Face Detection in Color Images Based on Explicitly-Defined Skin Color Model

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Abstract. Detecting human faces in color images plays an important role in real life application such as face recognition, human computer interface, video surveillance and face image database management. This paper proposes four new methods for human skin segmentation and one facial feature detection using normalized RGB color space. The linear piecewise decision boundary strategy is used for human skin detection techniques. Both adaptive and non-adaptive skin color models are used for skin detection. The rule based technique is used to detect facial features like lips and eye. These techniques are very effective in detecting facial features. The experimental results show that both the non-adaptive and adaptive skin color models produce better results as compared to other skin detection techniques proposed.

Keywords: Face Detection, Normalized RGB, Facial Features, Adaptive Approach, Non-adaptive Approach.

1 Introduction

Human face detection in color images is an important research area in the fields of pattern recognition and computer vision. It is a preprocessing step in the fields of automatic face recognition, video conference, intelligent video surveillance, advance human-computer interaction, medical diagnosis, criminal and terrorist identification [6]. It remains elusive because of variations in illumination, pose, expression, and visibility, which complicates the face detection process, especially under real-time constraints [5]. Face detection techniques are used to determine the presence and location of a face in an image, by distinguishing it from the background of the image, or from all other patterns present in the image.

Face localization can either be a preprocessing step or an integral part of face detection activity. A number of approaches are in use for detecting facial regions in color images [17]. One of the important approaches used to detect face regions in color images is through skin detection, because skin-tone color is one of the most important features of human faces. The skin regions in a color image can be segmented by processing one pixel at a time sequentially and independently. Skin segmentation means differentiating skin regions from non-skin regions in a color image [28].

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Although there are many color spaces that can be used for skin detection, the normalized RGB has been selected in this paper because this color space is more suitable for skin detection and facial feature detection. It is also used in this paper due to the evidences that human skin color is more compactly represented in chromaticity space than in other color spaces [3].This color space is useful in particular to detect lip regions and hence other facial features. Face detection techniques can be classified into two main categories: feature-based and image-based. The complete information of face is one of the necessary requirements of face detection technique. Feature-based techniques depend on feature derivation and analysis to gain the required knowledge about faces [5]. Face detection is inadequate without detecting its facial features. It generally includes salient points, which can be traced easily, like corner of eyes, nostrils, lip corners, ear corners, etc. The facial geometry is generally estimated based on the position of eyes. On the other hand, image-based techniques treat face detection as a general pattern recognition problem. It uses training algorithms to classify regions into face or non-face classes [5]. Jones [7] construct a generic color model as well as separate skin and non-skin models using RGB color space over large image datasets that are available on the World Wide Web. Jayaram [4] also has used large dataset for the making the comparison for combinations of nine color spaces, the presence or the absence of the illuminance component, and the two coloring models.

The methods described in this paper use feature-based technique to identify the human face regions in the color images. This paper proposed all the methods used for the face detection based on feature-based technique in terms of their effect on the color images of the database that is commonly used.

The remainder of the paper is organized as follows: Section 2 describes the previous work done on human skin color detection and face detection using normalized RGB. Section 3 focuses on skin detection techniques. Section 4 proposes four novel approaches that can be used for the human skin detection. Section 5 proposes facial feature detection technique. The section 6 focuses on experimental results and describes about the effect of methods on the color images. Finally, section 7 concludes the paper by suggesting some future enhancements.

2 Related Work

Brand et al. [8] assessed the merits of three different approaches to pixel-level human skin detection over RGB color space. The concept of one of the approaches used for skin detection is referred in this paper using normalized RGB instead of RGB. Pankaj et al. [11] has presented a fundamental unbiased study of five different color spaces in addition to normalized RGB, for detecting foreground objects and their shadows in image sequence. Caetano et al. [2] proposed a novel method to model the skin color in the chromatic subspace, which is by default normalized with respect to illumination. They used two image face databases, one for white people and another for black people, with two Gaussians, rather than with a single Gaussian. Boussaid et al. [14] has achieved pixel classification on readout in the normalized color space based on a statistical skin color model. Vezhnevets et al. [20] provided the description, comparison and evaluation results of popular methods for skin modeling and detection.

