the bright or white area is near to 255 gradations. The area of each histogram is set to the same value for all the images.

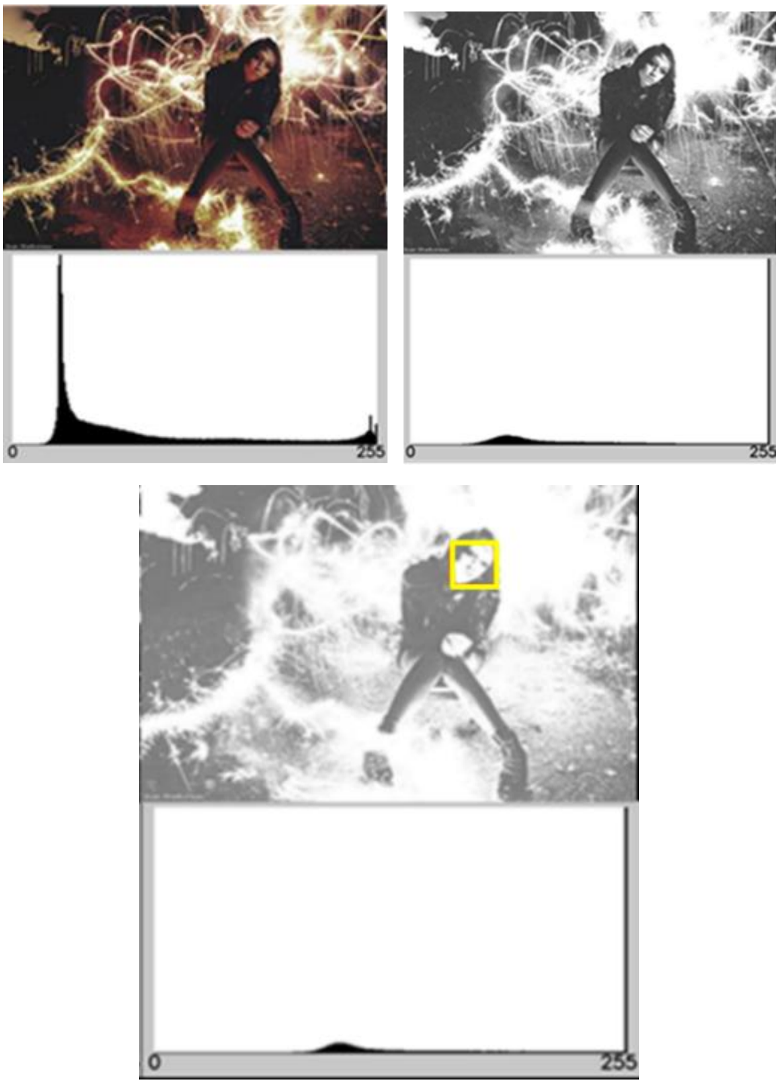
The case 1 image in figure 3.11 was downloaded from the internet which is taken in a dark room with the focus light. The image is enhanced by applying the Gaussian white noise level 1 and our SR summation series for three time. The three faces are detected after the third times SR iteration by using our high performance face detector [3-2]. Changes in the brightness of each image are represented by the histogram along with an image.



Original image $n = 1$ $n = 3$

Fig.3.11. Evaluation of robust face detector for illumination variant images along with the histogram (Case 1)

The case 2 image in figure 3.12 was downloaded from PhotoJosh.co.uk, taken outside at night in front of the sparkling light. In this case also the face is detected after applying the noise level 1 and 3 time iteration of our SR technique. The face in this case is slightly rotated, but the face detector detects the face up to 90 degree rotation, so this case was satisfied.

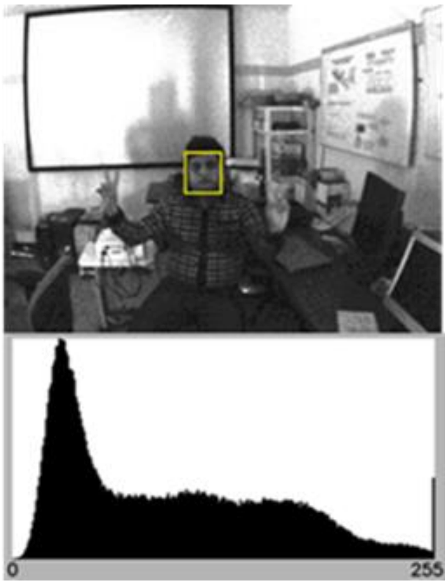


Original image n = 1 n = 3

Fig.3.12. Evaluation of robust face detector for illumination variant images along with the histogram (Case 2)

The case 3 image in figure 3.13 was taken in a dark environment without any beam of lights. The face is detected after applying the noise level at 1 and 10 times iteration of the summation series.

Original image $n = 1$



$n = 10$

Fig.3.13. Evaluation of robust face detector for illumination variant images along with the histogram (Case 3)

The case 4 image in figure 3.14 was taken in a dark environment but along with the emission of light in the background. The face is detected after applying the noise level at 1 and 10 times iteration.

