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Skin-representative region in a face for finding real skin color

Hayan Choi, Kyungah Choi, Hyeon-Jeong Suk; Department of Industrial Design, Korea Advanced Institute of Science and Technology; Daejeon, Korea

Abstract

Skin detection is used in applications in computer vision, including image correction, image–content filtering, image processing, and skin classification. In this study, we propose an accurate and effective method for detecting the most representative skin color in one's face based on the face's center region, which is free from nonskin-colored features, such as eyebrows, hair, and makeup. The face's center region is defined as the region horizontally between the eyes and vertically from the middle to the tip of one's nose. The performance of the developed algorithm was verified with a data set that includes more than 300 facial images taken under various illuminant conditions. Compared to previous works, the proposed algorithm resulted in a more accurate skin color detection with reduced computational load.

Introduction

With the development of information technology and mobile devices, various kinds of vision-based applications have been developed. Among those applications, many facilitate skin detection algorithms. A skin detection algorithm is a process of detecting skin-colored pixels and regions in a digital image. Skin detection is considered a key step because the color of human skin is cognitively highly relevant and, accordingly, it is an effective feature for computation. The main applications of skin detection are image correction, image–content filtering, image processing, and skin classification [1]. For example, hand gestures can be classified after detection and segmentation of the skin region [2–4]. A human tracking algorithm and pornographic image filtering also uses skin detection before tracking and filtering process [5–7]. Not limited to these purposes, a number of skin detection algorithms have been developed.

The approach of skin detection is largely classified by two types. The first type is a pixel-based skin detection method. Skin color mainly differs in lightness, but it does not show significant differences in hue and saturation, even across different ethnic groups. Likewise, skin colors are distributed in a narrow range of color spaces [8], so it is possible to screen pixels that should not be included in the skin color range. Because skin pixels should belong to the predefined range, the computational load could be relatively low. Many previous studies followed the skin range assumption, and the range is defined differently depending on the color spaces, such as RGB, normalized RGB, HSV, YCbCr, YUV, and CIE L*a*b* [9, 10]. However, the pixel-based skin detectors did not work properly for the color shifts caused by various illuminant conditions. In particular, there were high color shifts for facial images taken under various correlated color temperatures or under low illuminance. In addition, these methods cannot distinguish nonskin regions, which have similar colors to skin. As presented in Figure 1, brown hairs on the subject's forehead were detected as skin due to the similar color range. Furthermore, the images captured by camera can be distorted due to the illuminant and the characteristics of each device. As mentioned, the range of skin color is relatively narrow and the distortion may lead the algorithm not detecting the skin region correctly [11]. This type of existing pixel-based skin detector may filter out the skin region if it is distorted due to extreme chroma of the illuminant. One possible solution is to correct images first, which is known as color constancy. For example, some assumptions were suggested, such as the average color of the scene being gray [12] or the brightest pixel in the scene being white [13]. However, these assumptions are not truly operational in some cases, and we are not always able to control the illuminant.

Figure 1. The pixel-based skin detection often fails because it does not discriminate nonskin regions as far as hues belonging to the predefined detection boundary. In this case, the brown hairs were detected as skin.

The other approach of skin detection is an adaptive skin detection algorithm. This does not use a predefined detection boundary of skin regions. This takes the spatial arrangement of pixels into account; therefore, it has more flexibility in various illuminant [7, 12, 13]. Most of these methods detect the face first to extract the skin region. After facial recognition, the algorithm detects skin regions by calculating the dominant hue in the face, so it can detect the skin-colored pixels near the dominant color in the color space [14]. In this way, the adaptive skin color detection technique computes skin pixels in a device-dependent color space that works properly under various illuminant conditions. However, this method inevitably includes features that are not skin colored, such as eyebrows, hair, and makeup. These nonskin-colored regions may cause inaccurate results for further process after skin color detection. For example, an estimation of accurate skin color is rarely possible if the nonskin-colored region is included. In addition, this type of algorithm has more computational load than the pixel-based skin detection. As skin detection is a primary process for many of other applications, the computational load can be an important issue.
As such, an improvement in skin detection is necessary to meet users' needs for the development of vision-based. In this regards, it is anticipated to obtain the most representative skin color in one's face to detect the other skin regions in the image without considering the nonskin features of the face. In addition, it will be more effective if the representative skin color could be calculated instead of taking the whole face region for computation.

Objective

To obtain the most representative skin color in one's face, we focus on the facial area free of colored makeup and accessories. For this purpose, we looked for the facial features that do not have makeup. While the eyes and lips usually have colored makeup, the region near nose is taken for skin details in digital makeup based on photographs [15]. We made an assumption that the center of the face can be regarded as the representative skin color.

