Skin Color Measurements: Usefulness of the Metric Hue Angle of Uniform Color Spaces for Dermatological Treatment

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Abstract— Skin color is predominantly determined by pigments such as hemoglobin, melanin, carotene and bilirubin. The quantification of experimentally induced color changes is widely used method in dermatology and cosmetics since the color response can be used as an indicator of skin properties, drug properties and skin protection properties. The present study, we examined the usefulness of hue angle was calculated from the uniform color space. Metric hue angle is expected to correspond well to the appearance of skin color than the chromaticity coordinates or tristimulus values.

1. INTRODUCTION

Skin color and its variations are important in different fields such as cosmetics, dermatology, and medicine, as well as computer rendering [1, 2]. The diversity of skin colors among people, or according to different locations on the same person, at different times depends mostly on three main characteristic parameters. The concentration of melanosomes, the concentration of red blood cells, and the oxygen saturation of blood. The determination of these three parameters are of great interest. Previous studies to determine one or two of them have used the reflectance and absorbance spectra measured on real skin. For instance, the light propagation by the modified Beer-Lambert law and use a multiple regression analysis to determine the concentration of melanin and blood. Others use reflectance measurements at selected bands to estimate the melanin index and the erythema index, or the CIELAB coordinates to evaluate the individual typology angle that is related to the skin's pigmentation. How do the colours that we see on the surface arise? Light emitted by a source interacts with the surface and the interior of an object and through these interactions (mainly absorption and scatter) the spectral composition of the light is altered. The changes reflect the structure and optical properties of the materials constituting the object and in this sense the light remitted from the object encodes its properties. If this encoding is understood, it should be possible to deduce the structure and composition of the object from its color. Conventionally, Munsell color system and CIE color space have been used in the evaluation of skin color. However, these methods may not correspond to the subjective feeling has been pointed out. In this paper we examined the usefulness of metric hue angle was calculated from the uniform color space. Metric hue angle is expected to correspond well to the appearance of skin color than the chromaticity coordinates or tristimulus values. The focus areas of this work are as follows: a) examined the differences in the various color spaces using a standard skin color samples, and b) measuring the skin color such as cheeks and forehead of subjects by using a commercially available instruments.

2. STRUCTURE AND OPTICAL PROPERTIES OF THE SKIN

Skin has a definite layered structure as shown Figure 1. The epidermis is the outermost part of the skin and is subdivided into five layers (from superficial to the deepest) the stratum corneum, the stratum luceum, the stratum granulosum, the stratum spinosum, the stratum germinativum. The main substance concerning absorption and scattering of light are the melanin pigments [3, 4]. Stratum corneum outermost layer, also called the horny layer, is mostly comprised of polygonal flattened dead cells filled with mature keratinocyte that are pushed towards the surface and gradually die and break apart. It is covered with a layer of sebum, a oily-waxy material produced by the sebaceous glands, that keeps the layer flexible and waterresistant. Stratum lucidum also called the clear layer it represents a transition from the underlaying stratum granulosum to the above stratum corneum. Stratum granulosum also called the granular layer. The granules accumulated in the keratinization process contain lipides whose role is to help prevent fluid loss from the body. Stratum spinosum also called the spiny layer, it consists of several layers of newly created cells from the stratum germinativum. The stratum germinativum consists of a single layer of cells necessary

in the regeneration process of the above layers. Mitotic processes in this layer create new cells that migrate upwards through the different layers in the progressive maturation process of keratinization. Melanin Pigments are the most important part of the epidermis considering optics. Melanin pigments are found in skin, hair and eyes. These pigments are produced in the stratum germinativum and are also present in the stratum spinosum, the upper layers contain no melanin. These pigments protect the material of the underlying mitotic cells from ultra violett rays. Therefore the absorption spectrum increases towards shorter wavelengths to act as a protective filter. There are two types of melanin: eumelanin and pheomelanin. The black to dark-brown eumelanin is found in skin, black hair and the retina of the eye. The yellow to reddish-brown pheomelanin is found in red hair. All individuals have varying content of eumelanin whereas the pheomelanin is only found in inviduals with the corresponding genetic trait.
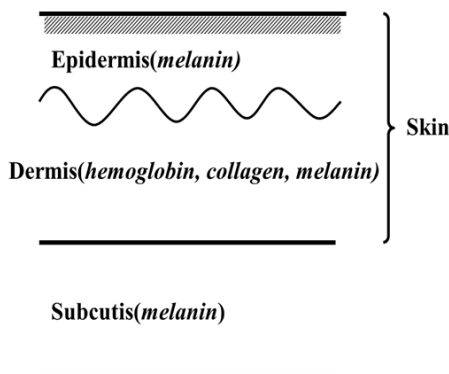