Bayoumi et al. [16] presented an online adapted skin-color model to handle the variations of skin-color for different images under different lighting conditions. Zarit et al. [19] presented a comparative evaluation of pixel classification performance of two skin detection methods in five color spaces. Hsieh et al. [18] proposed an adaptive skin color model which is based on face detection. Skin colors were sampled from extracted face region where non-skin color pixels like eyebrow or eyeglasses could be excluded. Gaussian distributions of normalized RGB were then used to define the skin color model for the detected people. Andreeva [29] has used nonparametric skin distribution modeling and parametric skin distribution modeling in addition to explicitly defined skin region method.

3 Skin Detection Techniques

Face detection in color images through skin detection is the preliminary step in the biometric technology like face recognition. It uses skin color to identify the human face. The methods belonging to the feature-based technique are based on texture and skin-color analysis. The human face texture can be used to separate human face from other objects. This technique is used as an auxiliary method because there may be other objects similar to human face texture. Human skin color has been used as an effective feature in face detection tasks. Several approaches have been used for skin color pixel classifier. They include piecewise linear classifier [26], Gaussian classifiers [3], [26], [27], Bayesian classifiers [13], [25], [26], neural networks [12], probabilistic approach [9], statistical approach [15]. Piecewise linear classifiers are used in this paper.

The technique determines whether the color of each pixel describes human skin or non-skin regions helping in finding the areas that can have facial regions. In order to discriminate the human skin from non-skin pixels, various skin color methods have been used from the past few decades [24]. Explicitly-defined skin region is one of the efficient methods used for detecting skin regions from the color images using different color spaces. In this method, the boundaries of skin cluster are explicitly defined in some color spaces. One of the main advantages of using this method is its simplicity that attracts many researchers. The simplicity of skin detection rules leads to construction of a very rapid classifier without much computational work [20].

Most of the color spaces can be used for the identification of skin or non-skin pixel. In this paper, normalized RGB color space is used to achieve high skin detection rates for the color images. The normalization process is very important for "skin-color" and "face" detection because the skin-colors of different people belonging to different ethnicity will be different. Still this color space can detect skin color of all people with different skin color with ease.

The normalized RGB can be represented as follows:

$$\mathrm{Base} = \mathrm{R} + \mathrm{G} + \mathrm{B} \tag{1}$$

$$r = R/Base \tag{2}$$

$$g = G/Base \tag{3}$$

$$b = B/Base \tag{4}$$

Normalized RGB is easily obtained from RGB values by the above normalization procedure. As the sum of the three normalized components is known (R + G + B = 1), the third component does not hold any significant information and can be omitted, reducing the space dimensionality. The remaining components are treated as "pure colors", for the dependence of r and g on the brightness of the source RGB color is diminished by the normalization.

There are two approaches that can be used for segmenting skin regions in the color images when the normalized RGB color space is used. The two approaches are called adaptive and non-adaptive skin color models. Chai [23] has used adaptive method to discriminate between skin and non skin color pixels.

The segmentation performance of the above methods can be measured in terms of the true negative and false positive. In true negative, non skin pixel is classified as skin pixel and in case of false positive, skin pixel is classified as non skin pixel. After segmenting the skin regions, any one of the several approaches commonly applied for face detection can be used. They include neural networks [21], geometrical and information analysis [22].

4 Proposed Methods

4.1 Adaptive Skin Color Model

The adaptive skin color model will use the threshold values using trial and error method for lower and upper bound on the red and green chrominance components. By changing these threshold values the skin regions can be detected. Many researchers have proposed different adaptive skin color models based on the explicit skin cluster method for detecting skin regions in color images using normalized RGB color space. For the evaluation purpose, the commonly used face databases, consisting of more than thousand face images are used for the human skin detection and face detection. Some of the sample images used from extended M2VTS face data base [30] is shown in figure 3(a). The methods has also tested on some other databases, namely Caltech Face Database [31], Indian Face Database [32], and Postech faces'01 [33].

There are two adaptive skin color models which are discussed in the following subsection. The outputs obtained by using these newly proposed novel methods are compared in the experimental results section using the standard face database. There are two adaptive skin color models which are discussed in the following subsection.

