

A Robust Face Detection Method Based on Skin Color and Edges

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Abstract—In this paper we propose a method to detect human faces in color images. Many existing systems use a window-based classifier that scans the entire image for the presence of the human face and such systems suffers from scale variation, pose variation, illumination changes, etc. Here, we propose a lighting insensitive face detection method based upon the edge and skin tone information of the input color image. First, image enhancement is performed, especially if the image is acquired from an unconstrained illumination condition. Next, skin segmentation in YCbCr and RGB space is conducted. The result of skin segmentation is refined using the skin tone percentage index method. The edges of the input image are combined with the skin tone image to separate all non-face regions from candidate faces. Candidate verification using primitive shape features of the face is applied to decide which of the candidate regions corresponds to a face. The advantage of the proposed method is that it can detect faces that are of different sizes, in different poses, and that are making different expressions under unconstrained illumination conditions

Keywords—Face Detection, Image Enhancement, Skin Tone Percentage Index, Canny Edge, Facial Features

1. INTRODUCTION

Face detection is concerned with finding whether or not a face exists in a given image; if face is present, it returns the image location and face size. This is the first step of any fully automatic system that analyzes the information contained in faces (e.g., identity, gender, expression, age, race, and pose). The advance of computer technology in recent years has facilitated the development of real-time vision modules that can interact with humans. Examples abound, particularly in biometric and human computer interaction, as the information contained in faces needs to be analyzed for systems to react accordingly. Faces first need to be located and registered to facilitate further processing to detect facial features accurately for applications, such as digital cosmetics. It is evident that face detection plays an important and critical role for the success of any face processing system. Often, face recognition systems work by applying a face detector to locate the face, and then apply a separate recognition algorithm to identify the face.

Face detection is a difficult problem that consists of finding one or more faces in an image or

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in a video sequence under different situations. This difficulty originates from the fact that the face is not a rigid body and the different conditions under which the image or the sequence of images was acquired. The main challenges facing any face detection system typically include pose variation, the presence or absence of structural components, facial expression, occlusion, image orientation, imaging conditions, and background variations.

Various algorithms, including skin color based algorithms, exist for face detection. Color is an important feature of human faces. Using skin-color as a feature to detect a face has several advantages. Color processing is much faster than processing other facial features. Under certain lighting conditions, color is orientation invariant. However, color is not a physical phenomenon related to the spectral characteristics of electromagnetic radiation in the visible wavelengths striking the retina.

Mainly, the face detection techniques are classified into four categories [1]: *knowledge-based methods*, *feature invariant approach*, *template matching methods*, and *appearance-based methods*. Table 1 of [1] summarizes the early algorithms and representative work for face detection in a single image within four categories.

Knowledge based methods are based on human knowledge of the typical human face geometry and arrangement of facial features. Facial features in an input image are extracted first, and face candidates are identified, based on the coded rules. A verification process is usually applied to reduce false detection. Several methods to detect faces based on facial appearance have been developed [2-3].

Feature invariant approaches aim to find structural features that exist, even when the viewpoint or lighting conditions vary, and then use these to locate faces. Different structural features, such as, facial local features, texture, shape, and skin color, are used. Local features, such as the eyes, nose, eyebrows, and mouth, are extracted using different methods. Statistical models are then built to describe their relationship and verify the existence of the face. The color-based approach labels each pixel according to its similarity to skin color, and subsequently labels each sub-region as a face, if it contains a large blob of skin color pixels. A survey on pixel-based skin color detection technique can be found in [4]. Numerous research has been conducted for face detection based on skin color; some of them are [5-12]. Skin color in combination with the edge of the input image is used to detect the face to improve the detection accuracy and can be found in [13-15].

In template matching, a standard face pattern, usually frontal, is manually predefined or parameterized by a function. Given an input image, the correlation values with the standard patterns are computed for face contour, eyes, nose, and mouth independently. The existence of the face is determined based on the correlation values. For example, J. Wang and H. Yang [16] presented face detection based on template matching and 2DPCA.

While template-matching methods rely on a predefined template or model, the “templates” in appearance-based methods is learned from examples in images. Face detection can be viewed as a pattern classification problem with two classes, “face” and “non-face.” The “non-face” class contains images that may depict anything that is not a face, while the “face” class contains all face images. Well-known appearance-based methods used for face detection are eigenfaces, LDA, neural networks, support vector machines, and hidden Markov models.