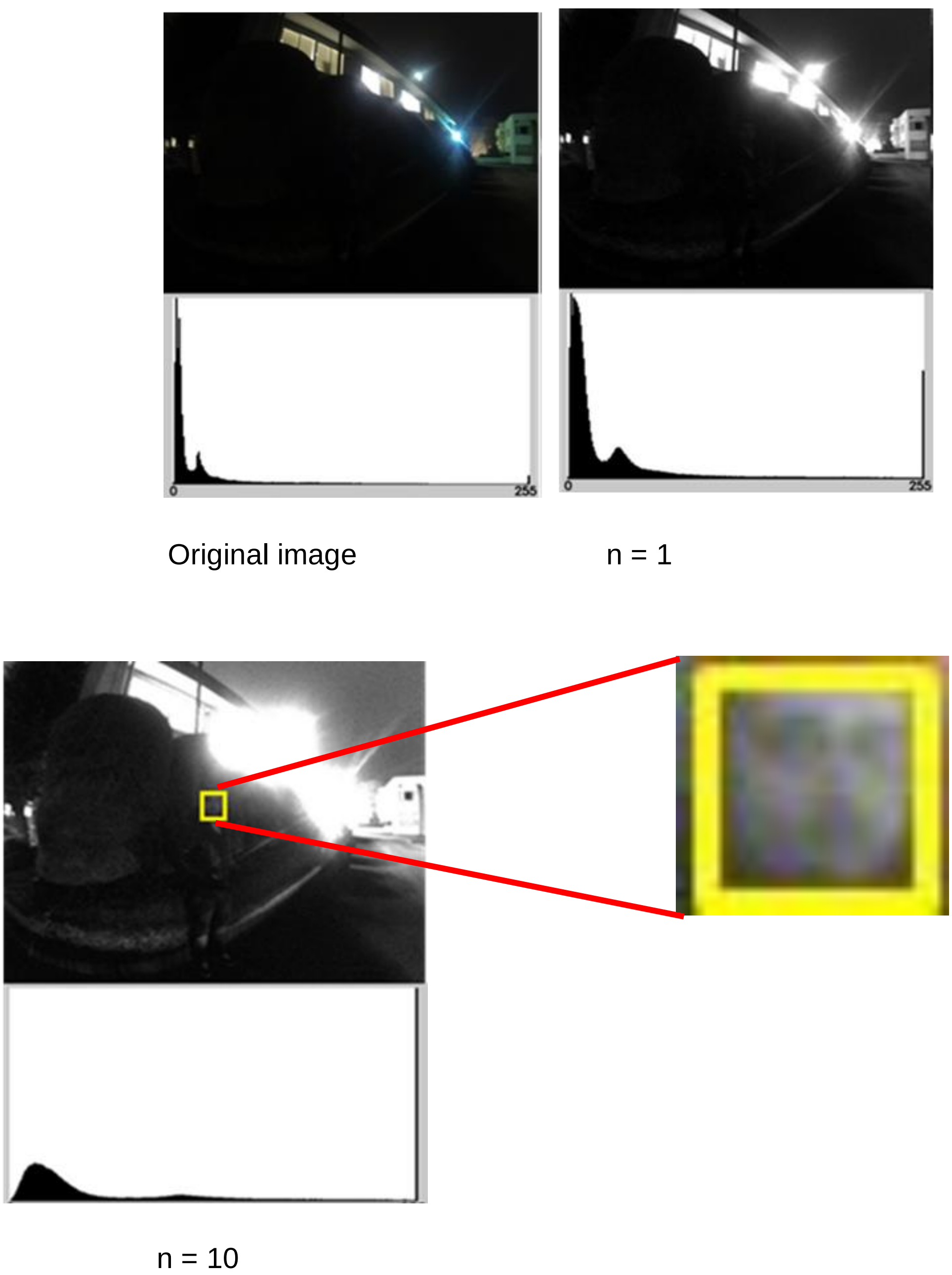


Fig.3.14. Evaluation of robust face detector for illumination variant images along with the histogram (Case 4)

The case 5 image in figure 3.15 was taken at night using the focus light. Due to the presence of excess brightness in the image, the image is first inverted before passing it to the image enhancement phase. This is one of the special case. The face is detected after applying the noise level 1 and three time iteration of our SR technique. One face is slightly rotated, but is satisfied by our high performance face detector using UKF.

Original image

n = 1

n = 10

Fig.3.15. Evaluation of robust face detector for illumination variant images along with the histogram (Case 5)

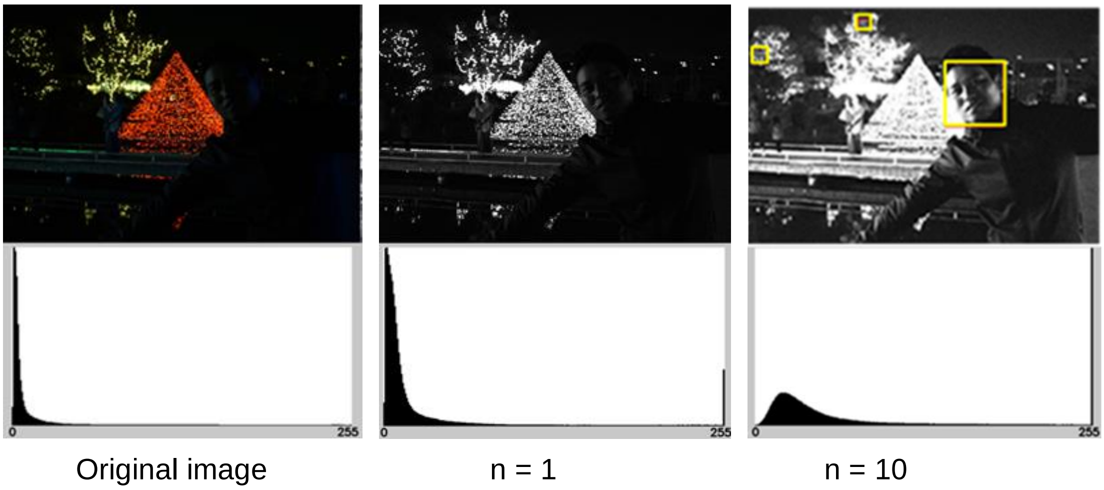


Fig.3.16. Evaluation of robust face detector for illumination variant images along with the histogram (Case 6)

Similarly, the case 6 image in figure 3.16 was taken at night in front of the illuminating light. After applying the summation series for ten times, we were able to detect the presence of a face in the image, but along with some false positives as shown in a red box. This type of images is a quite difficult case for the face detection because the faces can be seen by our human eyes but due to the emission of light in the face, the face detection system cannot detect the face in the image.

The iteration number varies in case of the dark and bright images. The iteration number is more in case of the dark images compared to the bright images. It takes a long iteration for the dark images to be enhanced and be visible because of the brightness level zero. All of the evaluated images mentioned in this chapter doesn’t satisfy the contrast adjustment process for image enhancement and face detection.

3.5. Discussion of this chapter

In this chapter, a high performance face detector using the modified SR technique for image enhancement that works in the dark and illuminant variant images was presented. The proposed algorithm enhanced the dark image and then detects the presence of faces in an image.

The environmental condition of illumination variant images for face detection was solved by the SR technique based face detector. The role of stochastic resonance played a vital role in determining the development of the high performance face detector. The smart and novel system was developed. The robustness of the proposed face detector can be known in this chapter.

The effects of stochastic resonance as a new approach was properly evaluated and experimented on different dark and illumination variant images with the appropriate results. The presence of a face, either in a dark or bright condition was detected by using the face detector along with the SR technique. This proposed face detector based on SR technique will help to increase the face detection rate on dark and illumination variant images as well.

Various experiments under different cases related to dark and illumination variant images were performed. The image case 1 to the image case 6 are the most complicated cases, which are not satisfied by the other related works except our proposed method.

The modified SR technique for image enhancement is designed to work on dark and illumination variant images. The proposed algorithm can detect faces with different scales even they are taken in a dark environment. The illumination variant images that were not detected by using the contrast adjustment process along with the face detector [3-2] are now detected by using our proposed robust face detector for illumination variant images.

The modified SR technique for image enhancement plays a vital role in the high performance face detector. The algorithm works properly in case of dark images, but in case of extra bright images, the image have to be equalized by inverting the image then only the modified SR technique can be applied. The iteration number for the summation series is less in case of bright images than dark images. The computation time of the proposed algorithm is 4 fps (frame per second).

The portrait images with excess accent light on the facial features are not detected by using the proposed algorithm or we can say these type of images are not satisfied by using any other techniques as well. It is because the facial features are diminished after applying the excess accent light on the images. The portrait images are the color combination of art not the digital pictures.

The auto tuning process is required for fixing the iteration number to perform the summation of a given image. The darkness and brightness of an image plays a major role in the summation iteration number. The bright images are less iterated whereas, the dark images are iterated for several times. In case of the brightest image, the image has to be inverted at first and then only the SR technique has to be applied.

The illumination variant images are solved by the modified SR technique for image enhancement, but if still the film grain noises and other high intensity noises are found in the image, they are cleared by using the high performance detector and after that only the faces are detected.

Chapter 4

Geometrical approach for face detection on occluded facial features

4.1. Introduction

This chapter associates the novel approach for detecting the face and facial features from the occluded images. Face detection is one of the developing trends in the field of biometrics. In the previous works, a face detection system [4-1] was developed, that works under the noisy images and the illuminant variant images [4-2]. These conditions were solved, but still some environmental conditions are left. Among them, the problem of occlusion [4-3] or the occluded face is also one of the environmental condition for face detection.

Face detection is especially difficult in this case because, the facial features are not properly visible in such type of images. The current chapter is based on the occlusion condition of face images. A face is occluded if some area of the face is hidden behind on an object like a mask, sunglass, hand or we can say the face is visible partially. Facial occlusions can degrade the performance of the face detection system.

To overcome up with these problems, face detection approaches have been classified into knowledge-based [4-4], feature invariant [4-5], template matching [4-6] and appearance-based [4-7] methods as a global approach. In recent years, the component based approaches have produced better results than global approaches. The component based approaches [4-8] can be used to construct detectors that can handle partial occlusions.

