Color Reality Implementation of Human Skin on Display Image

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Abstract

The utilization of online shopping continues to grow due to the influence of the contactless culture resulting from the prolonged effect of COVID-19. As an alternative face to face services, individual skin condition diagnosis services and non-face-to-face makeup cosmetic color evaluation are emerging. However, so far it has been necessary to use specific sensors possible to obtain an accurate service. Therefore, a service that consumers can use conveniently in any environment is required. In this study, the details of ambient light sources and individual skin spectral reflectance are estimated using a smartphone. This uses the individual skin reflection spectrum to determine the skin condition and predicts the spectral reflectance and color that could occur when makeup cosmetics are applied. Also, based on the accurate color reproduction method on the display of the smartphone, the color matching the actual color could be observed on the smartphone.

It was possible to represent the spectral reflectance of individual skin similar to that measured by spectrophotometer based on the Kubelka-Munk model. By analyzing the spectral reflectance spectrum through optical simulation, we established a system that extracts the main parameters, such as melanin fraction and, hemoglobin fraction. It is expected that this information can be applied to the healthcare field or linked with customized cosmetic recommendations. In addition, the spectral reflection spectrum of skin covered with cosmetics was obtained by applying a three-layer optical mode. It was confirmed that the color matching between the actual color and display color was successively implemented by using the obtained formula. This implies that if color information is corrected with the obtained formula, consumers will observe the same color as when the cosmetic are applied on their skin in any lighting environment.

Keywords:

Color; Skin optics; Kubelka-Munk theory; Cosmetic color simulation; Display; Light source

Introduction.

A makeup simulation system is that demonstrates the effect of makeup virtually using a mobile device, and general users can easily simulate cosmetics and makeup styles that suit them by applying various cosmetics to their faces virtually.[1-3] In these makeup simulation systems, the accurate color expression of cosmetics is the most crucial factor. However, when selecting cosmetics in the current makeup simulation system, the skin color of the user's face is not reflected, and only the color of the cosmetics are overlaid, showing unnatural results. In addition, it is challenging to expect realistic colors due to color transformation through the process of showing the makeup simulation results on mobile. For this reason, consumers who purchase cosmetics products are often unsatisfied with the resulting color that develops which is different from the image they want to express. Therefore, if the color developed after it the application a cosmetic product can be accurately provided to the consumer in consideration of the characteristics of the consumer's skin color, the customer's satisfaction with the product should be increased.

Color is information recognized by the human eye due to the degree of reflection (spectrum) of each wavelength from an object and the influence of the light source. Human color vision can detect only visible light among specific areas of light, which are electromagnetic waves with a broad spectrum.[4] Therefore, if we calculate the spectrum (reflectance) when cosmetics are applied through a prediction formula based on information about the specific cosmetics, we can obtain precise information such as color information when applying cosmetics and provide this to consumers. In this case, the Kubelka-Munk theory was used to develop the predictions.[5, 6]

In this study, to reproduce the color of cosmetics accounting for the skin color using makeup simulation, the color distribution was analyzed through the color of cosmetics and the actual skin. In addition, the color change was analyzed through spectral measurement before and after cosmetics were applied to the skin color.

When testing a cosmetic product non-face-to-face using a digital device, consumers should be able to see the actual color when it is applied. The display expresses colors using the three primary colors of RGB colors created by the backlight light source passing through the color filter.[7-10] When the previously acquired color information is input, the output color is changed under the influence of backlight and color filters. To solve this problem, we measured the color of the display that appears when a color is input from a mobile device and analyzed the color variation through machine learning. In addition, human vision is affected by the surrounding environment, so ambient lighting and background conditions must be considered.[11-15] The same experiment was repeated with various types of light sources to check the effect of the light source. In this study, we propose a method of color reproduction considering the effects of display characteristics and light sources so that consumers can feel the same color as the color information they want.