Consequently, this study suggests an algorithm for finding one's skin region based on the primary calculation of the center region of the face for accurate detection and reduced computational load. From this idea, this study aims to develop a skin detection algorithm to make it possible to 1) detect more accurate skin regions and 2) efficiently filter out the nonskin-colored features of the face. The performance of the developed algorithm was confirmed with a data set that includes more than 300 facial images taken under various illuminant conditions.

Algorithm Concept

We attempted to suggest the central region of the face as the region that best represents one's skin color. The central region of the face is defined as the region horizontally between left and right pupil and vertically from the middle to the tip of one's nose. This region is less likely to include nonskin-colored features, such as eyebrows, hair, glasses, and colored makeup (e.g., blush and eye shadow), enabling more reliable and accurate detection of one's skin color. Besides, this approach is expected to cost less computationally, as the primary hue range is determined with reduced pixels.

The proposed algorithm is comprised of the following four steps:

- First, the central region of the face is cropped from a facial image. Subsequently, the cropped rectangle should contain mainly skin-colored pixels.
- Second, the hue scores (H in HSV) of the pixels are collected and distributed on the hue histogram, ranging from 0–360° (See (b) in Figure 2).
- Third, based on the hue histogram, a scale–space filtering process is adopted. Scale–space filtering is a method that describes signals qualitatively. We adopted this method for identifying the peak of the skin hue and to identify the dominant hue range of the region. By calculating the differential of the scale–space filtered vector, the range of the skin hue is determined. In Figure 2 (b), the red and blue curve indicate the data before and after filtering respectively.
- Finally, the skin-colored pixels are selected from the entire face region according to the computed hue range. The example of the skin detection process is illustrated in Figure 2 below. See (c) in Figure 2.

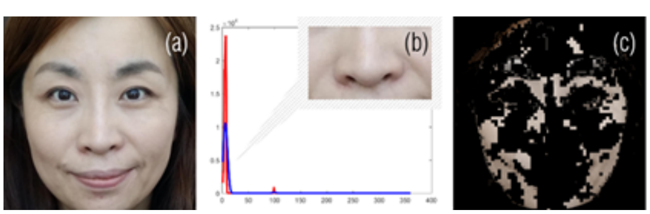

Figure 2. Method to detect the skin color focusing on the central region of the face. (a) Original facial image. (b) The hue histogram of the central part cropped from (a). Red and blue lines indicate the hue distribution before and after a scale–space filtering. The horizontal axis indicates the hue degree, H in HSV color space, ranging from 0–360 °. (c) Result: the detected skin color within the facial image.

Evaluation

To verify the proposed algorithm, we recruited 348 female passersby to take pictures of their facial images under various illuminant conditions. The illuminant condition for each participant was measured using a chroma meter (Konica Minolta CL-200A) at the position of participant's face. The correlated color temperature (CCT) of the illuminant ranged from 2,576–18,950 K, and the illuminance ranged from 6–85,550 lux. As displayed in Figure 3, outdoor pictures were taken under approximately 5,000 K, and indoor pictures were under much wider range of the correlated color temperature.

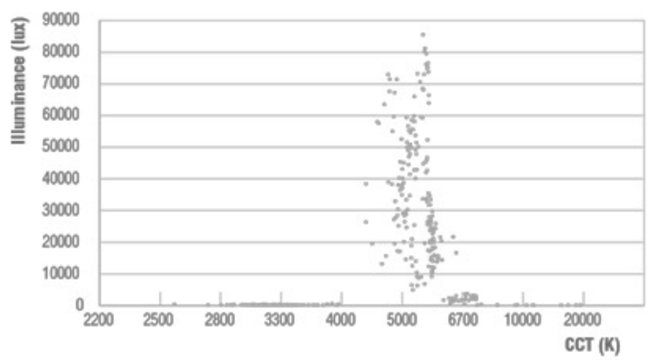

Figure 3. The illuminant conditions were recorded at the position of participants. The measured results are plotted in along the correlated color temperature and illumination level. (N = 348)

In most of the previous studies on skin detection, the entire facial region was included in the calculation, thereby resulting in a substantial amount of errors. On the contrary, our algorithm focuses on the center of the face, and it can easily avoid nonskin-colored features, such as eyebrows, hair, glasses, lips, blush, and highlights.

To examine the performance of the algorithm, we compared the hue distributions between the skin pixels from the whole face and those from the central facial region. As result, Figure 4 provides a clear distinction. For a comparative analysis, the Figure 1 (a) picture was used, assuming the rest of the pictures should have the same tendency. In the figure, four curves are presented, and each indicates the hue distribution of detected skin region pixels. Among the four curves, the green one shows the hue distribution of the facial color when the whole face is taken. Apparently, several peaks are observed. The yellow curve is the result after the space–scale filtering of the green curve. The red and blue curves describe the hue distribution of the central facial region, and only one sharp peak is observed in both curves. The hue refers to the H of the HSV color space, and the H angle corresponds to the horizontal axis. The vertical axis stands for the frequency of the pixels.