Similarly, Naser and Soderstrom [4-9] have used PCA (Principal Component Analysis) for occluded image reconstruction. The geometric based approaches [4-10] uses width, length and angle information of the facial points for face detection. In the current chapter, a face detection system is developed that detects the presence of face under different occluded conditions.

The modified skin color detector [4-1] is used for extracting the face region from the image. The face is then cropped for the feature extraction process. Then, the nose point, right and left eyes and mouth from the cropped face image are extracted by applying the geometrical model [4-11] for locating the position of the facial features. Different from the other process of geometrical model, the three triangles are generated by using the detected eyes and nose as the first, detected nose and the mouth as the second and detected eyes and mouth as a third triangle.

The formation of these three triangles helps to obtain the position of the facial features, so whenever a single triangle can be developed from the extracted the facial features, the face can be detected even in the different conditions of occlusion. Finally, the face is detected by using the modified Haar cascade classifier after clearing the film grain noise [4-12] by using the UKF [4-13]. Overall, can say that the geometrical approach is combined with the high performance face detector using UKF.

The three triangle method combined with the UKF, modified Haar cascade classifier and modified skin color detector reflects the novelty of the paper. Various experiments on different types of occluded images were performed for clarifying the effectiveness of the current research and draw the ROC curve with comparison to other related works. The CMU-MIT [4-14], INRIA [4-15] and FDDB datasets [4-16] were used for the experimentation.

4.2. Proposed algorithm on occluded facial features

4.2.1. Structure of the proposed algorithm

The structure of the proposed algorithm is shown by the flow diagram in figure 4.1. The image is first passed to the modified skin color detector, where the facial region is extracted. Once the facial region is extracted, the face is cropped and the facial features which include the nose, both eyes, and the mouth is extracted by using the geometrical model. If the nose point is occluded, the system detects the other visible points and locate the nose point at first.

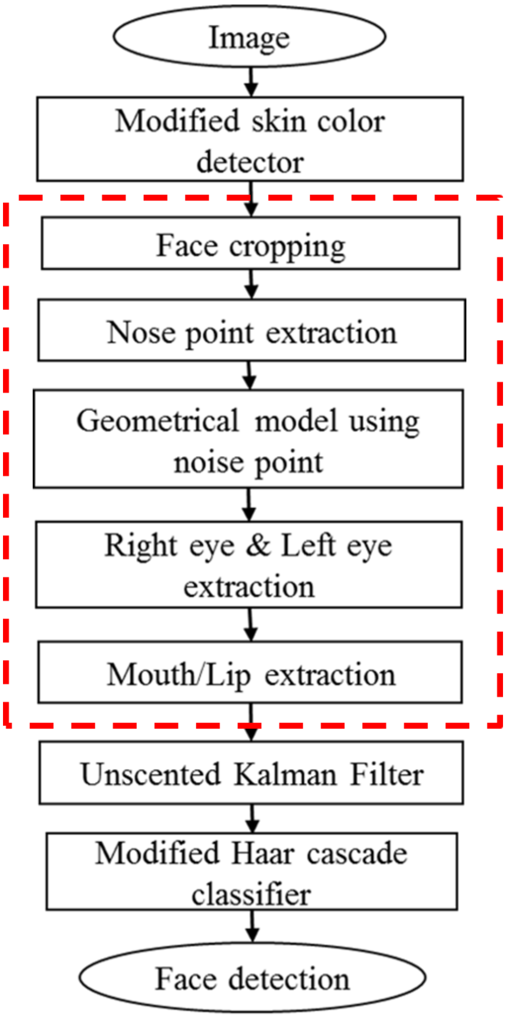


Fig. 4.1. Proposed algorithm on occluded facial features

The geometrical approach search for the two facial feature points. If two of the facial features are detected, the remaining facial features can be extracted from the detected features by using the geometrical model. The geometrical model is applied to the extracted facial features to locate the position of the eyes, nose and mouth by calculating the height, width, distance and angle between the face components.

As the geometrical model is applied in the process, there need to have a clear information about the facial geometry. The image showing the facial geometry is shown in figure 4.2. The distance between the two eyes is denoted by *d*. The distance between the eyes and the nose is denoted by *h*, where h is equal to 0.6times of distance between the two eyes that is 0.6 * *d*. The width of the face is denoted by *W*, which is calculated as 3 times the distance between two eyes that is 3 * *d*.

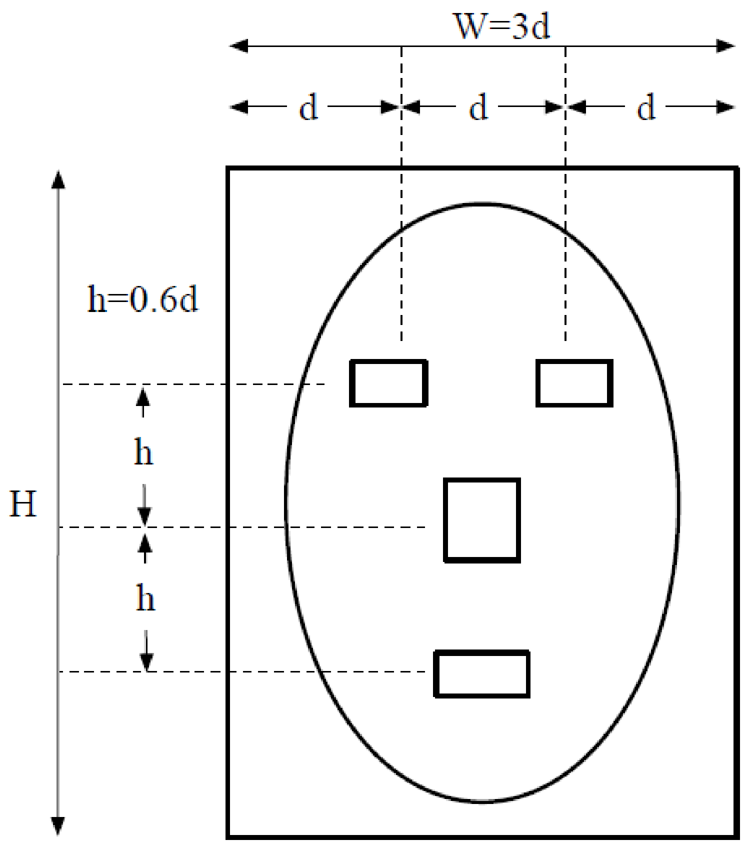
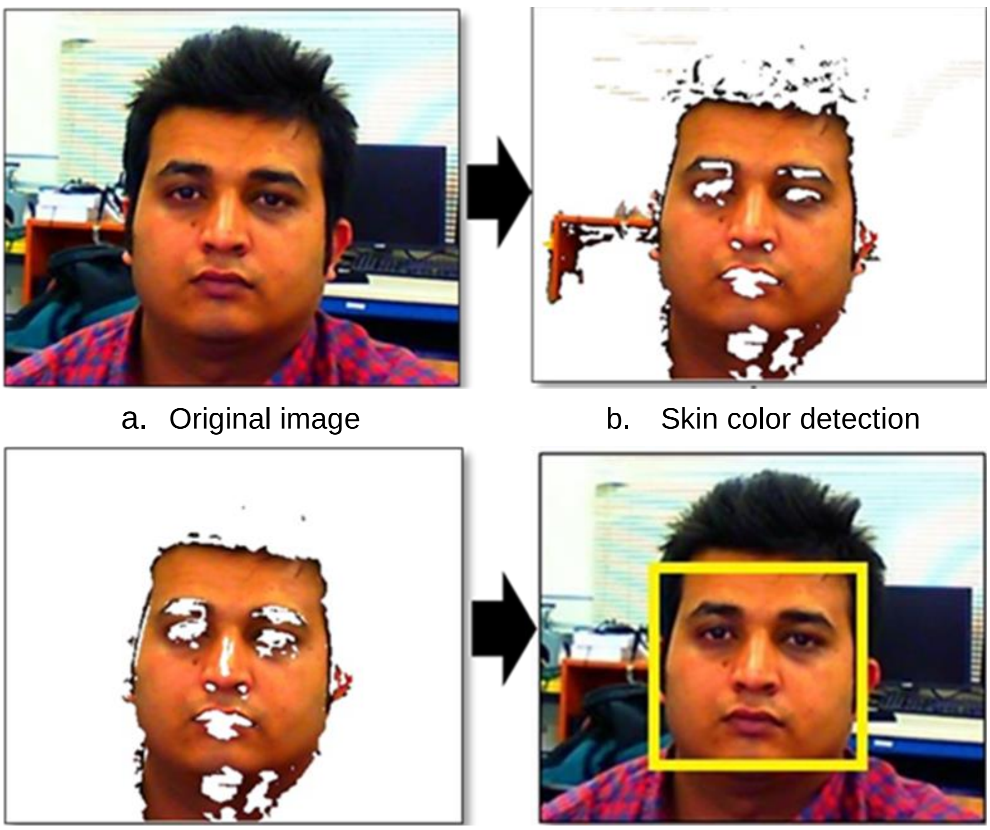