Considering the development of intelligent mobile devices, the spread of digital users, and the influence of the non-contact culture resulting from the prolonged effect of the coronavirus, and the increasing growth of online shopping there is also a growing demand for the accurate simulation of the appearance of cosmetics. This study aims to provide color development information for consumers to increase the accuracy of non-face-to-face product testing by confirming the same color on display as the actual color. In addition, we aim to provide recommendations for services that considers the characteristics of an individual's skin, personality.

Materials and Methods.

1. The color of cosmetics affected by the human skin

Color refers to the light reflected from an object and enters the eye.[4] Therefore, to predict the color development by cosmetics, it is necessary to calculate the reflection spectrum when cosmetics are applied to the skin. In order to formulate the behavior of light, it is simply divided into a skin layer and a cosmetics layer. At this time, the skin layer was tested by applying the two-layer skin (epidermis/dermis) spectrum model to which the previously published Kubelka Munk theory was applied. The reflection spectrum in the experiment was measured with a Konica Minolta spectrophotometer (CM-2500d).

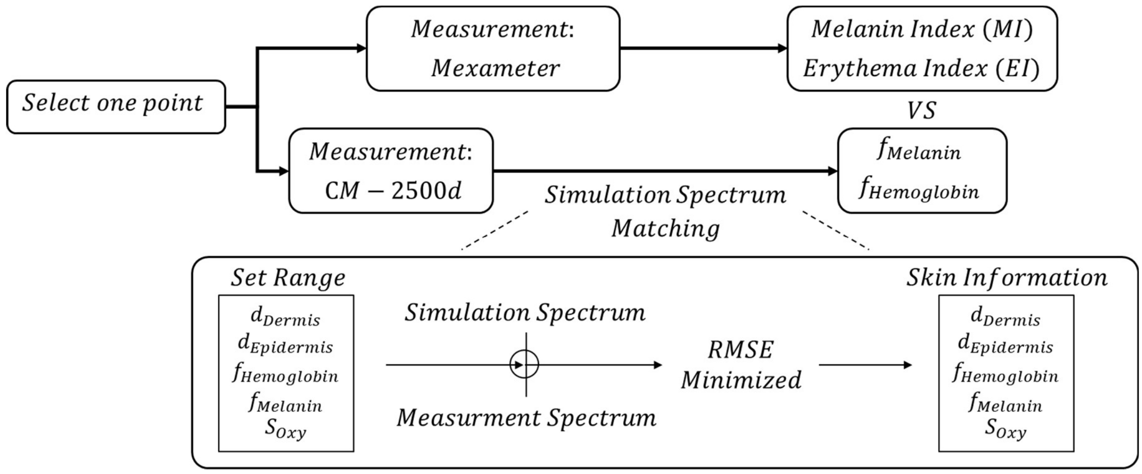
1.1 Acquisition of skin information by matching the reflection spectrum of individual skin layers

Light shows various optical behavior resulting from reflection, absorption, and scattering for each individual's skin. Using these characteristics, various skin diagnosis studies are conducted through light reflection behavior in the skin.[16]

The skin is a multi-layered structure composed of the outermost epidermis, dermis, and innermost subcutaneous tissue.[17] Among these, melanin in the epidermis and hemoglobin in the dermis are mentioned as chromophores that determine skin color. In addition, to know the spectral reflectance and transmittance of each layer, the absorption coefficient, scattering coefficient, and the thickness of the layer are required.

Therefore, The existing two-layer skin spectrum model is affected by dermis and epidermis thickness, hemoglobin and melanin fractions and , oxygen saturation such as, total of five parameters (d_{Dermis}, $d_{Epidermis}$, $f_{Hemoglobin}$, $f_{Melanin}$, S_{Oxy}).[18]

It is assumed that we can obtain the predicted value of skin information by fitting parameters through optimization by proceeding with a process in which the error between the actual skin spectrum and the simulated skin spectrum is minimized. We recruited 20 men and women in their twenties to verify this assumption. We conducted a clinical experiment comparing the predicted skin information results with the actual measured skin information. Melanin and hemoglobin fractions were selected among the five parameters, and MI (Melanin Index) and EI (Erythema Index) were measured using Mexameter, a skin measurement device.[19]