In this paper, we use a feature invariant approach that is based on skin and edge information for face detection. The main contributions of this paper are the use of image enhancement as a preprocessing operation to adjust the illumination of the input image, the combination of skin

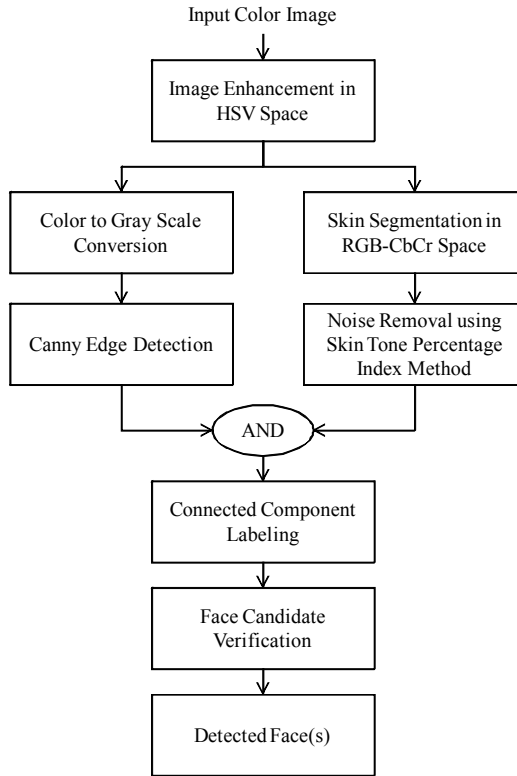


Fig. 1. Flow chart of the proposed face detection procedure

and edge information to improve the face detection rate, and the use of primitives shape features for fast and efficient face candidate verification. Fig. 1 depicts the complete system. It starts with image enhancement. The result of the enhancement is subjected to skin segmentation, which contains the possible face candidate, followed by the skin tone percentage index method for region adjustment and noise removal. In contrast, the gray component of the enhanced image is subjected to edge detection. Results from both ends are combined and each component is analyzed for verification as a face or non-face.

The remainder of the paper is organized as follows: Section 2 briefly describes the image enhancement procedure. Section 3 contains the detailed description of face detection. Section 4 shows some experimental results, along with evaluating the performance of the proposed method. Finally, the conclusion is given in Section 5.

2. COLOR IMAGE ENHANCEMENT

Image enhancement is an important preprocessing technique for face detection, especially if the images are acquired in unconstrained illumination conditions. Face detection using skin color information is greatly affected by the lighting condition in which the image is taken. Images in various lighting conditions need to be enhanced to a uniform lighting environment.



Fig. 2. Color image enhancement: Input image (left) and corresponding enhanced image (right)

Sung et al. [17] used linear lighting correction and histogram equalization to improve the image before face detection. A well-known face detection method proposed by Viola and Jones [18] uses a similar method as a preprocessing operation. However, some faces in the image appear different due to changes in nonlinear lighting. Therefore, Li Tao et al. [19] use a nonlinear image enhancement algorithm to improve the visual quality of the image. In this paper, we used a nonlinear transfer function that is based on a local approach for color image enhancement [20], to enhance the image to a uniform lighting environment. Instead of RGB space, this method uses HSV space for image enhancement. The V channel is taken from the HSV image and is subjected to enhancement. It consists of two separate processes, luminance enhancement and contrast enhancement. First, dynamic range compression is performed on the V channel image using a nonlinear transfer function. Next, each pixel in the image is further enhanced to adjust the image contrast, depending upon the center pixel and its neighborhood. Finally, the original H and S component images and enhanced V component image are converted back to the RGB image. Fig. 2 shows the result of image enhancement using this method. More details about the luminance and contrast enhancement process are explained in the following subsection.