Fig.4.2. Facial geometry of the human face

The geometrical model creates three triangles by locating the facial components of an image. From the two facial features detected, the occluded facial features are located being based on the facial geometry calculation. Once the facial regions are located and three triangles are formed, the image is then processed to the UKF for removing the noise from the image. Finally, the image is passed to the modified Haar cascade classifier for final face detection.

4.2.2. Modified skin color detector

The modified skin color detector is developed from the idea of skin color detector [4-17]. In case of the skin color detector, the skin color regions are detected, but the pixels similar to the skin color are also detected together as a false positives as shown in figure 4.3 b. These false positives are known as noise.



a. Original image   b. Skin color detection

c. Noise filtered skin region   d. Face region detection

Fig. 4.3. Example of modified skin color detector

To remove these noises, a modified skin color detector was developed by adding a low pass filter [4-18], Sobel edge detector [4-19] and the color region detector [4-17] to improve the efficiency of the system. The figure 4.3 c and 4.3 d represents the effectiveness of the modified skin color detector. This process was used for extracting the facial region being based on the skin color region. Once the facial region is extracted, the system will be able to detect the facial features in the face.

4.2.3. Face cropping

The process of extracting the facial area from hair to the chin and from right ear to left ear is known as face cropping. It is also defined as the separation of the skin part of the face from the non-face parts. This process can be regarded as the preprocessing for the facial feature extraction. The Open CV face cropping tools is used for cropping the face from the given image.

Once the facial region is detected by using the modified skin color detector, the faces are cropped from hair to chin and from right ear to left ear as shown in figure 4.4. In this process, the skin part of the face is separated from those of the non-face part such as arms, hands and shoulders. The size of the image is standardized as having a maximum of 200 pixels in width in order to minimize the variation due to the head tilt, rotation and shift of the image.

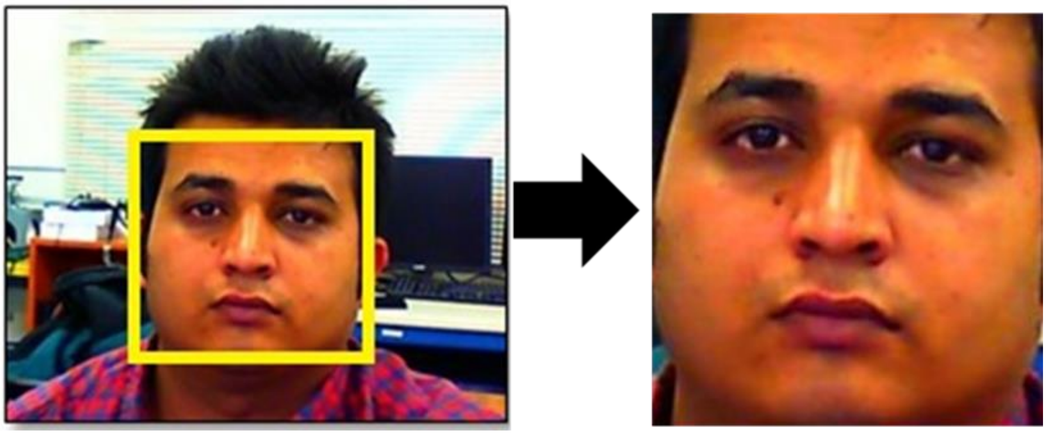


Fig. 4.4. Example image of face cropping

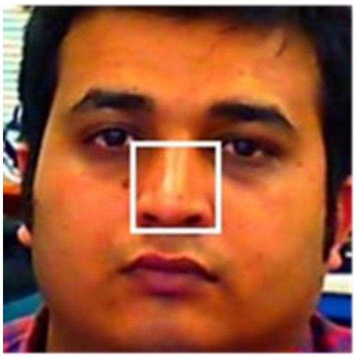


Fig.4.5. Nose detection using Haar cascade classifier

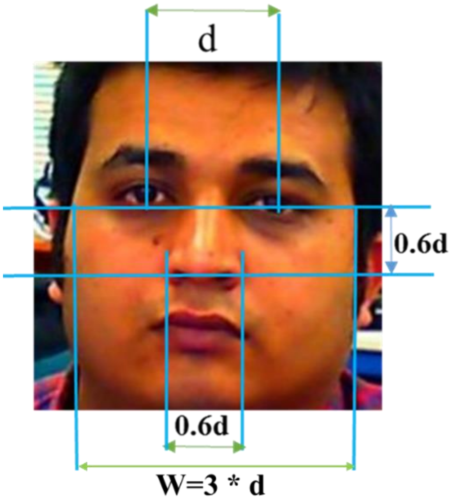


Fig.4.6. Height and width of the nose

4.2.4. Nose tip extraction

The nose tip extraction is the process of detecting the tip of the nose from the given facial image. To extract the tip of the nose, the nose region have to be detected at first. The nose region is detected by using the Haar cascades classifier [4-20]. The detected nose is shown in figure 4.5.

The defined width and height of the noise is 0.6d, where d represents the distance between two eyes as shown in figure 4.6. The height and width of the nose is calculated and determined by using the geometrical model as shown in figure 4.6 The nose is close to the center of the face so that the pixels that are closer to the centroid should be extracted using the morphological operations of the geometrical model.

The algorithm for extracting the nose tip is mentioned in the following steps.

1. Translate the co-ordinate to the centroid of the image.
2. Shift the position to the desired location.
3. Change the size of an object by scaling the image to the fixed size of square dimensions.
4. Taking the centroid, find the closest region of the nose tip by using morphological processing.

The morphological processing [4-21] is used to extract the tip point of the nose. The morphological processing is a collection of non-linear operations related to the shape or morphology features in an image. Morphological techniques probe an image with a small shape or template called structuring element. The structuring element is positioned at all possible locations in the image and is compared with the corresponding neighborhood of pixels.

The largest connected component which is closest to the centroid is the point known as the nose tip. The figure 4.7 reflects the detection of the nose tip or extraction of the nose tip. The distance and shape of the nose plays an important role in detecting or extracting the nose tip from the given facial image. The nose tip once extracted can form the triangles because the nose tip lies in the center of the face.