Method I

On the basis of mean and standard deviation of normalized red and green values, human skin pixels are determined by using the rules specified as inequalities. In this method, samples of human skin from different images of the database were collected and used. For every pixel in the skin samples the values of r, g and R are calculated, and then the mean and standard deviation of r, g and R in all skin samples are calculated. The mean values of the r, g and R components are denoted by μ_r, μ_g and μ_R respectively and the standard deviation of the r, g and R components are denoted by σ_r, σ_g and σ_R respectively.

Now, the above information is used with the normalized RGB color space to detect the human skin pixels. The first step of the skin detection is to compute r, g and R for every pixel of the input image. If the pixel values of r, g and R satisfy the following inequalities (5), then the pixel is considered as a skin pixel, otherwise, the pixel is classified as non-skin pixel. The value of α determines how accurate the skin detector will be and its value is to be determined by using the trial and error method.

$$\begin{gathered}\sigma_r - \alpha\mu_r < r < \sigma_r + \alpha\,\mu_r \\ \sigma_g - \alpha\mu_g < g < \sigma_g + \alpha\mu_g \\ \sigma_R - \alpha\mu_R < R < \sigma_R + \alpha\mu_R\end{gathered} \tag{5}$$

The output is produced in the form of binary mask i.e. ones represent the skin region and zeros represent the non-skin region.

Method II

In the method, the mean and standard deviation of Base are calculated in lieu of R that is used in the above method. The following inequalities (6) are used of the identification of skin and non-skin pixels in the method. The pixels that satisfy the inequalities are considered as a skin.

$$\begin{gathered}\mu_r - \alpha\sigma_r + \mu_r/\sigma_r < r < \mu_r + \alpha\sigma_r + \mu_r/\sigma_r \\ \mu_g - \alpha\sigma_g + \mu_g/\sigma_g < g < \mu_g + \alpha\sigma_g + \mu_g/\sigma_g \\ \mu_{Base} - \alpha\sigma_{Base} + \mu_{Base}/\sigma_{Base} < Base < \mu_{Base} + \alpha\sigma_{Base} + \mu_{Base}/\sigma_{Base}\end{gathered} \tag{6}$$

4.2 Nonadaptive Skin Color Model

The paper has proposed two nonadaptive skin color model that uses decision rules for the extraction of skin region of human face. The nonadaptive skin color model use a pre-defined inequalities which are given as rules as shown below.

Method I

It is the simple threshold as well as the simple skin color method. In this method, the skin pixels are explicitly identified by defining the boundaries of skin cluster in the specified color space. For every normalized green value g and the RGB red value R, there is a lower bound for discriminating the pixels whereas for every normalized red value, both upper and lower bound are applied for discriminating the pixels. If the pixel values of r, g and R satisfy the following inequalities (7), the pixel is considered as a skin.

$$(t1 > r > t2) \cap (g > t3) \cap (R > t4) \tag{7}$$

Method II

The method uses the concept of r/g ratio. The first step of the method is started with the calculation of the ratio of normalized red values r and normalized green values g. The ratio is denoted by a. The next step is to add all the components of normalized RGB, make a square of it and denote it in the name of bb. After that the values of c and d are calculated by using the following equations:

$$a = r/g \tag{8}$$

$$bb = (r + g + b)^2 \tag{9}$$

$$c = (r * g)/bb \tag{10}$$

$$d = (r * b)/bb \tag{11}$$

If the pixel values of a, c, d and g satisfy the following inequalities (12), the pixel is considered as a skin.

$$(a > t9) \cap (c > t10) \cap (d > t11) \cap (g > t12) \tag{12}$$

5 Facial Feature Detection

As mentioned previously, the purpose of extracting skin-color regions is to reduce the search time for possible face regions on the input image. The main goal of the paper is to find out the facial features accurately. The method proposed by Soriano [1] helps in detecting both skin region and facial features. The author had suggested quadratic equations in order to reduce the sensitivity to changing light. The skin color distribution would gather in r-g plane. The quadratic equations are given as follows:

$$Q+ = -1.3767r^2 + 1.0743r + 0.1452 \tag{13}$$

$$Q- = -0.776r^2 + 0.5601r + 0.1766 \tag{14}$$

$$W = (r - 0.33)^2 + (g - 0.33)^2 \tag{15}$$

The final equation for skin color detection is formulated as specified in the equation (16).

$$\mathrm{S} = \begin{cases} \mathrm{Q}+ > g > Q- \\ W > 0.0004 \\ 0.6 > r > 0.2 \end{cases} \tag{16}$$