[Figure 1] Schematic diagram of a method for obtaining skin information parameters through the simulation spectrum matching process and a trend analysis experiment through regression analysis using accurate skin information

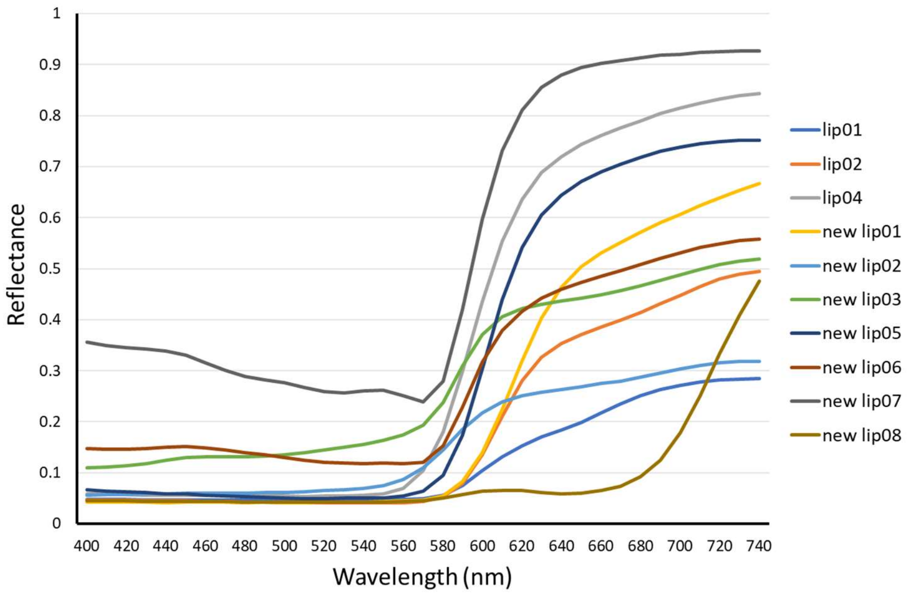
1.2. Cosmetic color reproduction simulation model

Assuming that the light behavior occurs in the three layers of cosmetics/epidermis/dermis, a color simulation formula was developed using the Kubelka-Munk formula which mathematically expresses the light behavior in the three layers. In order to predict the cosmetics color development spectrum through this color simulation formula, the reflection/transmission spectrum of the skin layer (epidermis/dermis) was obtained through the two-layer simulation. Furthermore, the cosmetics layer's reflection/transmission spectrum information is required.

Cosmetics are applied on the skin in the form of thin layer. Nevertheless, the reflection and transmission spectrum of the cosmetics layer depends on the thickness. Therefore, to obtain accurate cosmetics layer spectral information, appropriate transmission and reflection spectra were measured considering the thickness of the applied cosmetics.

1.3. Accuracy test of color simulation formula

To test the effectiveness of the color prediction simulation formula, the lip spectrum before and after applying ten lipsticks to 20 lips was measured and compared with the color prediction results. (Each spectrum is the average of the two spectrum measurement results.) Using the 'image j' program, each individual's lip area was calculated, and the amount of application was calculated by designating the amount to be applied per area. A total of ten lipsticks with different colors were used in the experiment. Figure 2 shows, the reflection spectrum of the lipstick measured by Spectro-radiometer.



[Figure 2] Reflectance Spectrum of 10 lipsticks measured by Spectro-radiometer.

2. Color on display

On the mobile screen, we should be able to check the color when the cosmetics are applied to the human skin. However, due to the color space of the mobile itself, color variations occur in the process of expressing colors through the display, and the lighting of the space, when the user inputs the color into the mobile, color produced on the device can be different from the real color. For this reason, to accurately deliver makeup simulation results to users through mobile devices, color errors that may appear due to display and lighting should be corrected. Therefore, to maintain higher accuracy and reproducibility, we propose a method of obtaining a color conversion matrix according to mobile color characterization and visual environment and correcting the color through this matrix. This study was conducted using the iPhone 13 Pro.