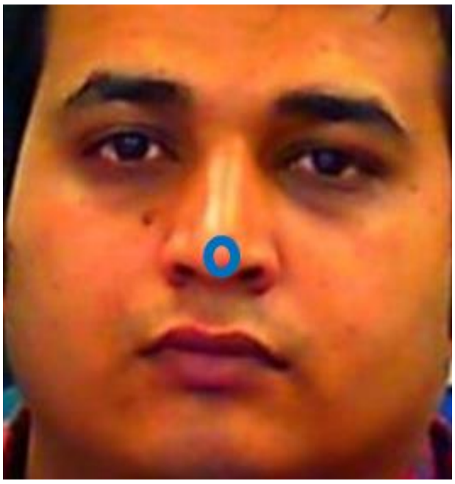


Fig.4.7. Nose tip extraction

4.2.5. Right eye and Left eye extraction

In the previous works, modified Viola Jones eye detector [4-1] is used for detecting the presence of the two eyes condition possible for face detection. In order to detect the presence of the eye in case of occluded eyes region, we have to calculate the distance of the eyes from the nose tip and detect the position of the eyes being based on the tip of the nose.

From the tip of the nose, we have to move upward towards the *y* axis and find the left and right side of the region to find the eye points as shown in figure 4.8. The face is divided into four sub parts keeping the nose point at the center. The morphological and filtering process are used to detect the center point of the eye in the darker region.

If the tip of the nose is occluded and the eyes are visible, the Viola Jones eye detector is applied for detecting the presence of the eyes, then from the eyes, a triangle is created and finally, apply the current process for verification.

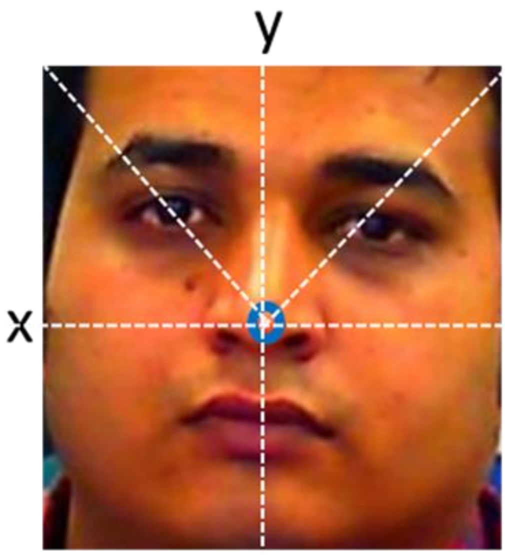
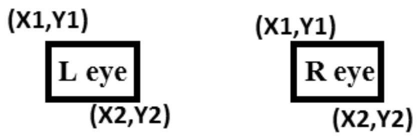


Fig.4.8. Geometrical construction for right and left eyes detection using nose point

The algorithm for detecting the right eye and left eye can be mentioned as,

1. Extract the right half of the face for the right eye and left half of the face for the left eye.
2. Find the gray image of the face.
3. Find the Max-Index on which the maximum difference between two adjacent intensities in the gray image of the face lies.
4. Extract a portion of a gray face image by using the given calculation.



$X1 = Max\text{-}index - (0.06*W)$

$X2 = Max\text{-}index + (0.06*W)$

$Y1 = 0.14*W$

$Y2 = W/2$

(Where, W is width of the face)

5. Apply median filter on the eyes
6. Normalize the eyes by adding 127 with the eyes and get a new matrix normalized eye.
7. Find edges of the eyes
8. Apply boundary detection algorithm [4-22] and get the exact eye region.

Fig.4.9. Left eye and Right eye detection

The figure 4.9 shows the detection of the right and left eyes. In this image, the nose is visible, so the eyes are calculated from the geometrical calculation using nose point.

4.2.6. Mouth / Lip extraction

The mouth / lip extraction is the process of extracting or detecting the region of the mouth in a face. The lips indicate the position of the mouth. Referring to the previous researches, there are lack of mouth detection results specifically dealing with the thick beard, mustache and open mouth.

In this process, the geometrical calculation is used for detecting or extracting the lip region.

The algorithm for detecting the lip region is mentioned below.

1. Predict the lip region as

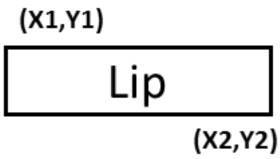
   $X1 = Lower\ nose + (0.05*W)$

   $X2 = Lower\ nose + (0.30*W)$

   $Y1 = 0.25*W$

   $Y2 = Y1 + 0.5*W$

   (Where, W is width of the face)



2. Apply median filter on the gray image of lip.
3. Normalize lip by adding 127
4. Find edges of the normalized lip
5. Using boundary detection algorithm and extract the lip region.

The figure 4.10 shows the division of upper face and lower face along with the horizontal axis X and vertical axis Y keeping the nose tip as a centroid. The figure 4.11 shows the mouth / lip region detection. The mouth / Lip is detected by using the geometrical process, when the nose point or eyes are visible.

In case of the occlusion of the other facial components except the mouth region, Haar cascade classifier is used. The two points of the mouths are calculated to form a triangle with the occluded nose tip and center of the mouth is calculated for creating the triangle with the two eyes.

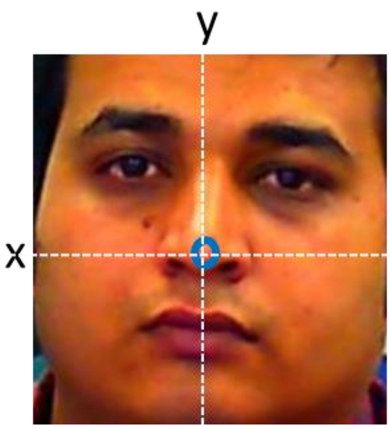


Fig.4.10. Upper and Lower face division

Fig.4.11. Lip/ Mouth detection

4.2.7. The Unscented Kalman filter (UKF)

In the current system, the unscented Kalman filter (UKF) is used for removing the film grain noise from an image in this process. The UKF is a method for calculating the statistics of a random variable which undergoes a nonlinear transformation. The two dimensional UKF for image restoration [4-23] is used in this process.

The film grain noise in an image is determined by the least squares method using the state equation and the measurement equation, then the detected noise are filtered by using the UKF. UKF is recognized for clearing the film grain noise from the image [4-13]. UKF is the only process for removing the film grain noise.

The image is scanned by using the non-symmetric half plane model (NSHP model). The image is scanned from the top-left pixel and scan the first column from top to the bottom. This process is applied for several times to achieve a better result with the noise filtered image. A noise filtered image using the UKF helps to increase the face detection rate.

4.2.8. Modified Haar cascade classifier

In the current research, the Haar cascade classifier is used for detecting the multiple faces or detecting and verifying the final faces in an image. Haar cascade classifier have various features required for the face detection. The Haar cascade classifier is modified by combining with the clustering algorithm for clearing the false positives from the images.

The clustering algorithm is used in this process because, the algorithm can be used for basic pixel level to feature level for the classification of the facial images. This system is used in order to reduce the false positives from the given image. The detection of the image part even without the presence of face is known as false positives.

As a current research is based on the occluded faces, this process is effective for working with the geometrical calculation of the facial features. The figure 4.12 shows the detected faces with the major facial components or facial features. In figure 4.12, the facial features are not occluded, so the nose is detected at first, then the nose tip, two eyes, lip/mouth and the whole face is detected.