2.1 Luminance Enhancement

Luminance enhancement is first applied to the value component of the input HSV image using Eq. (1). Suppose that $V_I(x, y)$ denotes the normalized V channel in the color HSV space and $V_{LE}(x, y)$ becomes the transferred value by applying nonlinear transfer function defined as follows:

$$V_{LE} = \frac{V_I^{(0.75z+0.25)} + 0.4(1-z)(1-V_I) + V_I^{(2-z)}}{2} \quad (1)$$

where z is the image dependent parameter and is defined as follows:

$$z = \begin{cases} 0 & \text{for } L \leq 50 \\ \frac{L-50}{100} & \text{for } 50 < L \leq 150 \\ 1 & \text{for } L > 150 \end{cases} \quad (2)$$

where L is the value (V) level corresponding to the cumulative probability distribution function (CDF) of 0.1.

In Eq. 1 the parameter z defines the shape of the transfer function or the amount of luminance enhancement for each pixel value. As the amount of illumination in different regions of the image is different, instead of using global z parameter we calculated the local z parameter for each small region of the image by dividing it into small blocks and then the luminance enhancement is carried out accordingly.

2.2 Contrast Enhancement

Contrast enhancement improves the overall quality of the image. Gaussian convolution using the Gaussian function $G(x, y)$ is first applied with the input value channel image in the HSV space. The convolution process can be expressed as follows:

$$V_{CON}(x, y) = V_I(x, y) \otimes G(x, y) \quad (3)$$

V_{CON} in Eq. 3 denotes the convolution result, which contains the luminance information from the surrounding pixels. The center pixel value is now compared with the Gaussian convolution result in order to find the amount of contrast enhancement of that center pixel. This process is described by the following equation:

$$V_{CE}(x, y) = 255 V_{LE}(x, y)^{E(x, y)} \quad (4)$$

where $V_{CE}(x, y)$ is the result of contrast enhancement and $E(x, y)$ is given by the following relation:

$$E(x, y) = (V_{CON}(x, y) / V_I(x, y))^g \quad (5)$$

Here g is the image dependent parameter determined by using the standard deviation of the input value channel image. If the center pixel is brighter than the surrounding pixels, the contrast of the pixel is pulled up. On the other hand, if the center pixel is darker than the neighboring pixel then the contrast of the pixel is lowered.

3. FACE DETECTION

This section describes all the steps that are employed for face detection. Image segmentation is performed using edge and skin color information after enhancement in the input image. Next, the connected components are analyzed individually for face verification. The detailed descriptions are given in the following subsection.

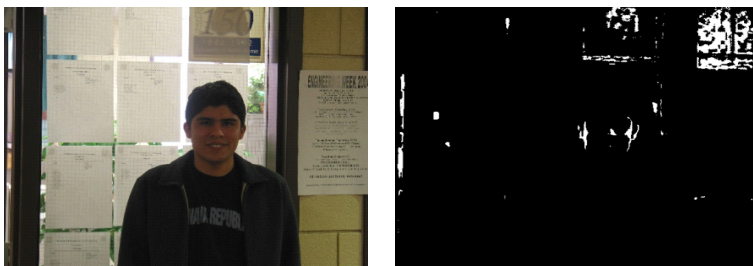
3.1 Skin Color Segmentation

Skin color has proven to be a useful and robust cue for face detection, localization, and tracking. Numerous techniques for skin color modeling and recognition have been proposed. A study

on skin segmentation using color pixel classification has been presented by S. L. Phung et al. [21]. A thorough survey of pixel-based skin color detection techniques can be found in [4]. Feature-based face detection methods using skin color as a detection cue, have gained strong popularity. Color allows fast processing and is highly robust to geometric variations of the face pattern. The method of skin detection falls into two main categories: pixel-based methods and region based methods. Pixel-based methods classify each pixel as skin or non-skin individually, independently from its neighbors. In contrast, region-based methods try to take the spatial arrangement of skin pixels into account during the detection stage to enhance the method's performance.

Numerous studies have been done to find the optimal color space for skin color distribution. Some popular examples of color spaces are RGB, Normalized RGB, YCbCr, HSI (Hue, Saturation, Intensity), TSL (Tint, Saturation, Lightness), HSV (Hue, Saturation, Value), HSL (Hue, Saturation, Lightness), as well as many others. Here, we use RGB and YCbCr color space for skin segmentation. We chose RGB space, as there is no need for color space transformation and we already adjusted the illumination of the input image using image enhancement in the HSV space. The transformation simplicity and explicit separation of luminance and chrominance components make the YCbCr color space very popular. Many researchers believe that skin segmentation in the YCbCr space provides better results. The result of RGB and YCbCr segmentation are multiplied together to find the combined result.

