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# The human sclera and pupil as the calibration targets

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## Abstract

*This research suggests a color constancy algorithm using the human sclera and pupil for estimating skin color. The human sclera is approximately white, reflecting the hue characteristics of the illuminant. On the contrary, the pupil is shown as approximately black, independently of the surroundings. Consequently, the sclera and pupil account for the color characteristics of a facial image. Based on this assumption, a new color constancy algorithm was developed, and we examined the performance by comparing the calibrated colors with actual skin colors measured with a spectrophotometer. As the dataset, we collected facial images as well as the CIEL*a*b* values of 348 Korean females. As a result, the error of the proposed algorithm was significantly smaller than the state-of-art skin estimation algorithms. The algorithm developed in this study provides evidence that the human sclera and pupil successfully serve as the calibration targets to estimate the color of human skin.*

## Introduction

A great deal of attention has been paid to detecting skin color in computer graphics and computer vision for face detection, body detection and gesture recognition [1]. In those algorithms, accuracy has not been focused on. However, skin color estimation focuses on finding accurate skin color from facial images. Because human vision is highly sensitive in the range of the skin color, even a marginal error should be improved for the practical application of accurate skin color estimation [2]. The most popular application of skin color estimation is cosmetics, including foundation matching and recommendation. However, the illuminant condition distorts the skin color captured by a camera (Figure 1), which affects the performance of those algorithms.

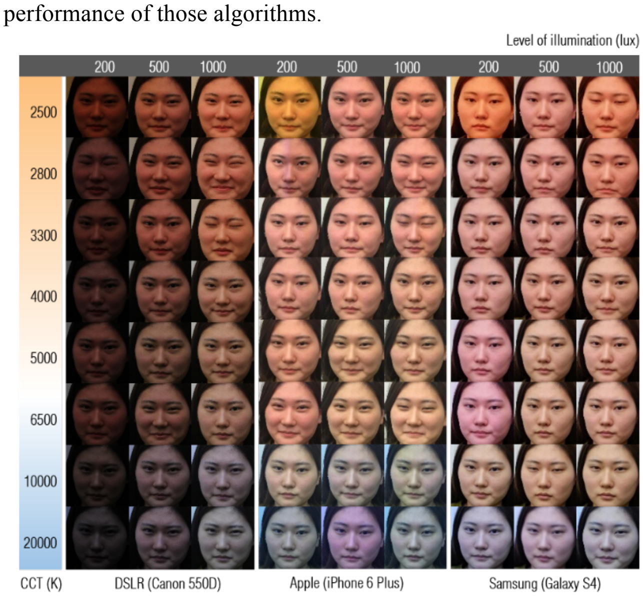


*Figure 1. Facial images under various illuminant conditions*

The concept of color constancy was introduced to eliminate color distortion. Color constancy is the human ability to recognize the color of an object regardless of the illuminant condition [3]. The actual mechanism of color constancy is not fully solved yet, so calibration using a color checker is regarded as the ground truth. However, because it is not possible to include the color checker in every image, color constancy algorithms are suggested.

The approaches to obtaining color constancy can be divided into two types in computer vision applications. The first type aims to correct an image by the features that are invariant under any illuminant condition, such as derivative-based image descriptors [4-6]. The other type aims to correct an image based on estimating the color of the illuminant [7, 8].

Based on the second type of algorithm, a few color constancy assumptions were suggested, with a focus on skin colors [9-11]. Bianco and Schettini [11] suggested a color constancy algorithm based on the fact that the human skin color is distributed in a limited range in a color space [12]. They conducted color correction in 548 image datasets, and the faces were detected to derive the predefined skin color range. Their algorithm detects skin pixels from a facial image by calculating the dominant hue for each face. Then, the colors of the detected pixels are transformed into the predefined range of skin color derived from their dataset. The algorithm provided a reliable performance for the calibration of the overall images. However, the algorithm may result in the same skin color throughout the transformation. Therefore, it is not appropriate for accurate skin color estimation.