2.1. Color characterization of iPhone 13 pro

The main problem related to color reproduction in a mobile display is that the color coordinates are shifted by the color space of the mobile itself. Therefore, it is necessary to reproduce the actual color by identifying the mobile color space and correcting it in advance.

We made the necessary measurements to characterize the color of the iPhone 13 pro display. The instrument for this measurement is a Konica-Minolta CS-2000 spectroradiometer with a spectral resolution of 1 nm between 380 and 780 nm and a measurement error of less than 2%. We selected 891 digital RGB values divided at equal and measured the XYZ tristimulus values for the corresponding RGB values of the iPhone display in a dark room. Next, we determined the relationship between the digital RGB values and the display XYZ tristimulus values. We obtained a model from multiple linear regression through machine learning after processing digital RGB values.

2.2 Light source adaptation

The chromaticity of the display changes depending on the chromaticity and illumination conditions of the ambient light. Thus, it paramount to reproduce accurate colors even when simulating makeup under different visual environmental conditions. We objectively investigated the change of color developed in the display according to the change in the light source. The iPhone 13rpo display measurements were made for with light sources. It was measured using a Konica-Minolta CS-2000 spectroradiometer, and 26 digital RGB values divided at equal intervals were selected, and the XYZ tristimulus values for the corresponding RGB values of the iPhone display were measured. At this time, we conducted measurements in a lighting booth that the brightness of the light source was adjusted in four steps. A total of 26 types of illuminance or chromaticity were measured under different light sources.

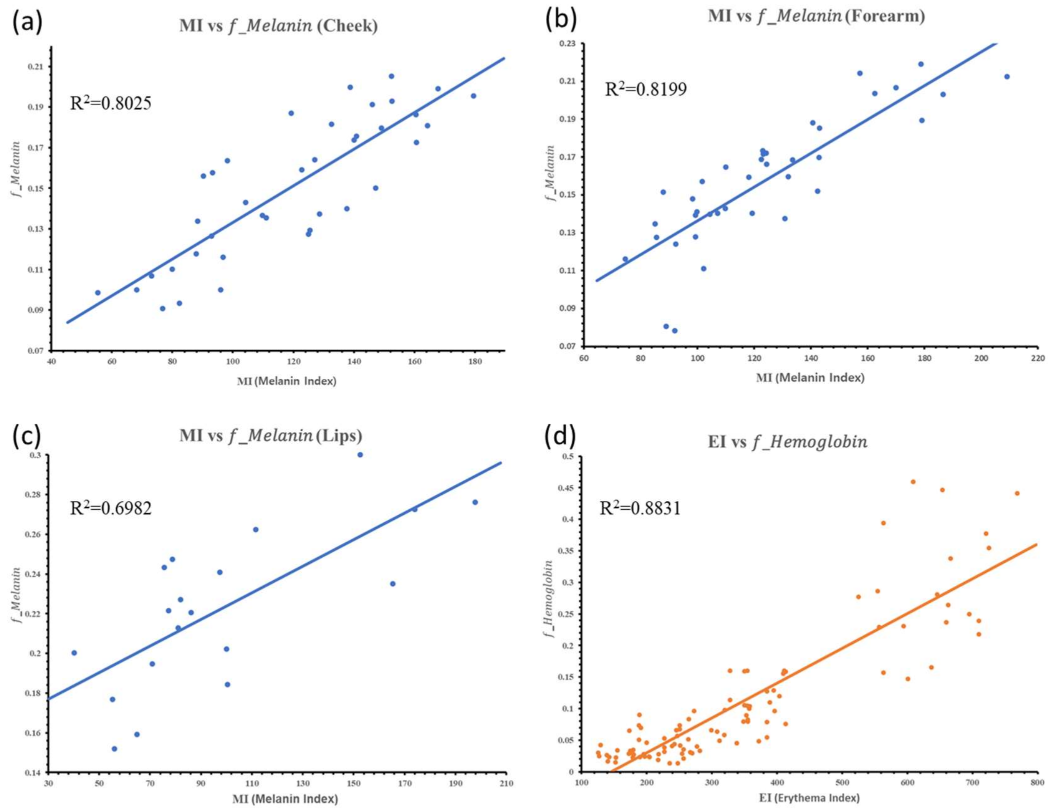
[Figure 3] Different 4 light sources represented in lighting booth. D65 (top left), A (top right), TL84 (bottom left) and D50 (bottom right)