The final goal of skin color detection is to build a decision rule that will discriminate between skin and non-skin pixels. We used explicitly defined rules to build the skin classifier. The simplest model is to define a region of skin tone pixels in the YCbCr color space using Cr and Cb



(1)



(2)

Fig. 3. Result of skin color segmentation (1) without applying image enhancement (2) after applying image enhancement

values from samples of skin color pixels. According to D. Choi et al. [22] the ranges of Cb and Cr for all types of input color images are [77, 127] and [133, 173] respectively. Similarly, according to J. Kovac et al. [23] the rules for skin segmentation in RGB space is given by:

$$\begin{aligned}
 &R > 95 \text{ AND } G > 40 \text{ AND } B > 20 \text{ AND} \\
 &\max\{R, G, B\} - \min\{R, G, B\} > 15 \text{ AND} \\
 &|R - G| > 15 \text{ AND} \\
 &R > G \text{ AND } R > B
 \end{aligned}$$

The result of skin segmentation using those rules is given in Fig. 3.

3.2 Skin Tone Percentage Index (STPI) Based Region Refinement

The skin tone percentage index (STPI) based method is used to filter non-skin tone face areas. Many authors use morphological operations after skin segmentation to remove the skin noise pixels, as well as to fill in small areas for result refinement. However, we know that the morphological operations, such as erosion, and dilation, have an equal effect in all regions of the image. For example, if we apply the erosion operation after skin segmentation to remove skin noise pixels, it simultaneously reduces the size of the regions containing faces. It sometimes disconnects the regions that need not be disconnected. The dilation operation has a similar but opposite effect. We used the STPI method proposed by Y. Huang et al. [24] to overcome this disadvantage in refining the results of skin segmentation. The main advantage of this method is that, with a carefully selected threshold, we can remove the noise like skin pixels from the skin segmented image and simultaneously the non-skin pixels are filled with skin pixels if most of the neighboring pixels belong to the skin pixels.

$$S_n(x, y) = \sum_{i,j=-1}^1 I(x+i, y+j) \quad (6)$$

Suppose the binary image is $I(x, y)$, in a 3×3 neighboring area, including the point itself. The sum matrix is computed to count the neighboring areas' binary image values. Thus, the possible value for $S_n(x, y)$ would be in the set of $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$. $S_n(x, y)$ is now thresholded using the second filter, which is given as:

$$S(x, y) = \begin{cases} 1, & \text{if } S_n(x, y) \geq T \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

According to the percentage of 1, 2, 3 respectively in $S_n(x, y)$, the threshold T may be 1, 2, 3, etc. Fig. 4 shows the results after applying STPI with different threshold values (T).

From Fig. 4 it is clear that only by varying the threshold value we have both erosion and dilation like results. Therefore, according to the percentages of 1, 2, 3 etc. in the sum matrix of the binary image, we can select the threshold value to produce suitable results.

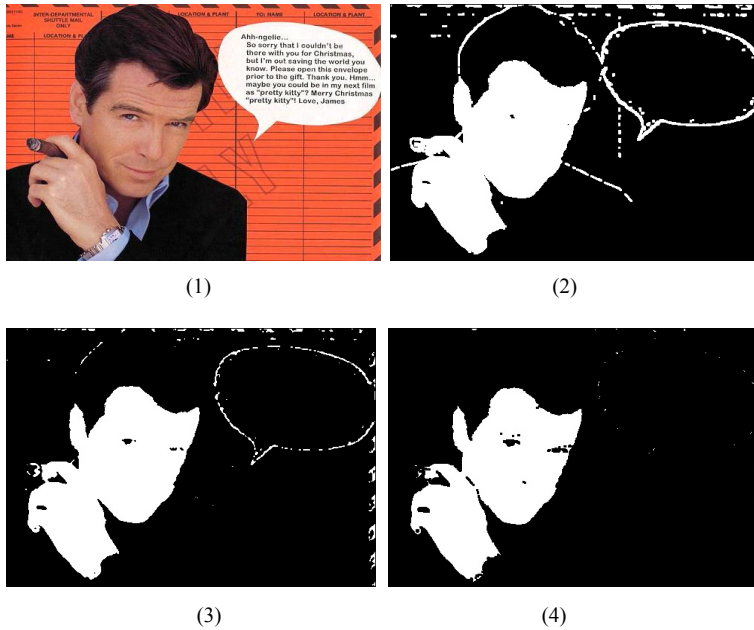


Fig. 4. Noise removing using STPI: (1) Original image, skin segmentation and STPI with (2) $T = 0$, (3) $T = 4$, (4) $T = 8$ in Eq. 7