Störring, et al. [9] suggested a color constancy algorithm using the highlights on skin. Their algorithm provided a reliable result; however, their purpose was not to estimate the accurate skin color but to raise the detection rate of the skin that is included in the HSV boundary. It also relies on the skin color in the input image, so that it is not accurate enough to use their assumptions directly in estimating skin color. Meanwhile, Do, et al. [10] suggested a color constancy algorithm based on the human sclera by assuming that the sclera is white under a canonical illuminant condition. However, the assumption does not consider the non-white features of sclera, such as the blood vessels, occasional dark spots, and the shadow cast by the eyelid. Moreover, the color of human sclera changes with aging, emotional valence and nuance [13]. Although it has non-white features, the human sclera is approximately white only in humans among primates [14], and it reflects the hue characteristics of the illuminant. To complement the performance of calibration using the sclera, we suggested the pupil as another calibration target. The pupil is shown as approximately black, independently of the surroundings. It is just an opening, and the light goes through the pupil to be absorbed in the retina. The actual color of the pupil is black under any illuminant, but a reflection may be occasionally captured due to the cornea, which is the transparent part in front of the pupil.

As such, this study attempts to develop a color constancy algorithm using the sclera and the pupil as the calibration targets for accurate estimation of human skin color more accurately. For this purpose, the target color value of the sclera and pupil was collected by facial images while holding a color calibration target. Based on this, a new color constancy algorithm was developed. Its performance was examined by comparing the calibrated colors with the actual skin colors measured with a spectrophotometer. As the dataset, we collected facial images and the CIEL*a*b* values of 348 Korean females.

## Method

The dataset is collected to investigate the values of the sclera and the pupil for the image calibration, and to evaluate the performance of the proposed algorithm (Figure 2).

To be more specific, the primary step for using the sclera and the pupil is to get the actual color values of the sclera and the pupil. However, the color of the pupil and sclera cannot be measured by the colorimetric devices since they are really sensitive to light and not big enough region for any measurement. For this purpose, we collected facial images holding color checkers. The calibration based on the color checkers makes it possible to compute the values of the sclera and the pupil without directly measuring the colorimetric values.

Lastly, we measured the colorimetric values of facial skin in terms of CIE L*a*b* to evaluate the accuracy of the color constancy algorithm using the sclera and the pupil. The measured skin colors are averaged into one representative color as a ground truth, and it will be compared to the estimated skin color after color correction by the proposed algorithm in terms of color difference.

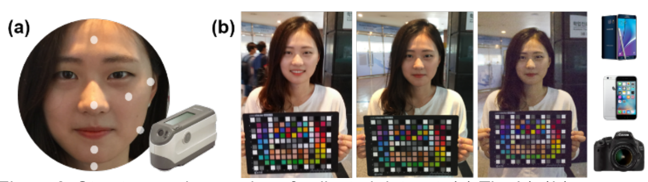


*Figure 2. Structure and examples of collected dataset: (a) The L*a*b* measured spots (forehead, nose-tip, chin, neck, cheek, cheekbone, jaw), (b) Images taken with three devices (Samsung GalaxyS4, Apple iPhone6, Canon 550D)*

### Dataset Collection

A total of 348 Korean females were recruited, and the age of participants ranged from 17 to 56 years old (mean 21.56 years, standard deviation 5.56 years); all were paid volunteers. Because the main users of skin color–based applications are females, we recruited female subjects for this study. Three images for each subject were taken using different camera devices, including a DSLR camera (Canon 550D) and two smartphone devices (Apple iPhone6 and Samsung Galaxy S4). The illuminance and correlated color temperature (CCT) was also measured with a chromameter at the same position of the face. The mean illuminance was 20,015 lux (standard deviation = 22,971 lux), and the mean CCT was 5,183 K (standard deviation = 1,890 K).

To compute the color of the pupil and the sclera, the facial images of the subjects were taken under various illuminants while holding the color checker. According to Harville, et al. [15], the color correction in the range of skin color performs better when using only skin-colored patches rather than primary colors. Based on this, we used the Digital ColorChecker® SG of the X-Rite Inc. because it includes 14 unique skin patches.

For the performance evaluation of the proposed algorithm, the L*a*b* values of seven spots in faces were measured with a spectrophotometer (Konica Minolta, CM2600d). The measured values were used to compute the ground-truth skin color for each subject. According to previous studies [16-18], the measured spots include the forehead, nose tip, chin, neck, cheek, cheekbone and jaw. The L* values ranged from 55.26 to 65.83, the a* values ranged from 6.62 to 13.16 and the b* values ranged from 12.07 to 21.64. The mean L*a*b* value was [61.06, 9.65, 17.36], and the standard deviation was [2.18, 1.21, 1.67].