Next, we determined the relationship between the display XYZ tristimulus values under each light source and the display XYZ tristimulus values in the dark. This process capable to obtain a model in the form of multiple linear regression through machine learning. The elements of the multiple linear regression model differed according to the chromaticity or illuminance of the light source. A matrix intercept function that can predict the intercept of the model in response to the light source change was also modeled.

Results.

1. The color of cosmetics affected by the skin

In order to verify the reliability of the data of the melanin fraction obtained by the numerical analysis of the simulation results, a clinical experiment was conducted with 20 men and women in their 20s and 30s as shown in Figure 4. The results of regression analysis with MI (Melanin Index) and EI (Erythema Index) for the parameters $f_{Melanin}$ and $f_{Hemoglobin}$ obtained through the simulation spectrum matching process are shown in Figure 4.

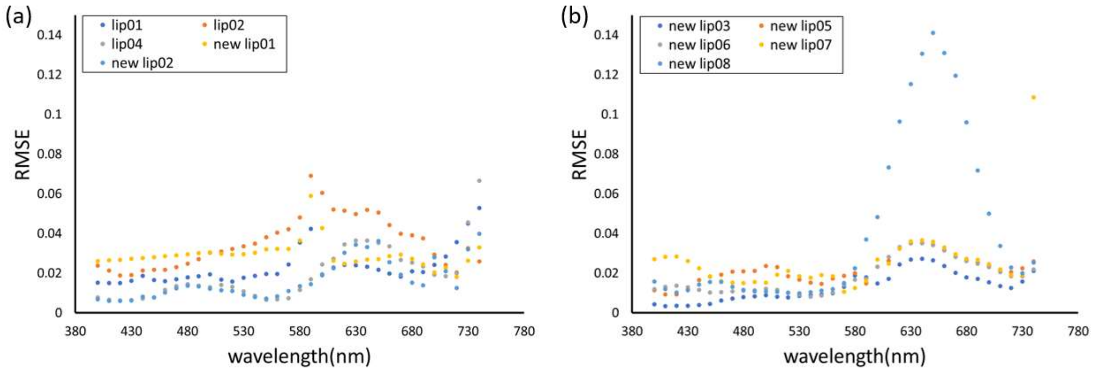


[Figure 4] (a) Regression analysis result of melanin index (MI) measured using Mexameter of Cheek area and $f_{Melanin}$ calculated through simulation (R^2=0.8025, p-value=4.75E-10) (b) Regression analysis result of melanin index (MI) measured using Mexameter in the Forearm region and $f_{Melanin}$ calculated through simulation (R^2=0.8199, p-value=9.67E-11) (c) Regression analysis result of the Melanin Index (MI) measured using Mexameter at the Lips area and $f_{Melanin}$ calculated through simulation (R^2=0.6982, p-value=0.00062) (d) Regression analysis result of Erythema Index (EI) measured using Mexameter at Cheek/Forearm/Lips and $f_{Hemoglobin}$ calculated through simulation (R^2=0.8831, p-value=5.5857E-34)