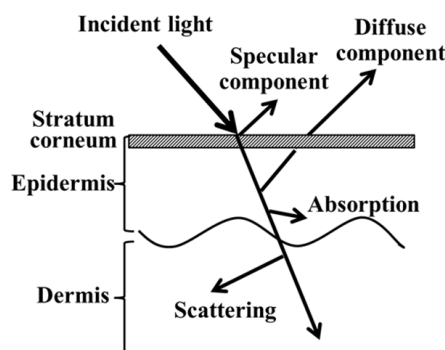Figure 1: A cross section of human skin.

Figure 2: A schematic representation of the skin layers and their optical properties.

The skin consists of a number of layers with distinct function and distinct optical properties as shown Figure 2. White light shone onto the skin penetrates superficial skin layers and whilst some of it is absorbed, much is remitted back and can be registered by a camera. The stratum corneum is a protective layer consisting of keratin-impregnated cells and it varies considerably in thickness. Apart from scattering the light, it is optically neutral. The epidermis is largely composed of connective tissue. It also contains the melanin producing cells, the melanocytes, and their product, melanin. Melanin is a pigment which strongly absorbs light in the blue part of the visible spectrum and in the ultraviolet (see Figure 2). In this way it acts as a filter which protects the deeper layers of the skin from harmful effects of UV radiation. Within the epidermal layer there is very little scattering, with the small amount that occurs being forward directed. The result is that all light not absorbed by melanin can be considered to pass into the dermis. The dermis is made of collagen fibres and, in contrast to the epidermis, it contains sensors, receptors, blood vessels and nerve ends. Haemoglobin, present in blood vessels across the whole dermis, acts as a selective absorber of light. The dermis consists of two structurally different layers, papillary and reticular, which differ principally by the size of collagen fibres. The small size of the collagen fibres in the papillary dermis makes this layer highly back scattering; i.e., any incoming light is directed back towards the skin surface. The scatter is greatest at the red end of the spectrum and increases even further in near infrared. As absorption by melanin and blood is negligible in the infrared, this part of the spectrum is optimal for assessing the thickness of the thicken papillary dermis. Within the reticular dermis, the large size of collagen fibre bundles causes highly forward directed scattering. Thus any light which gets to this layer is passed on deeper into the skin and does not contribute to the spectrum remitted from the skin.

3. CALCULATION OF COLOR SPACE

The color and appearance of skin is more important in the field of medicine. During the diagnosis of skin diseases such as pigmented lesions, careful observation and visual assessment of the diseased area is always the first and most important step. In 1976, CIE suggested two uniform color spaces, the $CIEL^*a^*b^*$ (CIELAB) and $CIEL^*u^*v^*$ (CIELUV), based on XYZ tristimulus values [5]. The former was a nonlinear transformation of the tristimulus space and widely used in the colorant industry. These two spaces have opponent color axes representing redness-greenness

versus yellowness-blueness denoted as a^* against b^*, and u^* against v^* for CIELAB and CIELUV respectively. Both of them are three-dimensional space involving three attributes: lightness, hue and chroma. The lightness scale L^* shown in tristimulus values of color considered to Y_n of the reference white, expressed as (Y/Y_n)

$$L^* = 116 \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 \tag{1}$$

The hue and chroma of CIELAB and CIELUV are fomulated in Eq. (2) and Eq. (3) respectively.

