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A Skin Color Model Based on Modified GLHS Space for Face Detection

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Abstract. *Face detection is one of the most useful research topics in computer vision. In the past several decades, there has been noticeable and successful achievement in face detection. However, it is still a challenge to obtain both low computational complexity and high detection efficiency. The main problem in existing skin color based face detection algorithms is that different illumination conditions will lead to different clustering results of the skin colored pixels. In this paper, we propose a new skin color model based on the modified GLHS (generalized LHS) color space to solve this problem. Experimental results show that our model can detect skin pixels with high accuracy under various illumination conditions and backgrounds.*

Key words: Face detection, Skin color clustering, Skin color model.

1. **Introduction.** Face detection is a very important key step in fully automated face recognition systems. The purpose of face detection is to determine the locations and sizes of human faces in images. Face detection has been successfully used in biometrics, video surveillance, human-computer interface and image database management. For example, a webcam can be embedded into a television and detect any face that walks by. The system then estimates the race, gender, and age range of the face, thus a series of advertisements can be played that are specifically designed for the detected face.

In the past several decades, face detection has been widely researched due to its potential application value, and many face detection algorithms have been presented [1, 2]. Face detection schemes can be roughly classified into three categories, namely, neural network based, feature-based and color-based methods. Neural network based methods [3] train the neural network based on a number of training data including facial and non-facial datathen the trained neural network can distinguish faces from non-facial parts. Feature-based methods [4] utilize features to detect faces, such as the shape of the face and the locations of eyes, nose and mouth. Color-based methods [5] use skin color models to detect faces. As one of the most important physical surface features, the skin color features embody more information than gray-scale features, which are suitable for real-time applications. The skin color differs from person to person and race to race, however, they can be closely clustered in color spaces, because the difference in the color composition of human skin is small [6]. Many face detection algorithms based on skin color features have been proposed. However, since the color of facial pixels is sensitive to different illumination conditions [7], it is hard to achieve stable detection performance. Therefore, skin color based detection methods have limitations in practice. Thus, some researchers have been focusing on highly robust detection algorithms that are insensitive to illumination changes [8, 9, 10, 11].

In fact, it is essential to select a proper skin color model for color-based face detection schemes. The YCbCr based skin color model [7] is very simple, but it has poor detection performance if there is a great lightness contrast between the face and background. In order to overcome this problem, in this paper, we propose a new skin color model based on the modified generalized LHS color space. The effectiveness of our model is illustrated in theory and demonstrated by experiments.

2. **The Proposed Skin Color Model.** Skin color models are mathematical models used to characterize the skin color distribution. Before designing skin color models, it is essential to select a proper color space. There are many color spaces. Some are proposed for color coding, such as RGB, LUV, LAB, XYZ, and YUV. Some are designed for computer graphics, such as YIQ, HSV, HIS and GLHS (generalized LHS) [12]. It is proved that the RGB color space is unsuitable for constructing an effective skin color model due to the high correlation among the three components. To improve the detection performance of skin color models, this paper adopts the GLHS color space [12] that has a nonlinear relationship with the RGB space.

Since other color spaces can be directly transformed from the RGB space, it is necessary to analyze the skin color distribution in the RGB space. In general, the skin pixels satisfy the inequality R>G>B. Detailed statistical analysis on a large number of skin pixels was made in [8]. In that work, 107 non-overlapping regions containing 3,420,408 skin pixels are segmented from 94 photos taken under standard illuminations for Europeans, Asians, and Native Americans. The statistical results show that, for skin pixels, the mean values of the R, G, B components and lightness are 235.3, 195.9, 176.6 and 205.5 respectively, while the standard deviation values of the R, G, B components and lightness are 15.7, 26.2, 33.2 and 22.9 respectively. Therefore, for skin pixels, the distribution of their RGB components complies with certain inherent laws and restraint relationships.