MI (Melanin Index) and $f_{Melanin}$ measured using a Mexameter were regression analyzed. In regression analysis, if the p-value is less than 0.05, it can be considered that the influence of the independent variable on the dependent variable is significant. As shown in Figure 4(a) and (b), in the Cheek and Forearm regions, the p-value is much smaller than 0.05, so it can be concluded that the higher the $f_{Melanin}$ analyzed by simulation has led to the higher the MI (Melanin Index). The experiment was conducted with the same experimental method, the Lips result in Figure 4(c) shows that the p-value is less than 0.05. However, unlike the graph of the cheek/forearm region, the tendency is low because the R-squared value is less than 0.7. It is expected that this is because the stratum corneum of the lips is very thin compared to other areas and has the property of exfoliating dead skin cells.

In addition, a regression analysis of the trend between the EI (Erythema Index) and the $f_{Hemoglobin}$, a chromophore that gives the skin red color, was analyzed. As a result, as the p-value is less than 0.05 shown in the graph in Figure 4(d), it can be seen that the higher the $f_{Hemoglobin}$ obtained through the simulation of the skin spectrum, the higher the EI (Erythema Index).

Comparison of measured and modeled 10 lipsticks reflection spectra of the 20 people is shown in Figures 5(a)-(b). The result of comparing the color development prediction result and actual color development of cosmetics applied to the skin is expressed using the total root mean square error (RMSE) over the whole spectrum. For each of the10 lipstick, Wavelength-wise errors averaged over all 20 people are shown in the table given Figure 5(c).



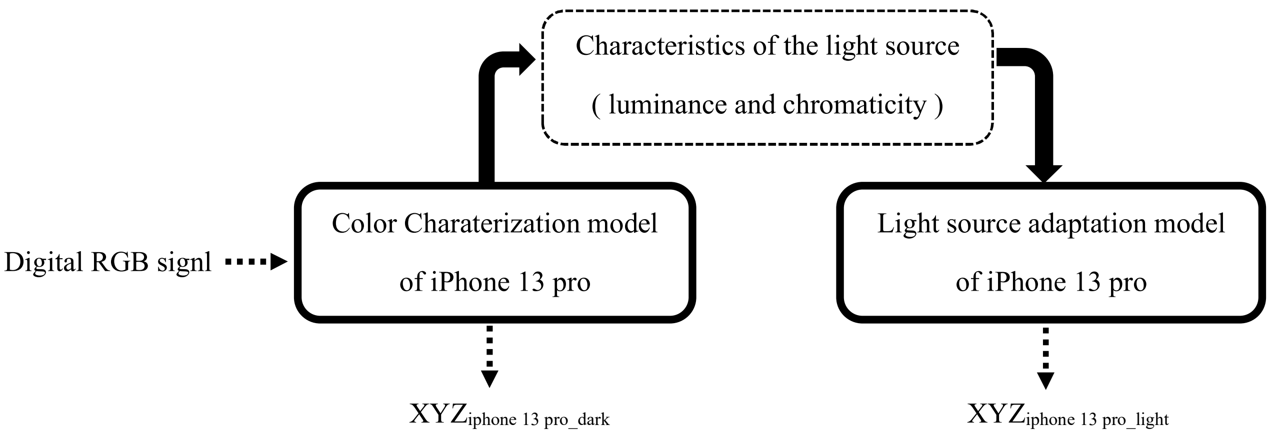
(c)	lip01	lip02	lip04	New lip01	New lip02	New lip03	New lip05	New lip06	New lip07	New lip08
Total RMSE (%)	2.27	3.52	1.94	2.93	1.66	1.31	2.16	1.82	2.52	4.16

[Figure 5] Average root mean square error between measured and simulated reflectance of each lipstick over the 20 people (a) lip01/lip02/lip04/new lip01/new lip02 (b) new lip03/new lip05/new lip06/new lip07/new lip08 (c) The total root mean square error (RMSE) over the whole spectrum and all 20 people (for each lipstick)

Modeled reflectance spectrum differs significantly from the measured reflectance spectrum only in 580-650nm. If the theoretical maximum value of the mean error is 1, the largest mean error here is less than 0.045, (less than 4.5%) so the color development simulation model is considered to be accurate.