It is the possibility that some skin detecting equations produce better result for some images as compared to others. There is also another equation [10] that doesn't produce better result for the database used. In this paper, the above equation has been slightly modified because it is not producing better result for the database used by us. So by making a change to the inequalities, the better results are obtained by us for the images. The modified equation (17) is given as follows:

$$\mathrm{S} = \begin{cases} Q+ > g > Q- \\ W > 0.0999 \\ r > 0.387 \cap g < 0.24 \cap b > 1.963 \cup R > 145 \end{cases} \tag{17}$$

There may be possibilities that the above methods don't produce good result for some images. This is done because of the effect of variations of lights in color images that leads to missed skin pixels.

Based on the observation, the above quadratic polynomials help in detecting the facial features like eyes, and lips. In this paper, another quadratic polynomial is defined as the discriminant function for facial feature pixels.

The quadratic polynomial of the lower boundary of the Q- defined in eq. (14) can be reused with a slight modification. The modified polynomial proposed by Soriano [1] is defined as follows:

$$f = -0.776r^2 + 0.5601r + 0.165 \tag{18}$$

The following rule is modified by us and is now defined for detecting facial feature pixels:

$$F = \begin{cases} g \leq f \\ r \geq 0.48 \cap g \geq 0.275 \cap B \geq 35 \end{cases} \tag{19}$$

where F = 1 means the pixel shows the facial feature.

6 Experimental Results and Discussions

All the methods used in this paper are implemented using IDL (Interactive Data Language) language which is ideal software for image processing. The practical implementation of the above methods produces better results. The steps for skin detection are as follows: transforming the color of pixel to another color space i.e. from RGB color space to normalized RGB, using only two color components in the classification, and classifying by modeling the distribution of skin color [4]. Two skin color models are used for skin detection in this paper: adaptive skin color model and non-adaptive skin color model. Some of the two adaptive and two nonadaptive skin color models are proposed for the evaluation of human skin detection. After detecting human skin regions in the color images, facial features are detected using the same normalized RGB color space. The results obtained for human skin and face detections are much better. For the evaluation purpose, the commonly used face databases, consisting of more than thousand face images are used for the human skin detection and face detection. Some of the sample images used from extended M2VTS face data base [30] is shown in figure 3(a). The methods has also tested on some other databases, namely Caltech Face Database [31], Indian Face Database [32], and Postech faces'01 [33].

The first method in the adaptive skin color model produces better results in terms of facial feature for most of the images. Background is classified correctly. There is no problem with the clothes and hair for most of the images except the images having some colors close to the skin color. The accuracy of skin detector depends on the value of α as shown in fig 3.b. The second method also produces better result for all of the images but if it is compared with the first method it has some false positives in terms of clothes as shown in fig 3.c. The clothes which are light in color or in other words close to the skin-tone are considered as a skin by this method.

Table 1. Skin Detection Rates of Adaptive Skin Color Models

S.No.	*Methods*	*No. of images producing better results*	*Percentage of detection rates*	*Percentage of false detection rates*
1.	Method I	43	98	0.02
2.	Method II	42	95	0.04