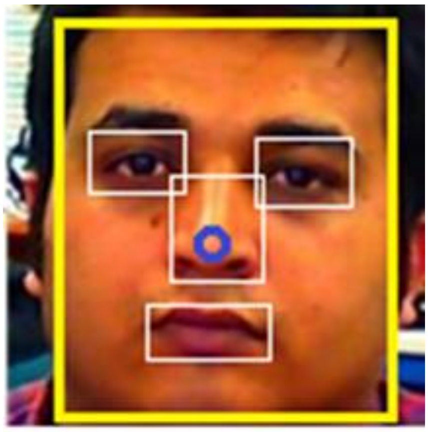


Fig.4.12. Face detection with facial features and nose point

4.3. Geometrical model

4.3.1. Three triangle process

The current system is able to find the nose point, eyes and lips as a facial components by using the proposed algorithm of geometrical approach. This process creates a triangle from the point of different facial features. The occluded facial features are detected only when the system is able to detect the two feature points of the face i.e. either two eyes, one eye or nose tip, nose tip or mouth/lip and either an eye or mouth/lip. From the two detected points, a triangle can be developed to detect the occluded feature.

To make the algorithm work together for detecting the position of the facial components even if they are occluded, the three triangles are constructed by using the facial feature points as shown in figure 4.13. The relationship between the facial features can be presented by their relative distance and positions as shown in figure 4.2. In a frontal face image, the eyes, nose and the mouth can be represented by using three triangles method. Where the eye comes at the top, nose in the middle and the lips / mouth at the bottom.

The figure 4.14 reflects the detection of face and facial components along with their geometrical relations. This process is useful for detecting the occluded facial component of the facial images as shown in figure 4.15 and 4.16. When the facial features are occluded, this process executes to calculate the region and location of the occluded parts.

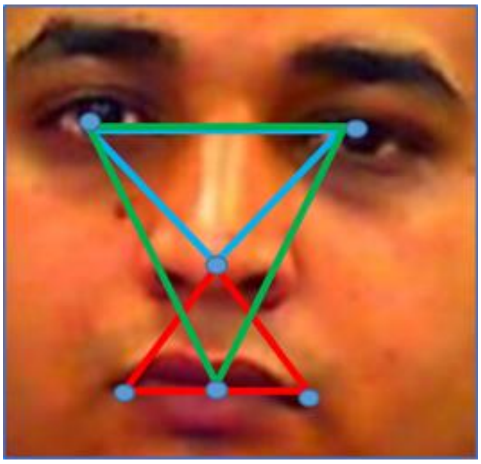


Fig.4.13. Geometrical relation of the facial features

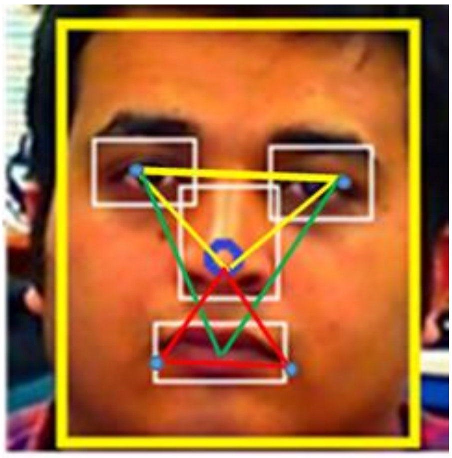


Fig.4.14. Face detection with all facial features

In figure 4.15, the mouth and the nose is occluded by the mask. In this case, the process detect the two eyes by using the modified Viola Jones eye detector and search the nose tip and the mouth points by using the geometrical calculation process. Once, all the facial features are located, the height and weight of the face is calculated to locate and detect the face region.

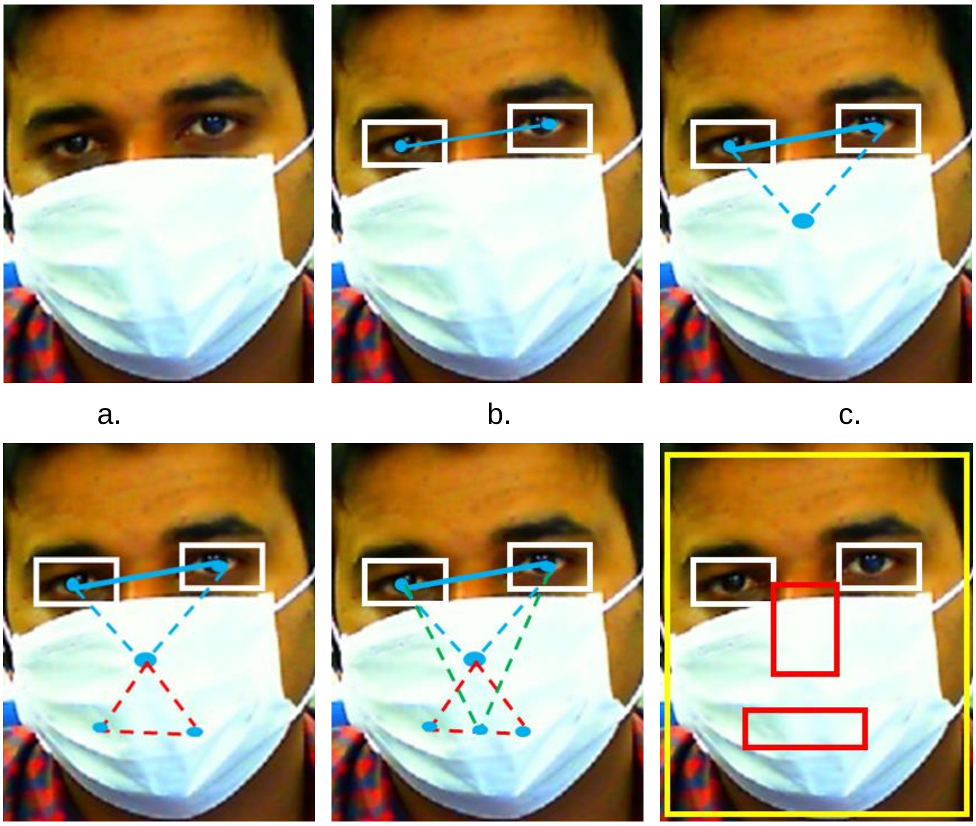
In figure 4.16, the mouth is occluded by the mask and left right eye is occluded by the hand. In this case, the nose is detected at first by using the Haar cascade classifier, detects the nose tip, and left eye. The two facial feature points search for the right eye region to form a triangle and finally after locating all the facial region, the face region is located and detected.

Fig. 4.15. Occluded nose and mouth by mask

Fig. 4.16. Occluded right eye and mouth by mask

4.3.2. Process for masked facial feature detection

A three triangle approach for face detection on occluded facial features image is developed. The diagrammatical representation of the process for masked face detection is shown in figure 4.17 along with the process of our proposed system for occluded facial features detection.



a. b. c.

d. e. f.

a. Occluded face image with mask

b. Two feature point's detection

c. Nose point detection

d. Mouth point detection

e. 3 triangle formation

f. Occluded facial features and face detection

Fig.4.17. Process for masked face detection

In figure 4.17, we can see the process of face detection for masked image. In this figure, “a” is the original image with a masked face, where the facial features like mouth and nose are occluded with a mask. Figure “b” shows the detection of two eyes and eye points along with a line joining the two points. Figure “c” shows the formation of the triangle with the detection of the nose point by calculating the distance from the two eyes detected.

Figure 4.17 d shows the detection of mouth points and formation of the second triangle by calculating the distance between the mouth, nose tip and the two eyes. In figure “e”, the three triangles are formed by calculating the center point of the mouth and connecting it with two eyes detected. Finally, after locating all the facial features, the detected eyes, located nose, located mouth along with the detected face is shown in the figure “f”.

4.4. Experimental results and evaluation

4.4.1. Tools and databases used

In order to validate the proposed algorithm, a C programming code is developed for implementing the proposed system. The experiments are performed using the PC (i7-3770 CPU, 8GB main memory and Windows 8.1 64 bit) machine. Some experiments were performed on different types of occluded images from CMU-MIT database [4-14], FDDB database [4-16] and INRIA database [4-15].