### Color of Sclera and Pupil

The image correction using only the 14 skin-colored patches performs better than image correction using the standard 24-color patches [15]. Based on this, we used the 14 skin-colored patches for the derivation of the target values of the sclera and pupil.

For calibration, we detected the 14 skin-colored patches in the color checker that each subject was holding when the picture was taken. After having the patches, the regions for each patches are averaged to obtain the color value of the patch. Then, the values are transformed into the known values for each patch. The calibration used the von Kries model [19]. Because the von Kries model corrects each pixel in the image with the inverse of estimated illuminant color I in RGB space, the color of the sclera and pupil are also computed as [0.70, 0.59, 0.54], [0.19 0.15 0.14] in RGB, respectively.

### Color Constancy Algorithm Using the Sclera and the Pupil

The proposed algorithm is composed of the following steps: the face and eye region are detected from the image, and the sclera and pupil are extracted. Based on transforming the extracted pupil and sclera into the computed values, the image is corrected and the skin color is estimated.

To be more specific, the face is primarily detected as shown in Figure 3(a) from the image using a face detector of Viola-Jones [20] that is widely used in computer graphics and vision applications. Then, the eyes are detected as in Figure 3(b). The pupil is detected by the Hough transform [21], as shown in Figure 3(c). The Hough transform finds the boundaries of the pupil and the iris to be circular contours. The intersection of an eye-shaped mask with detected pupil area is segmented as in Figure 3(d) and (e). The darkest region of the pupil is extracted to remove the effect of the cornea, as shown in Figure 3(f). The darkest region was extracted due to the transparent attribute of the cornea, which can reflect the light. Then, the extracted region will be averaged into a single color of pupil for image calibration.

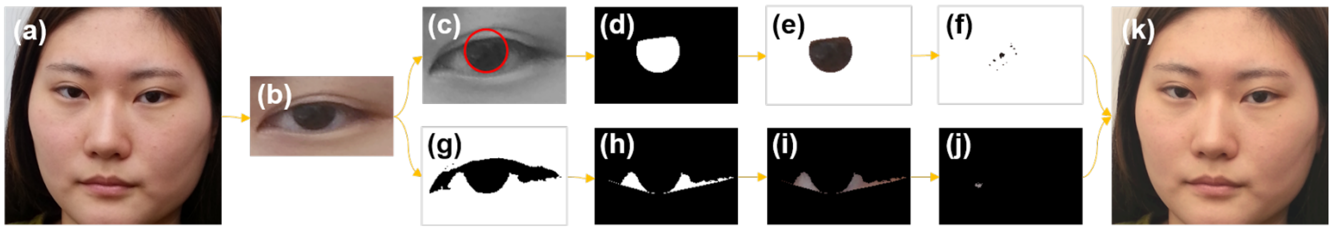


*Figure 3. Algorithm flowchart: (a) original image, (b) detected eye, (c) pupil detection using Hough transform, (d) pupil mask, (e) detected pupil, (f) the darkest region, (g) eye shape extraction using Otsu algorithm, (h) sclera mask, (i) detected sclera, (j) the brightest region, (k) corrected image*

As shown in Figure 3(g), the sclera region is segmented by an eye-shaped mask and Otsu algorithm as developed in previous studies [3, 21] from the detected eye regions. The Otsu algorithm classifies pixels into bright and dark groups by finding the luminance threshold to segment the sclera from the skin pixels. By applying the eye-shaped mask, the sclera is segmented, as in Figure 3(h) and (i). After the sclera segmentation, the brightest region was extracted as Figure 3(j) for color correction to eliminate the effect of vessels, dark spots on the sclera and the shadow by the eyelids. The brightest region of the sclera is regarded as the whitest region on the face, which minimizes these effects. Similar to the pupil color extraction, the brightest region of the sclera is also averaged into one single color for image calibration.

Based on the extracted color of the pupil and the sclera, the image is corrected using both colors. Image correction is performed by transforming the extracted colors to the reference colors from our dataset, as calculated in the previous section. Finally, the resulting image is generated from the image-correction process. As in Figure 3(k).