3.3 Segmentation Using Skin Color and Edges

Most skin color based face detection algorithms consider images with a non-skin tone background, people wearing non-skin tone clothing, etc. However, the situation will be different if images contain skin tone backgrounds, as shown in Fig. 5. In such cases, the entire region is identified as a skin region. Sometimes the skin region of a face may connect to the skin region belonging to the background (Fig. 5). Therefore, a mechanism is needed to disconnect those background regions from face regions for easy localization of the face in the images.

The result from the previous step is now combined with the edge of the input image to solve this problem. Specially, the edges are needed to separate the skin-segmented regions from the background. Therefore, the edge of the input image is determined first.

Some common methods used for edge detection are the Sobel edge, Robert's cross edge, Canny edge, Prewitt edge, and the Laplacian of Gaussian edge. We used the Canny algorithm for edge detection. Even it is more computationally complex than other methods; it outperforms all the other available edge detection algorithms in all aspects. We can vary the lower and upper threshold to control the edge density in an image in this method. The image boundaries generated by the Canny method are thinner, so we applied the morphological dilation operation. One issue with the Canny edge detection algorithm is that we need to specify a high threshold and a low threshold. We use a simple threshold selection scheme using the mean of the gray scale image pixel values. We set the low threshold to be $0.7 \times [\text{mean value}]$, and the high threshold to be $1.5 \times [\text{mean value}]$. These values are found to be suitable for our face detection purposes. Fig. 6 shows an example of edge detection using Canny's algorithm with auto threshold selection and corresponding dilated and complemented edge image.



Fig. 5. Input color images and corresponding skin tone images

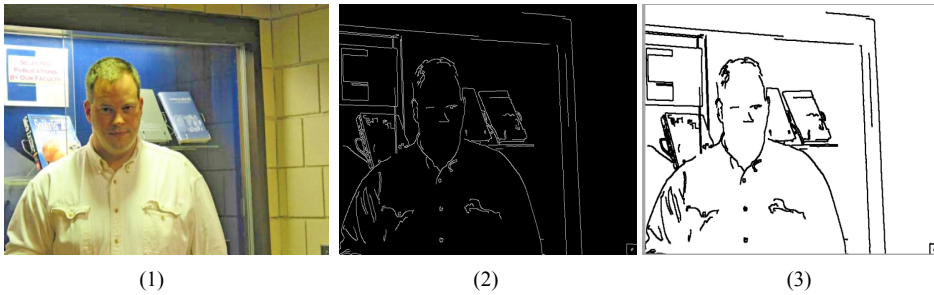


Fig. 6. Edge detection: (1) Input image after applying image enhancement, (2) Canny edge image with auto thresholds (lower threshold = 100, upper threshold = 229), and (3) corresponding dilated and complemented edge image

Fig. 7 (1) shows the dilated and complemented Canny edge images of the input images shown in Fig. 5. The result of the canny edge image combined with the skin segmented image using logical AND operation are shown in Fig. 7 (2). We can see the skin tone region belonging to the face and background are now separated (see Fig. 5). Finally, the hole-filling algorithm is used to fill the holes inside the binary component. This is useful if there are holes inside the face region due to edges.

3.4 Connected Component Labeling

The resulting image, which is a combination of the skin tone image and edge image, as shown in Fig. 7 (2), is now searched for connected components according to the adjacent 8-neighbor pixels. The algorithm works as follows:

1. The 1D connected components of each row are labeled first.
2. The labels of row-adjacent components are merged using an associative memory scheme.