2. Color on display

For high accuracy and reproducibility in mobile makeup simulation, we propose a method of characterizing mobile colors and obtaining a color conversion matrix according to light sources and correcting colors through this matrix. The whole process is shown in Figure 6.



[Figure 6] The diagram of total color correction model

In Figure 6(a) is the mobile characterization process, and the Equation (1) is as follows. Predicting the XYZ tristimulus values of the iPhone 13 pro against digital RGB values. By checking the iPhone 13 pro's response to digital RGB signals, it is possible to know the movement of color coordinates by color space. The R-value was 0.9973, which showed high accuracy when comparing the measured XYZ value with the XYZ predicted through the mobile characterization model.

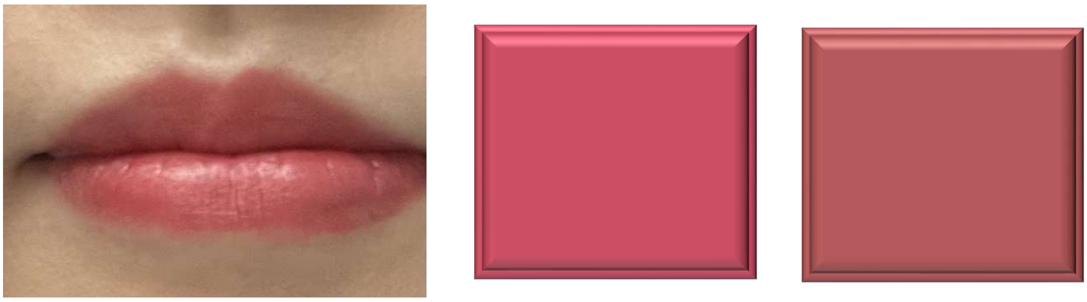
$$X_{\text{iPhone 13 pro\_dark}} = 0.771633 * \text{processed R} + 0.577448 * \text{processed G} + 0.326881 * \text{processed B}$$
$$Y_{\text{iPhone 13 pro\_dark}} = 0.376533 * \text{processed R} + 0.2422128 * \text{processed G} + 0.119704 * \text{processed B} \quad \cdots (1)$$
$$Z_{\text{iPhone 13 pro\_dark}} = 0.027323 * \text{processed R} + 0.165050 * \text{processed G} + 1.755295 * \text{processed B}$$

In Figure 6(b) is the light source adaptation process, and the Equation (2), (3) is as follows. The relationship between the display XYZ values in the dark room and the display XYZ values under the light source is shown. $X,Y,Z_{\text{iPhone 13 pro\_dark}}$ indicates the display XYZ tristimulus value in the dark room, and $X,Y,Z_{\text{iPhone 13 pro\_light}}$ indicates the display XYZ tristimulus value under each light source.
In Equation (2), the intercept values of each relational expression L_X, L_Y, L_Z can be obtained through Equation (3). Equation (3) contains X, Y, $Z_{\text{Light source}}$ terms representing the illuminance and chromaticity information of the light source, so the intercept value of the light source adaptation model (2) can be determined from the chromaticity and illuminance of the light source using the Equation (3) matrix. The R-value of all equations was 0.99 or higher. As a result, display XYZ tristimulus values in a dark room under a light source of known chromaticity and illuminance.