However, the RGB components cannot characterize the chromatic features perceived by the human visual system, such as lightness, hue and saturation. Thus, people start to adopt other suitable models, such as HSL and HSV models. They can be derived via geometric strategies, and can be thought of as specific instances of a "generalized LHS model" [12]. In the GLHS color space, the lightness component of a color $\boldsymbol{c}$ (its three components in the RGB space are R, G and B) can be calculated as follows.

$$L(\boldsymbol{c}) = w_1 \cdot \max\{\text{R,G,B}\} + w_2 \cdot \text{mid}\{\text{R,G,B}\} + w_3 \cdot \min\{\text{R,G,B}\} \tag{1}$$

Thus, different color models can be formed by simply adopting different w_1, w_2 and w_3 values under the constraints $w_1 > 0$ and $w_1 + w_2 + w_3 = 1$. Secondly, the hue component of the color $\boldsymbol{c}$ can be computed as follows.

$$H(\boldsymbol{c}) = 60 \cdot \pi(\boldsymbol{c}) + 60 \cdot \varphi(\boldsymbol{c}) \tag{2}$$

where $\pi(\boldsymbol{c})$ stands for which sector $\boldsymbol{c}$ belongs to and $\varphi(\boldsymbol{c})$ denotes the hue-fraction of $\boldsymbol{c}$ within the sector as follows.

$$\pi(\boldsymbol{c}) = \begin{cases} 0 & R > G \geq B \\ 1 & G \geq R > B \\ 2 & G > B \geq R \\ 3 & B \geq G > R \\ 4 & B > R \geq G \\ 5 & R \geq B > G \end{cases} \tag{3}$$

$$\varphi(\boldsymbol{c}) = \begin{cases} \frac{\text{mid}\{\text{R,G,B}\} - \text{min}\{\text{R,G,B}\}}{\text{max}\{\text{R,G,B}\} - \text{min}\{\text{R,G,B}\}} & \text{if} \quad \pi(\boldsymbol{c}) \quad \text{is even} \\ \frac{\text{max}\{\text{R,G,B}\} - \text{mid}\{\text{R,G,B}\}}{\text{max}\{\text{R,G,B}\} - \text{min}\{\text{R,G,B}\}} & \text{if} \quad \pi(\boldsymbol{c}) \quad \text{is odd} \end{cases} \tag{4}$$

Finally, the saturation component of the color $\boldsymbol{c}$ can be calculated as follows.

$$S(\boldsymbol{c}) = \begin{cases} \frac{L(\boldsymbol{c}) - \text{min}\{\text{R,G,B}\}}{L(\boldsymbol{c})} & L(\boldsymbol{c}) \leq L(q(\boldsymbol{c})) \\ \frac{\text{max}\{\text{R,G,B}\} - L(\boldsymbol{c})}{M - L(\boldsymbol{c})} & L(\boldsymbol{c}) > L(q(\boldsymbol{c})) \end{cases} \tag{5}$$

where M is the R (or G, or B) coordinate of a white color (in general, M=255), $q(\boldsymbol{c})$ is a color that depends on $\pi(\boldsymbol{c})$ and $\varphi(\boldsymbol{c})$, satisfying $H(q(\boldsymbol{c}))$=$H(\boldsymbol{c})$, and $L(q(\boldsymbol{c}))$ in Eq. (5) can be computed as follows.

$$L(q(\boldsymbol{c})) = w_2 \cdot \frac{\text{mid}\{\text{R,G,B}\} - \text{min}\{\text{R,G,B}\}}{\text{max}\{\text{R,G,B}\} - \text{min}\{\text{R,G,B}\}} \cdot M + w_1 \cdot M \tag{6}$$

Before constructing our new skin color model, we should introduce the illumination law. For color images, the changes in RGB components caused by the changes in illumination are nearly the same [9], namely:

$$\Delta\text{R} = \Delta\text{G} = \Delta\text{B} \tag{7}$$

The reason is that changing illumination conditions has the same effect as adjusting the proportion of the white light whose RGB components are all the same. Based on Eqs. (1),(2), and (5), we can see that the changes in illumination will affect the clustering performance of the skin pixels in the GLHS space. Let $\boldsymbol{c}$ be the original color and $\boldsymbol{c}'$ be the modified color caused by the changes in illumination. Based on Eq. (7), we can easily see that the differences between min{R,G,B}, mid{R,G,B} and max{R,G,B} keep unchanged after illumination adjustment, namely, $\varphi(\boldsymbol{c})$=$\varphi(\boldsymbol{c}')$. Similarly, we can easily prove that $\pi(\boldsymbol{c})$=$\pi(\boldsymbol{c}')$. Thus, the hue defined by Eq.2 follows $H(\boldsymbol{c})$=$H(\boldsymbol{c}')$. However, the lightness defined by Eq. (1) will be changed, consequently the saturation defined by Eq. (5) will also be changed. Thus, we can draw a conclusion that adjusting illumination conditions only affects the lightness and saturation values of the surface color, while the hue value keeps unchanged. Therefore, Eqs. (1) and (5) should be modified to improve the clustering performance.

As we know, in the GLHS space, the effect of illumination changes on the lightness component is inevitable although w_1, w_2 and w_3 can be set to different values under the constraints w_1 >0 and w_1+w_2+w_3=1. To simplify the lightness definition as well as make Eq. (1) immune to illumination changes, in this paper, we adopt a special parameter setting as w_1=1, $w_2 = -2$, w_3=1 to define the differential lightness as follows.

$$L_{new}(\boldsymbol{c}) = \max\{\text{R,G,B}\} + \min\{\text{R,G,B}\} - 2 \cdot \text{mid}\{\text{R,G,B}\} \tag{8}$$

The differential lightness $L_{new}(\boldsymbol{c})$ indicates the constraint relationship among RGB components. We can easily prove that $-M \leq L_{new}(\boldsymbol{c}) \leq M$ and $L_{new}(\boldsymbol{c})$ keeps unchanged if the changes in RGB components satisfy Eq. (7). According to the statistical analysis results in [8], as far as the skin color distribution is concerned, the $L_{new}(\boldsymbol{c})$ values of different skin colors should be clustered tightly around a positive number. Here, we should note that the proposed lightness $L_{new}(\boldsymbol{c})$ characterizes the differential relationship among RGB components rather than the actual lightness.

Obviously, the computation of the saturation value defined by Eq. (5) is complex. Furthermore, its performance in skin color clustering is unstable. To simplify the saturation definition as well as make the saturation immune to illumination changes, we consider the HIS model, where the saturation and lightness values of a color $\boldsymbol{c}$ are calculated as follows.

$$S_{HIS}(\boldsymbol{c}) = 1 - \frac{3 \cdot \min\{\text{R,G,B}\}}{(R+G+B)} \tag{9}$$

$$L_{HIS}(\boldsymbol{c}) = \frac{1}{3} \cdot (R+G+B) \tag{10}$$

We can easily prove that the saturation $S_{HIS}(\boldsymbol{c})$ defined in Eq. (9) is still affected by illumination changes. However, we can easily prove that the product of $S_{HIS}(\boldsymbol{c})$ and $L_{HIS}(\boldsymbol{c})$ will keep unchanged after illumination changes. Thus, we can define a special saturation as follows.

$$S_{new}(\boldsymbol{c}) = \frac{S_{HIS}(\boldsymbol{c}) \cdot L_{HIS}(\boldsymbol{c})}{M} = \frac{R+G+B-3 \cdot \min\{\text{R,G,B}\}}{3 \cdot M} \tag{11}$$

Based on above discussion, we can finally obtain a new skin color model formed by Eqs. (2),(8) and (11), which can be summarized as follows:

$$\begin{cases} H_{new}(\boldsymbol{c}) = 60 \cdot \pi(\boldsymbol{c}) + 60 \cdot \varphi(\boldsymbol{c}) \\ L_{new}(\boldsymbol{c}) = \max\{\text{R,G,B}\} + \min\{\text{R,G,B}\} - 2 \cdot \text{mid}\{\text{R,G,B}\} \\ S_{new}(\boldsymbol{c}) = \frac{R+G+B-3 \cdot \min\{\text{R,G,B}\}}{3 \cdot M} \end{cases} \tag{12}$$

Since we have considered the effect of illumination changes on each component, Eq. (12) can be used to cluster skin pixels with a very good performance even if the input photo contains highlight and dark regions. Therefore, it is robust to irregular illuminations.