Then, the skin region is extracted by an adaptive skin detector [2]. This adaptive skin detector finds a dominant hue in the face region and then filters out the pixels that are not close enough to the dominant hue. In addition, we added a skin-filtering process by using the collected dataset. The range of the measured L*a*b* values is the actual skin color without any distortion by the illuminant condition, such as shadows and highlights on the skin. Therefore, the skin pixels are filtered based on the range of the L*a*b* values to exclude the non-skin area. The remaining pixels are averaged into a skin color as a result of the proposed algorithm.

## Result and Analysis

The performance of the proposed algorithm is verified by the color difference ($\Delta E$) between estimated skin color and the ground truth skin color. The measured seven L*a*b* values were averaged to a representative skin color for each subject that was considered the ground truth. Two evaluations were conducted for verifying the performance of the proposed algorithm as the color correction using the sclera and the pupil and additional skin-filtering process. All evaluation processes compared the images with the opened eyes and the detected face.

The first evaluation compared the color correction using the sclera and the pupil as calibration targets with the color corrections using the color checker. This study compared both the color correction using only skin-colored patches [15] and the 24 colored patches. For accurate verification, the same skin estimation process (adaptive skin detector) was used for the first evaluation. The average $\Delta E$ of each color correction are as below; using the sclera and the pupil was 9.13 (standard deviation = 4.25), using the 24 colored patches was 9.25 (standard deviation = 3.86) and using the 14 skin-colored patches was 8.56 (standard deviation = 3.92).

The results yielded statistical significance at an alpha level of 0.05. [$F(2, 1606) = 10.15$, $P < 0.05$]. Although the performance of proposed color correction using the sclera and pupil is similar to color correction using the color checker, color correction using the skin-colored patches was better than color correction using the color checker. The pairwise mean differences were statistically significant between color correction using skin-colored patches and others from the post-hoc test.

The second evaluation compared color correction using the skin-colored patches and the proposed color constancy algorithm combined with the skin color filtering process. In terms of $\Delta E$, there was a statistically significant improvement in the proposed algorithm combined with skin color filtering than the skin-colored checker [$t(803) = 37.53$, $P < 0.05$]. The mean $\Delta E$ value was 3.06 (standard deviation = 1.39) for the proposed algorithm combined with skin color filtering, and the mean $\Delta E$ value of the color correction using the skin-colored patches was 8.56 (standard deviation = 3.92), an improvement of 5.50 ± 4.15. This result provides evidence that it is more accurate to estimate skin color based on the proposed algorithm with skin-color filtering than using skin-colored patches as a calibration target.

## Discussion

The study examined the human sclera and the pupil as calibration targets for digital images to estimate human skin. The evaluated $\Delta E$ revealed that the proposed algorithm performs as well as the correction based on the color checker. This improvement of color constancy algorithm is primarily due to the dataset we have collected. By taking the brightest part of the sclera, the extracted color becomes whiter, but it is still a pinkish region rather than a white or gray region. The dataset collection of the real colors of the sclera and pupil made it possible to derive the improved performance.

This study recruited subjects that were only Asian females. Because few studies have focused on Asian skin, this dataset will have points of difference. In addition, we regarded that if the proposed algorithm estimates skin color successfully in a narrow skin color range, it would be easily expanded to the broader range of skin color. Moreover, the sclera and pupil are consistent regardless of ethnic groups; the performance will not be much decreased due to the difference of ethnic groups. Further study might also be extended to a broader skin color of subjects for more reliable validation.

Because our color constancy algorithm works well in the range of skin color, the overall image may be distorted by the proposed color correction. The overall image may not be corrected well when focusing on skin color. This may remain a limitation of the algorithms, which focus on skin colors.

Moreover, the skin filtering method based on the measured color using spectrometer showed a large improvement in accuracy.

Different to the color constancy algorithm using the sclera and pupil, this skin filtering method has limitations in that it can only be applied to a group with homogenous skin color. Further investigation of the skin filtering method and consideration of the spatial meaning of extracted skin regions will make it possible to find a skin region less affected by the illuminant.

## Conclusion

Because human vision is highly sensitive to the range of skin color [4], few studies have tried to improve the accuracy of skin color estimation. This study suggested a color constancy algorithm based on the color of human sclera and the pupil for the accurate estimation of skin color. The results provided evidence that color correction based on the human sclera and the pupil performs as well as the widely used 24-color calibration target. In addition, the L*a*b* threshold from the dataset measurements highly improved the performance and decreased the error ($\Delta E$).

This study opens up the possibility that a skin-color based application does not need any additional calibration targets, even with improved performance and convenience.

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