Fig. 7. Segmentation using edge and skin: (1) Canny edge with manual thresholds, (2) edge and skin segmentation results with separated face and background regions

3. After merging, a relabeling is performed to give a consecutive set of positive component labels.

At the end of this process, all the connected components are found and the next step is to decide which connected components correspond to a face and which do not.

3.5 Face versus Non-Face

Each of the connected components is then analyzed to judge whether it is a face. Suitable discriminative criteria, which are extracted from prior knowledge about facial geometric structure and shape features, are defined to filter the explicit non-face regions. Each of these features can be considered as a weak classifier. The features are:

1. *Area*: Generally, the components with small areas correspond to the non-face components or simply we can say are noise generated in the segmentation process. Thus, the components with small areas are dropped.
2. *Bounding Box Proportions*: The anatomy of the face suggests that the ratio of the bounding box width to its height is in some fixed range. So, any component satisfying the following condition is classified as a face component: $Tl < R < Th$, where Tl is the lower bound and Th is the higher bound and R is the ratio. In our experiment we use $Tl = 0.5$ and $Th = 1.1$.



Fig. 8. Results of face detection after applying face verification rules

3. *Centroid*: The face is evenly distributed in the region where it is located. Therefore, the centroid of a face region should be found in a small window centered in the middle of the bounding box. The dimensions of this window were found to be 20% of the dimensions of the bounding box. Any region whose centroid is outside this window corresponds to a blob that is not evenly distributed and therefore it is not a face.
4. *Extent*: The extent of a blob is the area of this blob divided by the area of the bounding box surrounding it. From the experiment it is determined that the extent for a face is between 0.45 and 0.90. Any region whose extent is not in this range is eliminated.

This cascade is applied to the connected components and a component that agrees with all the above four conditions is a face; any components that disagree with any of the conditions are dropped. In addition, we also checked the standard deviation of the face region that was verified by the above rules. Defining some criteria as the lower bound and upper bound of the standard deviation for the face region helps to reduce the false positive rate of face detection. Fig. 8 shows the result of face detection after using these rules, in which the face region is labeled in red.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Dataset

We selected poorly illuminated images containing upright frontal human faces from the FRGC database [25] to evaluate the performance of the proposed face detection method. We selected 302 face images with dim brightness or low illumination and where each image contained a single face. The proposed algorithm is invariant to lighting conditions, scale, pose, position, and expression. However, all the face images from the FRGC database contain only frontal upright faces. Therefore, we also collected 100 color pictures randomly from the web and from a personal collection containing 228 face images. Images in this collection are from both genders; from various ethnicities with varying skin colors; under different lighting conditions; and vary in pose, scale, position, and expression. The original face images and enhanced face images produced by the image enhancement algorithm from both databases were examined using the proposed face detection algorithm and the performance is compared with the methods in the literature [13, 18].

4.2 Performance Evaluation and Discussion

The following parameters were chosen to evaluate the performance of the proposed face detection method:

- TP: True Positive (number of correctly detected faces)
- TN: True Negative (number of lost faces)
- FP: False Positive (number of non-face items detected)
- TF: Total Faces (TP+TN)
- CDR: Correct Detection Rate (TP/TF)
- FPR: False Detection Rate (FP/TF)
- MR: Missing Rate (FN/TF)

From Table 1 we can see that out of 302 faces from the FRGC database, 250 were correctly detected by the proposed face detection method. The detection rate was 82.78% with a 22.84% false positive rate. In the same image set, face detection without image enhancement produces only a 66.22% correct detection rate. This proves that image enhancement is a crucial step before skin segmentation in skin color based face detection methods. The same image set is used to detect faces using the skin and edge based face detection method proposed by H C V. Lakshmi and S. PatilKulkarni [13]. They used skin segmentation in the HSV and YCbCr space. First, they removed non-face like regions using shape properties and the resulting binary skin tone image was then combined with the edge image that was obtained by combining Canny and Prewitt edge images. The detection rate using this method is only 62.58% with a 30.13% false positive rate. The result of our proposed method was much better compared to this method due to the use of the extra preprocessing operation and different algorithmic flow in the face detection procedure. We also compared the proposed method with the Viola & Jones [18] method. Here we used the OpenCV implementation of this method to find the detection performance. The result is comparable with the proposed method. They used histogram equalization in order to improve the contrast of the input image. Actually, it's a bit unfair to compare the proposed method with the Viola & Jones method because their method only detects frontal faces. As explained earlier all the faces in the FRGC dataset are frontal, therefore the performance of this method is comparable with the proposed method. The face detection rate of the proposed method in the FRGC database is low, because most of the face images' skin color is like background, and the face region is connected to the background region in the segmentation process for some images. The FPR of the proposed method is also a bit higher. This is because the proposed method is based on the skin regions and if the background region in the image looks like color it confuses with the skin regions as face regions. Fig. 9 shows the face detection result from the FRGC database using the proposed method for some test images.