3. **Experimental Results.** To test the effectiveness of the proposed skin color model, a number of skin regions are manually selected from 200 indoor and outdoor photos taken under a wide range of illumination conditions and 200 color images with faces downloaded from the Internet. We compute $H_{new}(\boldsymbol{c})$, $L_{new}(\boldsymbol{c})$ and $S_{new}(\boldsymbol{c})$ for all skin pixels and obtain the distribution of skin colors. Fig. 1 shows the distribution of $L_{new}(\boldsymbol{c})$ and $S_{new}(\boldsymbol{c})$, from which we can see that the lightness and saturation values of different skin colors are tightly clustered.

According to above statistical results, we can use a simple threshold technique to check skin pixels. Furthermore, a large number of statistical results on skin colors also show that the R component is generally not smaller than 90 no matter how poor the illumination

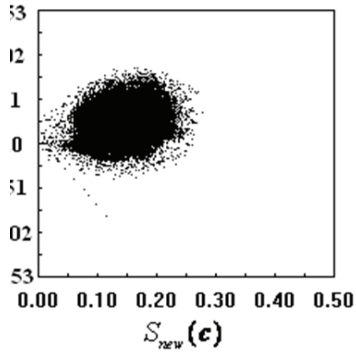

FIGURE 1. Clustering results of skin colors.

condition is. Finally, we obtain the following criteria to detect skin pixels.

$$\begin{cases} 0.065 \leq S_{new}(\boldsymbol{c}) \leq 0.25 \\ -38.25 \leq L_{new}(\boldsymbol{c}) \leq 68.85 \\ 0.005 \leq H_{new}(\boldsymbol{c}) \leq 0.12 \\ \mathrm{R} \geq 90 \end{cases} \tag{13}$$

Based on Eq. (13), we perform a number of color detection experiments to test the effectiveness of the proposed skin color model. The typical detection results under different illumination conditions are shown in Fig. 2, Fig. 3 and Fig. 4 respectively. In Fig. 2, the overall illumination is low. In Fig. 3, the speaker is with normal illumination, but the people behind him are with low illumination. In Fig. 4, the overall illumination is high, and the left part of the body is with relatively low illumination while the right part of the body is with relatively high illumination. From these results, we can see that, despite of various illumination conditions, all of the skin regions have been accurately detected.

FIGURE 2. Original photo with average lightness 85 and corresponding skin color detection result.

However, in our experiments, we find that some false detection will occur in the parts with extremely high illumination if there are continuous reflecting areas on the skin surface. The reason is that Eq.(7) is no longer suitable and the RGB components of these skin pixel are almost the same, resulting in the decrease of . Fortunately, the loss of skin pixels does not have much effect on the face detection performance unless a considerable number of skin pixels is lost. In general, the photos can provide a sufficient number of skin color pixels for face detection. In addition, the problem that the skin detection results contain some non-skin pixels commonly exists in most of the skin color models [10].

FIGURE 3. Original photo with average lightness 104 and corresponding skin color detection result.