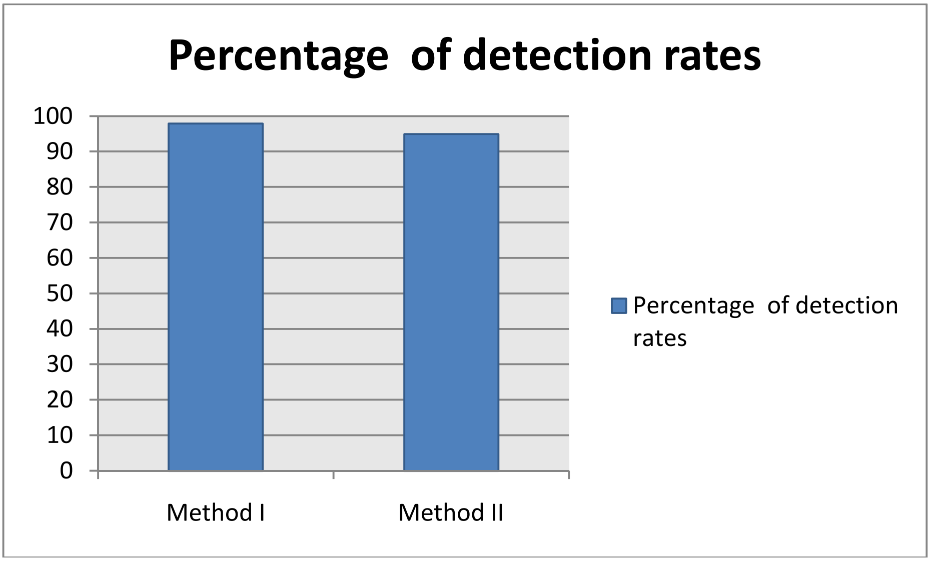


Fig. 1. Graph showing skin detection rate of adaptive methods

Table 2. Skin Detection Rates of Non-Adaptive Skin Color Models

S.No.	*Methods*	*No. of images producing better results*	*Percentage of detection rates*	*Percentage of false detection rates*
1.	Method I	42	95	0.04
2.	Method II	43	98	0.02