Likewise, we observed the hue distributions of all of the pictures (N = 348) and identified that all of them followed the same trend as Figure 4. In addition, the computational time is drastically reduced when the central facial region is put into the calculation. For example, the red line in Figure 4 takes more or less 50% of computational time compared to the duration acquired for the green line.

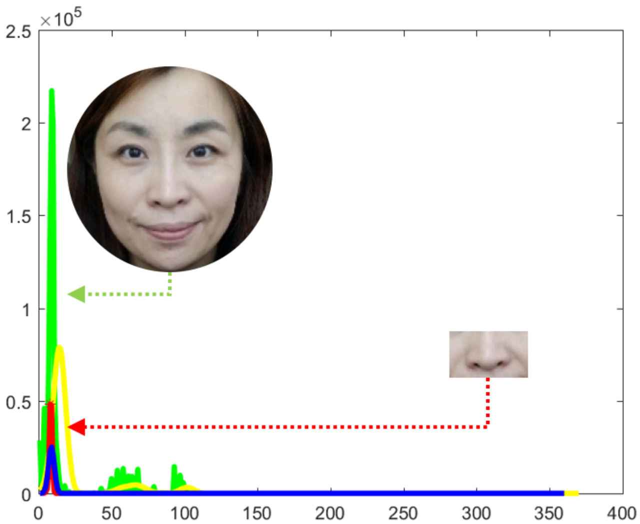

Figure 4. The hue distributions of pixels depending on the detected facial areas and adaptation of scale–space filtering. Green: entire facial image (before filtering); yellow: entire facial image (after filtering); red: central region only (before filtering); blue: central region only (after filtering). The horizontal axis corresponds to the hue degree in HSV color space. The vertical axis indicates the number of pixels. (Image source: Figure 1(a).)

Discussion

We have been motivated from a question where we consider a certain part of a face instead of considering the whole when we want to detect one's skin color. From literature reviews, we identified that no one has yet tried to crop the sample region. To explore the skin-representative region, we heuristically analyzed errors resulting from the existing algorithms. For example, a major drawback in pixel-based skin detection is a false detection of nonskin objects, such as hair (see Figure 1), because the detection includes any color as long as the color values are within the skin color boundary. As a complimentary technique, the adaptive detection was tried by recent studies. This detection focuses on the most frequent hue, assuming the dominant hue should be from the skin. Basically, our algorithm takes advantage of the adaptive detection, and what is particularly new is use of the central part of face—specifically, near the nose. By doing so, the algorithm can be more robust against makeup, hair, eye brows, and so on.

As demonstrated in Figure 4, the proposed algorithm contains less noise and takes much less time than the whole face to be put into the computation. The tendency is consistently found in all of the 348 pictures taken under various illuminant conditions. Because the adaptive detection is less likely used due to its heavy computational load, the proposed algorithm could be a plausible alternative. It takes less than 50% of computational time that might have taken with the whole face.

However, this study has several limitations. First, the algorithm is highly dependent on the illuminant conditions, because it does not yet involve the calibration process. Though the algorithm helps focus on the real skin color, it does not result in the true color. Second, the algorithm needs to be verified by various ethnic groups. Nevertheless, the algorithm contributes to a more robust and faster computation to detect and calculate one's skin color. Considering the market growth of skin-related industries, including cosmetics and smartphone applications, any technical advances in the detection of skin color attracts a lot attention from industries and academia. By combining this work with a color-correction method—such as a color constancy algorithm or an illuminant sensor in mobile devices—the algorithm could be developed to obtain the true skin color.

Conclusion

This study proposes a new step in detecting one's skin color in digital imaging. Instead of taking the whole face into consideration, the suggested algorithm crops a central facial part around nose. As an alternative method in adaptive detection, we found this algorithm is more robust against nonskin items on the face. Moreover, it takes less than 50% of workload to compute compared with the existing method that considers the whole face.

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Author Biography

Hayan Choi received her B.S. in industrial design(ID) and minored computer science M.S. in ID from the Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea. Currently, she is a Ph.D. candidate of KAIST in a color laboratory (color.kaist.ac.kr). Her research interests include computational imaging and skin color.

Kyungah Choi received her B.S. and M.S. in industrial design from the Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea. Currently, she is a Ph.D. candidate of KAIST in a color laboratory (color.kaist.ac.kr). Her research interests include psychophysics, color perception, and lighting technology.

Hyeon-Jeong Suk received her BS and MS degrees in industrial design from KAIST, Republic of Korea, and her PhD degree in psychology from the University of Mannheim, Germany. Currently, she is an associate professor of KAIST leading a color laboratory. Her research interests include color psychology and emotional design