$$X_{\text{iPhone 13 pro\_light}} = 2.9107 * X_{\text{iPhone 13 pro\_dark}} + L_X$$
$$Y_{\text{iPhone 13 pro\_light}} = 2.9217 * Y_{\text{iPhone 13 pro\_dark}} + L_Y \quad \cdots (2)$$
$$Z_{\text{iPhone 13 pro\_light}} = 2.8439 * Z_{\text{iPhone 13 pro\_dark}} + L_Z$$

$$L_X = 0.0041577\ X_{\text{Light source}} - 0.0021113\ Y_{\text{Light source}} + 0.0008429\ Z_{\text{Light source}}$$
$$L_Y = -0.0040567\ X_{\text{Light source}} + 0.0056258\ Y_{\text{Light source}} + 0.0009805\ Z_{\text{Light source}} \quad \cdots (3)$$
$$L_Z = -0.0179222\ X_{\text{Light source}} + 0.0181575\ Y_{\text{Light source}} + 0.0017356\ Z_{\text{Light source}}$$

The proposed method predict is a method to predict the output tristimulus value for the input RGB value in the lighting environment. Conversely, the input RGB value can be obtained so that the target tristimulus value is displayed. This study shows the color of cosmetics applied to the skin through mobile makeup simulation. Therefore, the target tristimulus value is the predicted color value when cosmetics are applied to the skin. Through the proposed process, it was possible to obtain the input RGB value for which the target tristimulus value is displayed.



(a) (b) (c)

[Figure 7] Images of applying New lip 05 on the lips(a), iPhone 13 pro screen before correcting(b), iPhone 13 pro screen after correcting(c)

Figure 7(a)-(c) are photos taken under lighting booth D65 50% brightness. (a) is a photograph of the subject applying New lip 05 on the lip. By predicting the color when New lip 5 is applied to the subject's lip and entering the predicted the subject's lip color value without correction, the iPhone 13 pro screen is displayed as image (b). Image (c) is a picture of the iPhone 13 pro screen when the predicted the subject's lip's color value was corrected through mobile and lighting characterization process and input. Many observers felt that the display color after calibration was the same as the actual color.

Discussion.

In this study, we developed a makeup simulation system to apply individual skin color by accurately predicting light scattering in the skin and cosmetic layers. For this purpose, the state when cosmetics are applied to the skin is reproduced with the epidermis/dermis/cosmetics, that is, a three-layer model. Our model was able to analyze skin information using the values of parameters that could be obtained in the process of describing the behavior of light interacting with the skin tissue.

As shown in Figure 4, the $f_{Melanin}$ / $f_{Hemoglobin}$ obtained through simulation significantly affects each other with the MI and EI values, which are skin information measured with a Mexameter. Consequently, the MI/EI value and the $f_{Melanin}$ / $f_{Hemoglobin}$ are proportional. However, at this time, more research is needed on the lip area with the property of peeling off.

Through the root mean square error (RMSE) result in Figure 5, it was found that the reflection spectrum during the simulated cosmetics was similar to that of the actual cosmetic after application to the skin. In the future, if more cosmetic information is input into the simulation the accuracy can be improved, and a much broader cosmetic color prediction experience could be provided to consumers.

In addition, a makeup simulation system developed in this study exhibited high reproducibility and precision under various environmental conditions to provide consumers with a color prediction experience without deformation. We used machine learning and multiple linear regression analysis, and the color characteristics of mobile display and color change due to ambient light were modeled. The R-value of the model was 0.99 or higher. When displaying the color of skin applied with cosmetics, this model was applied to correct the color. As a result of observing the performance of the implemented simulation, it was possible to visually confirm the improvement of color reproducibility when the color correction model was applied. In future research, it will be possible to implement an equipment-independent and highly complete makeup simulation system by adding an algorithm that extracts the light source's characteristics and the skin's spectrum from the image.

Conclusion.

From this research, we can offer a system to virtually represent individual skin conditions and the color of natural human skin covered with cosmetics. Our system mainly includes two steps.
Firstly, it measures the skin information of consumers through the simulation spectrum matching process and uses this information to provide consumers with a cosmetic color test experience.
Secondly, by applying a color correction model according to the display and light source, consumers can check the color of skin covered with cosmetics by smartphone to help them purchase cosmetics.
This study will assist in boosting the growth rate of the beauty market, which is evolving into personalization and digitalization.

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Conflict of Interest Statement.

NONE.

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