The images that were not detected by our previous works [4-1] [4-2] due to the occlusion conditions are now detected by using the current proposed method [4-29]. We are using only the occluded facial images for our current experimentation.

4.4.2. Evaluation and benchmarking

The experimental results of the occluded images by using the proposed method is shown in figure 4.18. The figure in 4.18 a, and 4.18 b, is taken from the CMU-MIT database, c, d, e, f and g are taken from the FDDB database and 4.18 h is taken from the

INRIA graz-01 database. These images were not satisfied by our previous works [4-1] [4-2].

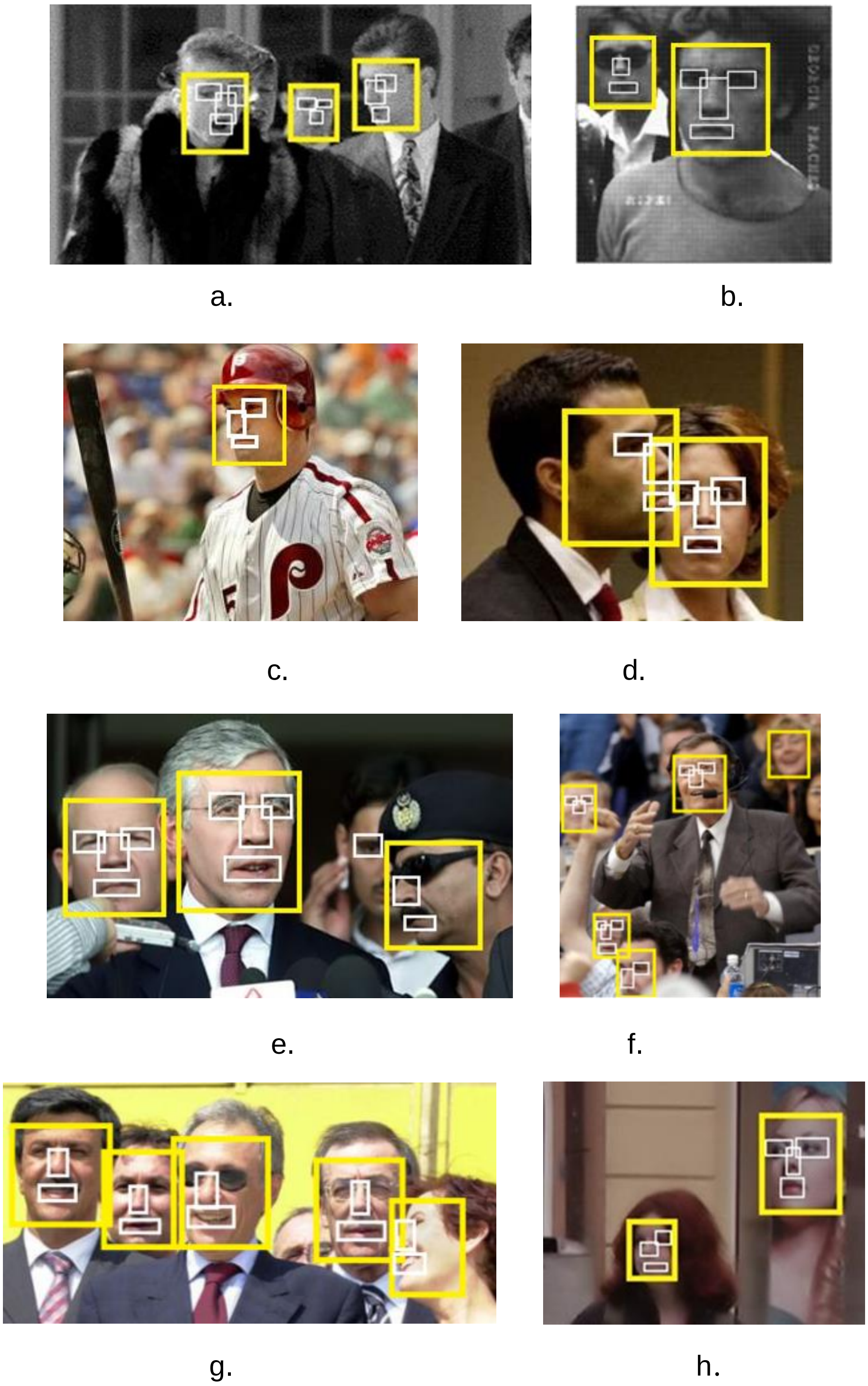


Fig.4.18. Experimented images under various occlusion conditions

In all of these figures, the faces partially visible or occluded are detected. In the proposed system, if two of the facial components are visible, then the system can detect the face with the geometrical relation and calculation of the position of the face, but if any of the facial components are not visible, the image remains undetected like one of the facial features invisible image in figure 4.18 a.

In figure 4.18 b, the two faces are detected, one face with the black glasses with the occluded eyes is also detected, because the nose and the mouth is clearly visible. In figure 4.18 c, the face image with a helmet and side faced image is also detected because the left eyes and the nose point is and one mouth point is visible. In figure 4.18 d, the side faced image of a guy with partially occluded facial features is detected, along with the detected lady's face without any occlusion.

In figure 4.18 e, the man with side faced, wearing a black glass is detected because of the visibility of the nose point and the mouth point in this image. Similarly, in the same image, the man talking on the phone at the back is occluded by the side faced man, with the visibility of an eye. The system detects the presence of one eye for this man, but the occluded facial features and the face isn't detected. It is due to the invisibility of the two facial features in a face.

In figure 4.18 f, five faces are detected even some of them have several occluded facial features but, the faces without two visible facial features are not detected. In figure 4.18 g, there seems to be the six faces, but only five faces are detected. It is also due to the problem of detectable facial features count. Finally, in the figure 4.18 h, the faces of two ladies are detected. In this figure, one lady is inside the picture with a slight occlusion but all of the facial features are detected which results to the proper face detection.

A benchmarking test is performed based on the FDDB database and draw ROC curves to evaluate the position of the current proposed algorithm. The ROC curve in figure 4.19 shows the face detection rate of the proposed algorithm compared with the previous works [4-1] XZYJ method [4-24] and viola Jones face detector [4-24]. The ROC curve is drawn from the first 2000 images from the FDDB database, by referring the ROC curves shown in Reference [4-24].

The proposed algorithm shows the highest face detection rate compared to the previous work, XZYJ method and the Viola Jones face detector. The ROC curve clearly reflects the increase in the face detection rate of the proposed algorithm, after clearing the condition of occlusion. The face detection rate is 84.1% with the calculation time of 0.33 millisecond in case of FDDB database.