Table 1. Face detection performance on subset of FRGC database

Method/Parameter	TF	CDR (%)	FPR (%)	MR (%)
Skin and edge based Segmentation	302	66.22	19.86	33.78
Image enhancement + skin and edge based segmentation	302	82.78	22.84	17.22
[13]	302	62.58	30.13	37.42
Viola & Jones [18]	302	80.13	3.31	19.87



Fig. 9. Some examples of input images from the FRGC database and corresponding enhanced images with the result of face detection

Table 2 consists of the face detection performance of the proposed method in our collected face image database. In this database out of 228 faces from 100 images, 196 were correctly detected by the proposed face detection method. The successful detection rate was 85.96% with a 22.80% false positive rate. On the other hand, in the same image database face detection without image enhancement, it produced only 71.49% of a correct detection rate. We found the faces in this database using [13]. Only 63.75% of the faces were detected by this method with a false positive rate of 28.50%. This database also contains images from the dark illumination and skin color like background; therefore, the detection rate of this method is low. If the image is taken into dark illumination, the edge of the image is not detected well enough to separate the face regions from the occluded backgrounds. The detection performance of the Viola & Jones method in the same dataset is only 77.63% with 6.14% of FPR. Here also, the FPR of the proposed method is high because of skin color like regions in the background. Fig. 10 shows the face detection result in some test images. (Note the variation in pose, scale, illumination, and expression.) Obtaining a detection rate above 85% on images under such variations is considered a good result.

The proposed method is mainly focused to detect faces on the images with dark illumination or bad lighting conditions, as well as with differently posed faces. Actually, there is no any pub-

Table 2. Face detection performance on our collected face image database

Method/Parameter	TF	CDR (%)	FPR (%)	MR (%)
Skin and edge based Segmentation	228	71.49	22.80	28.50
Image enhancement + skin and edge based segmentation	228	85.96	22.80	14.03
[13]	228	63.75	28.50	36.25
Viola & Jones [18]	228	77.63	6.14	20.61



Fig. 10. Some example face detection results in our collected face image database

licly available dataset that is suitable to test the performance of the proposed method. The FRGC dataset contains some images with dark illumination, but all of the faces are frontal. If the dataset is normal with good lighting conditions, the performance of the proposed method will not be superior than other methods in the literature. In such case our method will also give the comparable result with the other methods in the literature [13, 18].

The introductory section of this paper mentioned many challenges in face detection. Most of those challenges are solved by the proposed face detection method to some extent. The system becomes pose invariant, using skin color as a detection cue, because the feature skin color is invariant to poses. If there are structural components, such as glasses, beards, and masks on the face, the system is unable to detect the face, because those components distract the shape of the face component in segmented images. The problem of facial expressions is solved by the proposed method and the partial occlusion problem is also solved, because Canny edges are used to separate face components from the background or foreground regions. Image enhancement is applied before skin segmentation, so the system is invariant to lighting changes, to some extent.

5. CONCLUSION

This paper proposed a novel approach for face detection in color images. First, the image enhancement is applied in the HSV color space to convert the images in various lighting conditions to a uniform lighting environment. The experimental result showed that image enhancement before skin segmentation greatly affects the result of face detection, especially if the imag-

es are acquired in unconstrained illumination conditions. Image segmentation is conducted after enhancement using skin color and edge information to separate the face components from the background. Connected components are later analyzed using primitive shape features and the standard deviation of the candidate face region in the corresponding grayscale image of the edge and skin segmented image. The experimental result shows that the proposed method is invariant to the lighting condition under which the image was taken. The results also revealed the robustness and efficiency of this method under varying conditions, such as pose, and expression.

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