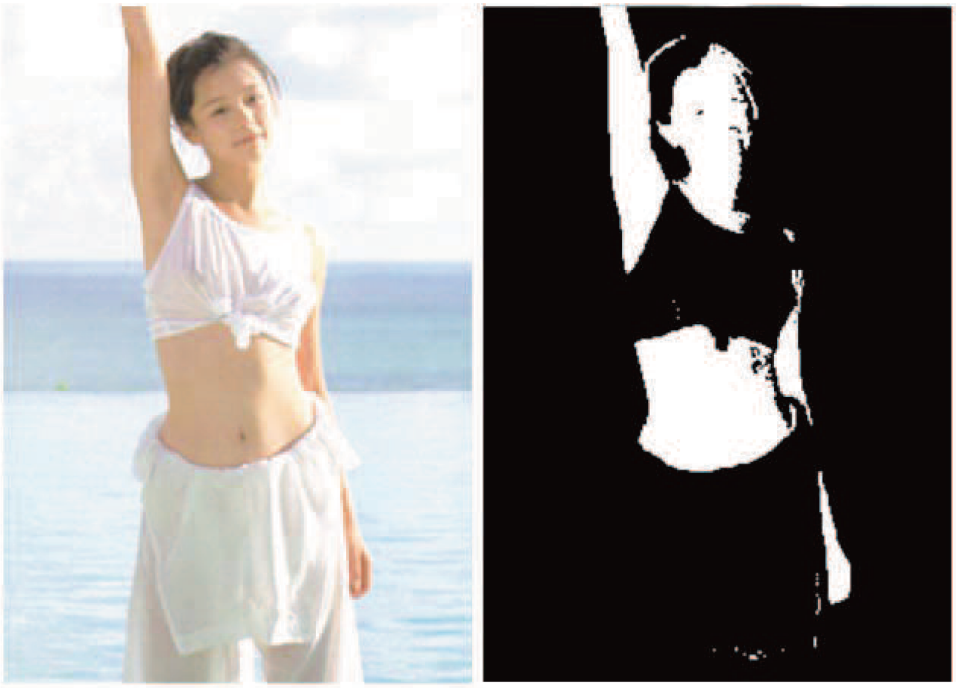

FIGURE 4. Original photo with average lightness 224 and corresponding skin color detection result.

To further prove the superior of our scheme over some existing skin color models, we also compare our scheme with the method in [7], where a simple skin color model based on the YCbCr space is adopted. The comparison results are shown in Fig. 5. The first column shows the original photos, the second column shows the detection results by the method in [7], while the third column shows the detection results by the proposed method. From these results, we can see that the method in [7] is much worse than our method.

4. **Conclusions.** This paper proposes a new skin color model to detect skin pixels. Through studying the distribution of the skin pixels in different color spaces and the features of hue and saturation, we improve the GLHS color model and then propose novel criteria to check skin pixels. Since our model can overcome the illumination sensitivity problem, it can be used for face detection under various illumination conditions. Experimental results demonstrate the effectiveness of the proposed model and our model is

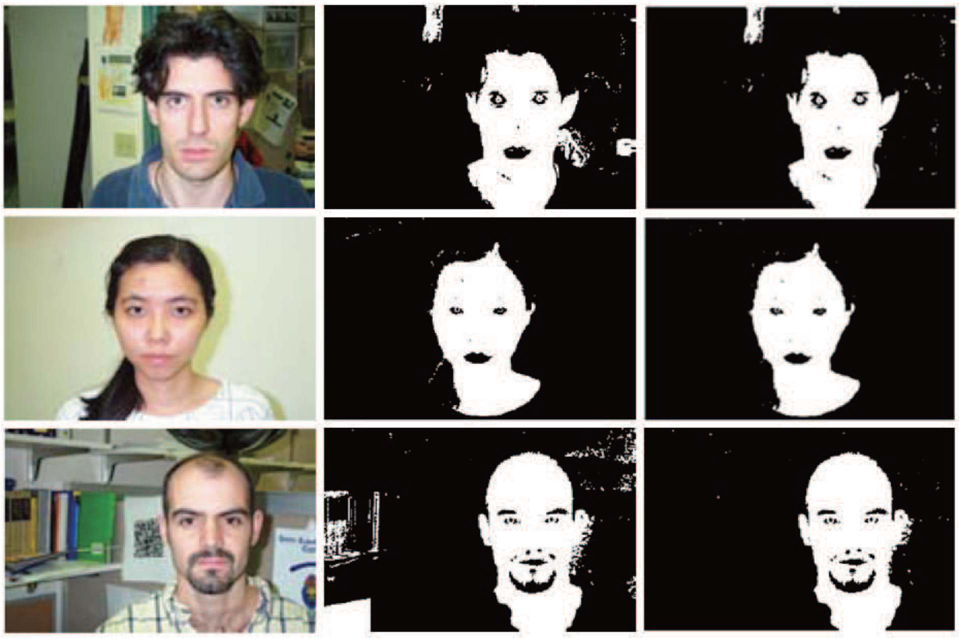

Figure 5. Comparisons of skin color detection results between our scheme and the method in [7]. The first column shows the original photos, the second column shows the detection results by the method in [7], while the third column shows the detection results by the proposed method.

superior to the scheme in [7]. Future work will focus on combining local information of photos with skin color models to achieve better detection results for photos with more complexity background.

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