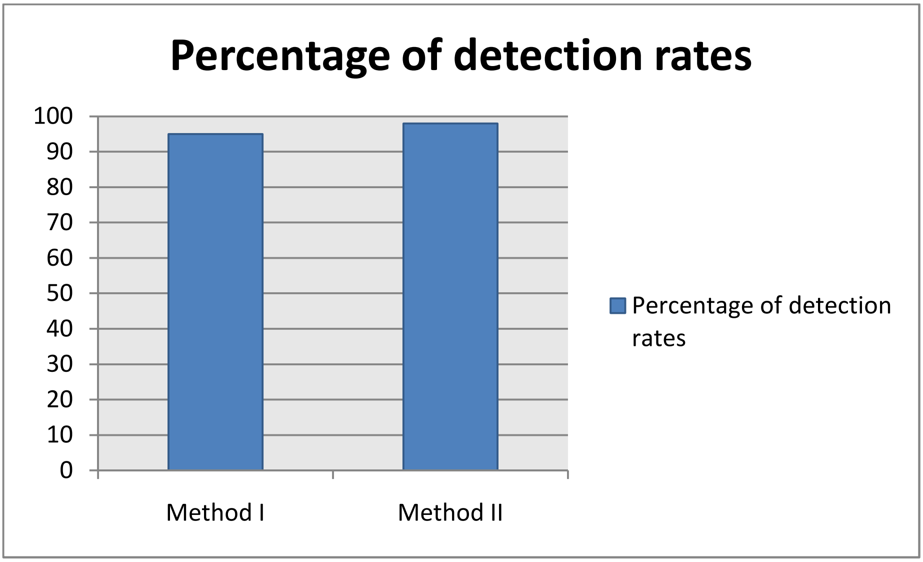


Fig. 2. Graph showing skin detection rate of nonadaptive methods

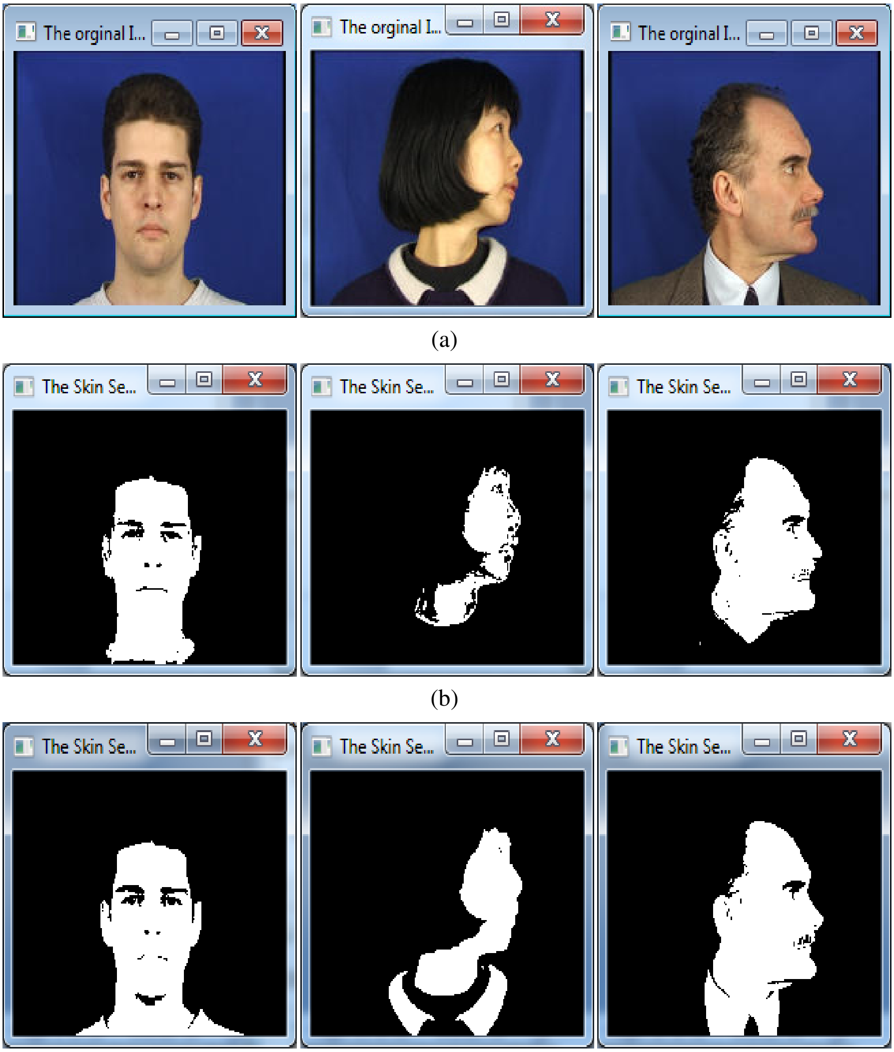


Fig. 3. Sample images and the results produces by the methods of adaptive skin-color model: (a) Input image; (b) Result produced by first method; (c) Result produced by second method

In the non-adaptive skin color model, face and neck are detected by most of the methods but clothes, background and sometimes hair of the person in the image may not be easily classified. The method I produce better result in terms of facial feature detection for most of the images as shown in fig 4.b. Background is also correctly classified. There is no problem with the hair colors shown in all of the images except the golden hairs. If the color of the hair and clothes are the same as skin color, the hair or clothes are detected as skin regions resulting in false positives. The second method produces much better result in terms of facial feature detection for all the images.

Background is correctly classified. The major problem with this method is in detecting the golden hair as skin if the skin color and hair color are the same. The result of this method is shown in fig 4.c.

After extracting the skin-color region of human face, the next step is to identify the facial features like eyes and lips by using face detection technique. The detection of facial feature pixels can be done in parallel with the detection of skin-color pixels. This technique detects nostrils, eyes, mouth, etc as shown in fig. 5. The technique produces the results with 82% accuracy.