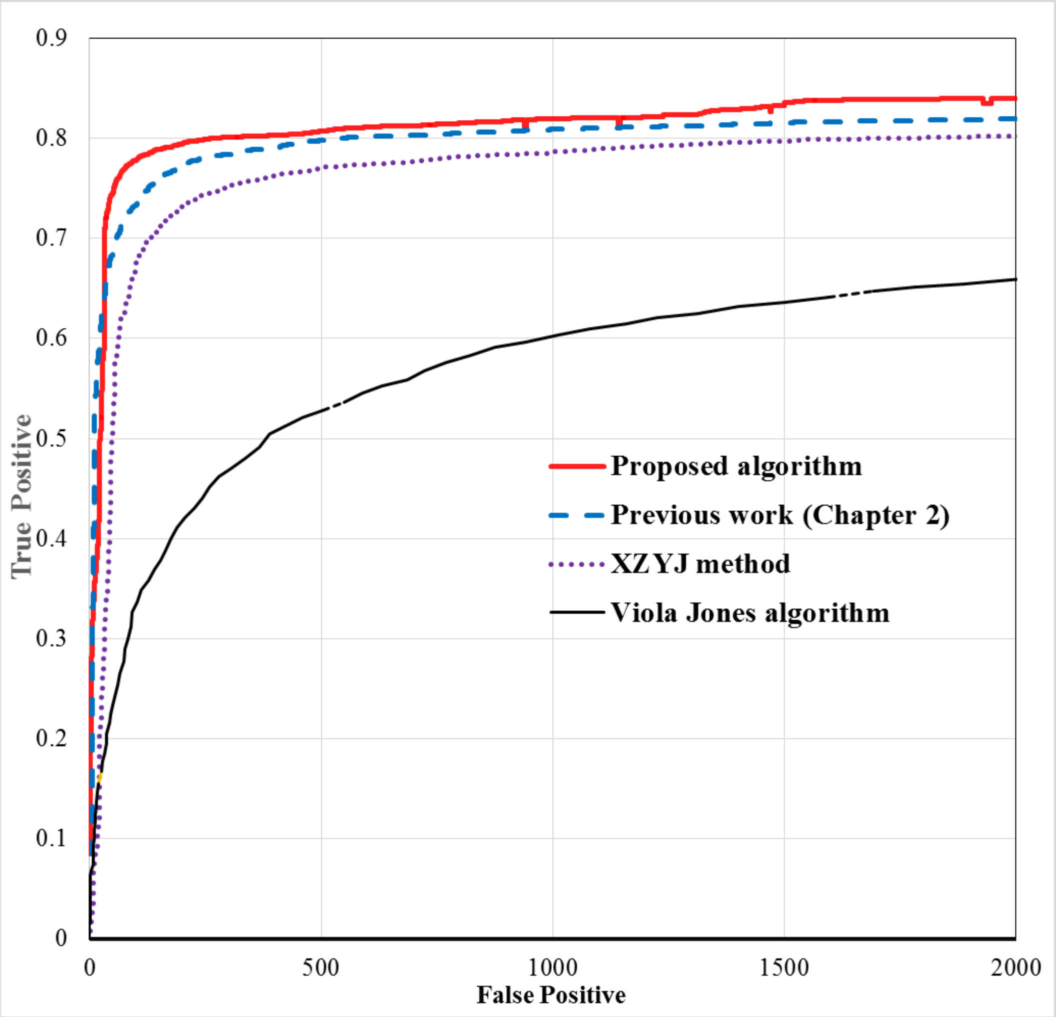


Fig.4.19. ROC curve for comparing our proposed face detector for occlusion

4.5. Discussion of this chapter

In this chapter, a novel face detection algorithm for occluded images based on the geometrical model of nose point extraction was presented. The face and the facial components were detected by using the method of noise point extraction.

This process helped to clear the environmental condition of occlusion for face detection and increase the face detection rate on FDDB database when compared to the previous works. The face detection rate of the proposed algorithm by using FDDB database was 84.1%. The calculation time of the proposed system is 30fps that equals to the 0.33ms.

Various experiments and the benchmark tests were performed under the occlusion condition by using the proposed algorithm. The proposed algorithm can detect the faces under different occlusion conditions. This research was started as the development of the high performance face detector described in chapter 2, are able to clear the environmental condition of occlusion by using this proposed method.

The three triangle geometrical calculation process combined with the high performance face detector, helped to detect the facial components and face from the image by calculating the distance, height and width of the facial components. The three triangle methods detect either of the two facial components and calculates the position of the other occluded facial features and finds out the actual position of the face. The presence or absence of the structural components in a face such as the faces with beard, masks, and glasses on the eyes, hidden facial parts and partially visible faces are detected by the proposed algorithm.

The combination of the three triangle method geometrical calculation using noise point method and the Unscented Kalman filter reflects the novelty of the current research.

Chapter 5

Conclusions and future research

5.1. Conclusions

In the current thesis, a robust high performance face detector under different environmental conditions was developed for increasing the face detection rate. This research focuses on three main environmental conditions or problems of the face detection. The three main environmental conditions are the image noise, illumination variant images and the occluded facial features. The efforts to overcome up with these problems plays an important role in the field of face detection.

Based on the research works, this dissertation can be summarized as follows.

1. The three different process for the face detection have been developed in this thesis. The high performance face detector using UKF was developed as a first process to work on image noise, where the skin color detector, Haar cascade classifier and the Unscented Kalman filter process are modified and combined. The combination of these three process, in the face detector reflects the novelty of our system.
2. An image enhancement system was developed by using the stochastic resonance (SR) technique to work under dark and illumination variant images as our second process. The image enhancement system was then combined with the high performance face detector for detecting the presence of face on illumination variant images. The implementation of SR in the face detection algorithm reflects the novelty of the second process.

3. The geometrical model approach for face detection on occluded facial features was developed as a third process to work on partially occluded facial features and occluded faces. In the current process, the high performance face detector was combined with the geometrical model approach. The three triangle process reflects the novelty of the proposed algorithm.
4. By combining these three process, robust face detector under various environmental condition was developed. The highest face detection rate on FDDB database was 84.1%, face detection rate on CMU-MIT database was 98.3% and the calculation time was 0.33millisecond.

More specifically, Chapter 2 deals with the high performance face detector that detects the presence of face under various environmental conditions like: different scales, multi faces image, rotated images up to 90 degree and the noisy images with the film grain noise.

The first section was about the modified skin color detector, which was developed by combining the skin color detector along with the low pass filter, Sobel edge detector and color region detector. The modified skin color detector was aimed to remove the unnecessary noise similar to the skin color and were able to make it happen.

The second section was about the modified Viola Jones eye detector, which was developed by combining the Viola Jones eye detector with the geometrical test. This process was used to detect the presence of the two eyes in a face detected by using the modified skin color detector. The accuracy of the face detection was increased by this process.

The third section was the Unscented Kalman filter (UKF) process, used for removing the film grain noise from the image. The UKF is the only process, to work on for the film grain noise, which have been applied on the proposed system.

The fourth section was the modified Haar cascade classifier, combined with the clustering algorithm to detect the multiple faces in an image without any false positives. This process was used for the verification of the detected faces as well. The combination of these ideas and process, were able to develop the high performance face detector with a face detection rate of 98% on CMU-MIT database and 81.9% on FDDB database with the calculation time of 0.33 millisecond.

Chapter 3 deals with the face detector on illumination variant images. The modified SR was developed for the enhancement of dark and illumination variant images and combined with the high performance face detector. The dark and invisible images were made visible and made able to be detected by the high performance face detector. The system worked clearly on the original illumination variant images rather than the contrast adjusted images, which were not satisfied by other face detectors.

Chapter 4 deals with the face detector, that works on partially occluded facial features. The system was developed by studying about the geometrical construction of the face being based on the facial geometry. The distance, angle, width and height of the facial features were used to locate the occluded facial features. The process was developed by combining the systems that were used for high performance face detector.

The combined system increased the face detection rate compared to the previous works and the face detection rate was gained as 84.1% on FDDB database and 98.3% on CMU-MIT database. The average computational time for the proposed face detector was calculated to 30 fps (frame per second). This result shows the effectiveness of the proposed robust high performance face detector.

5.2. Future research

This dissertation developed and discussed the robust high performance face detector under various environmental conditions on still images. As an extension of this research, we will work on the development of the robust face detector on video images. The current system will be made able to work on with the video images by modifying the current process in use.

The GPU and Deep Learning technology will be used for the fast computation of the face detection system to work in a real time. The problem of facial expressions will be performed by using the Deep learning. Once these problems are all solved, we will extend our work to the face recognition stage, for recognizing and identifying the person on a huge data within a short time. This system will be modified and will be made available for working with the robots and security sectors.

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