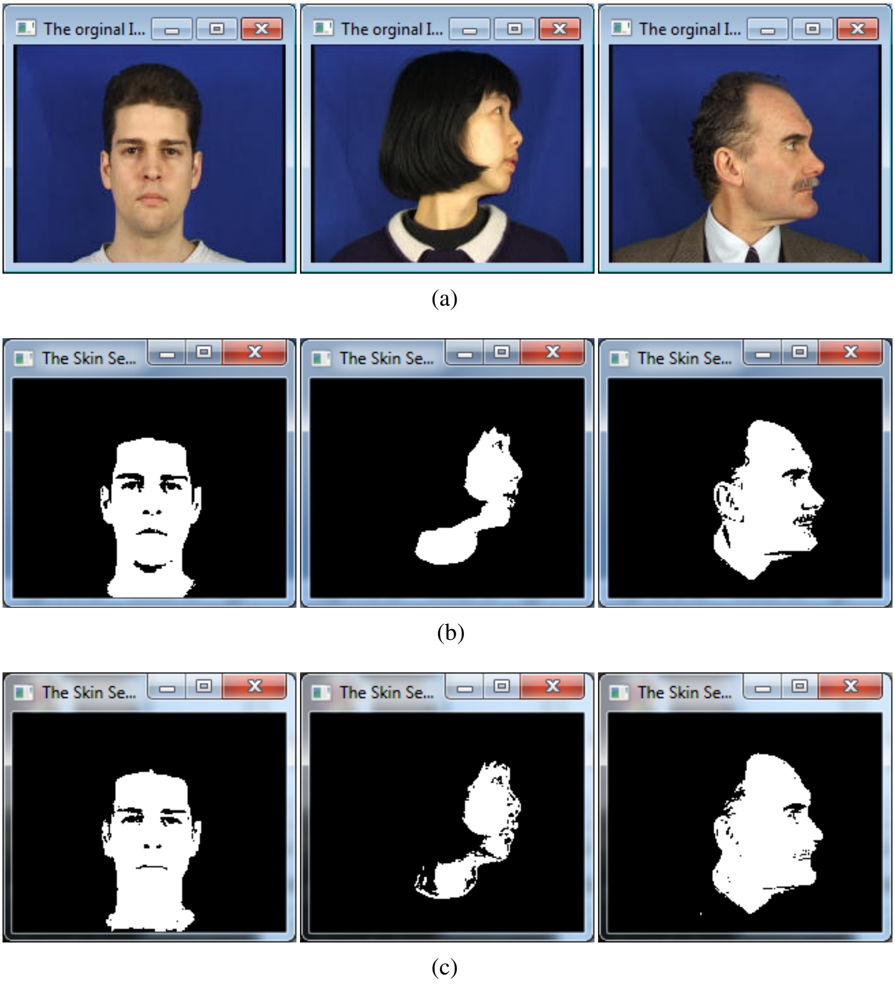
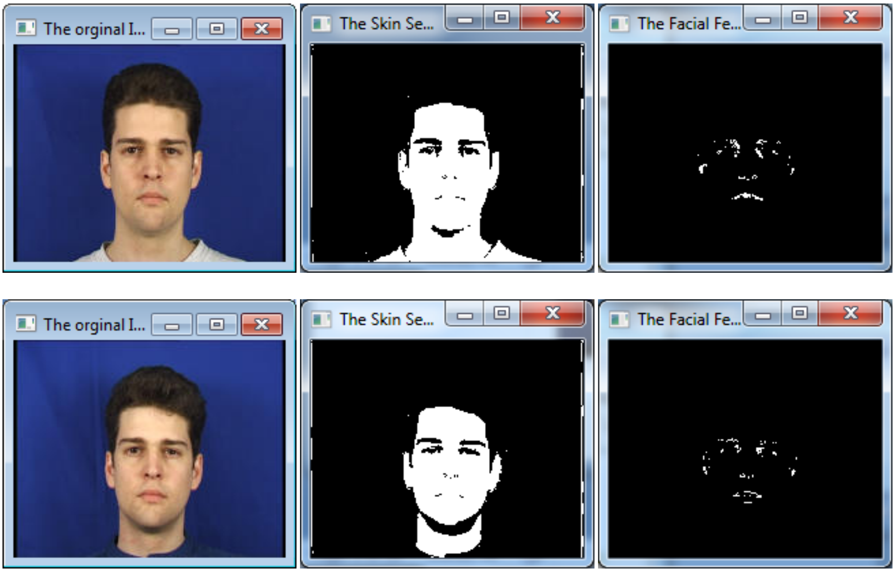


Fig. 4. Sample images and the results produces by the methods of nonadaptive skin-color model: (a) Input image; (b) Result produced by first method; (c) Result produced by second method



(a) (b) (c)

Fig. 5. Result of facial feature detection technique (a) Input image; (b) Skin segmented image; (c) Facial feature

7 Conclusion

This paper focused on a comparative study of adaptive and non-adaptive skin color model used for skin detection techniques. The experimental results show that the methods belong to adaptive and non-adaptive skin color model respectively produces much better results in terms of skin and facial feature detection. Most of the methods proposed as adaptive and non-adaptive skin color models produce better results. If the color of the hair or clothes is the same as that of skin color, the hair or clothes are detected as skin regions resulting in false positives. If these two methods are compared, the non-adaptive skin color model produces better result as compared to the adaptive skin color model which is shown by comparing the table 1 and 2. After extracting the skin-color region of human face, the next step is to identify the facial features like eyes and lips by using face detection technique. The detection of facial feature pixels can be done in parallel with the detection of skin-color pixels. This technique detects nostrils, eyes, mouth, etc as shown in fig. 5. The technique produces the results with 82% accuracy. This paper can be improved by incorporating special methods that may be used to detect face regions in the color image containing one or more faces.

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