$$a^* = 500 \left\{ \left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} \right\} \tag{2}$$

$$b^* = 200 \left\{ \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}} \right\} \tag{3}$$

$$h_{ab}^* = \tan^{-1} \left(\frac{b^*}{a^*}\right) \times \left(\frac{180}{\pi}\right) \tag{4}$$

$$C_{ab}^* = \sqrt{(a^*)^2 + (b^*)^2} \tag{5}$$

where X_n, Y_n and Z_n are the tristimulus values of the specific reference white, han and C_{ab}^* are the metric hue angle and chroma component in CIELAB space. The term $180/\pi$ is necessary to convert the output of the inverse tan function from radians to degrees. The hue angle is measured in degrees starting with $h_{ab}^* = 0$ in the $+a^*$ axis direction and increasing counter clockwise.

$$u^* = 13L^* \left(u' - u_n'\right) \tag{6}$$

$$v^* = 13L^* \left(v' - v_n'\right) \tag{7}$$

$$h_{uv}^* = \tan^{-1} \left(\frac{v^*}{u^*}\right) \times \left(\frac{180}{\pi}\right) \tag{8}$$

$$C_{uv}^* = \sqrt{(u^*)^2 + (v^*)^2} \tag{9}$$

where $u' = 4X \left(X + 15Y + 3Z\right)$, $v' = 9X \left(X + 15Y + 3Z\right)$, u', v' and u_n', v_n' are the u', v' coordinates of sample and reference white; huv and C_{uv}^* are the metric hue angle and chroma component
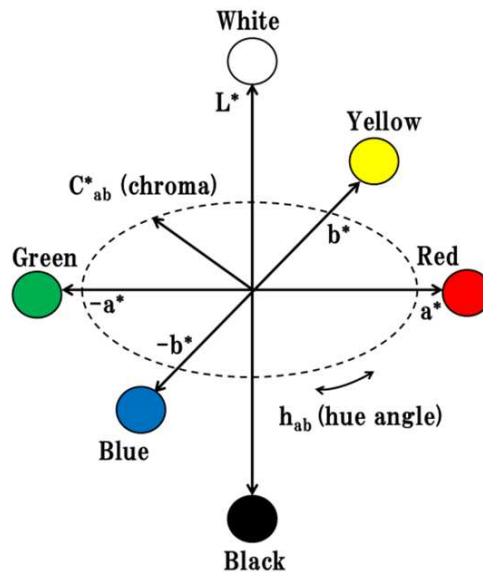

Figure 3: Diagrammatic representation of the CIELAB color space.

in CIELUV space. Both of the CIELAB and CIELUV define the hue and chroma by converting the rectangular axes into polar coodinates. Figure 3 shows a three dimensional representation of the CIELAB color space. The center of the color space is the neutral scale. The L^* values of 100 and 0 represent white and black respectively. The hue angle, h_{ab}, lies between $0°$ to $360°$ with the color arranged following the sequence of the rainbow colors. The C^*_{ab} scale is an open scale with a zero origin. The colors in the neutral scales have zero chroma value and do not exhibit hue. The CIELUV space has similar structure to the CIELAB space.

4. APPLICATION OF DERMATOLOGY TREATMENT

Reflectance spectroscopy is based on physical measurement of reflected light at specific wavelengths (400–700 nm), corresponding to the spectrum of visible light [6]. One tristimulus chromameter (Minolta Chromameter CR-200) and spectrophotometer (Minolta spectrophotometer CM-1000) were used in the study. With both instruments it is possible also to convert and display results as colorimetric values in the $L^*a^*b^*$ system where the CIELAB color space parameters are calculated from the spectral data. The aim of this study was to demonstrate that the colorimeter could measure a skin color and reproduce a rank order of the potency of the test formulations. For instrument measurement of skin color, basic studies on the 200 healthy female subjects have been chosen and divided into two groups; 100 young adults from 10 to 19 years old (average 16 years old) and 200 middle aged adults from 30 to 59 years old (average 35 years old and 54 years old). They were informed of the details of the experimental process and their consent was obtained prior to the measurements being made.

5. RESULTS AND DISCUSSION

The skin colors for the eighty male subjects in terms of the $CIEL^*a^*b^*$ color parameters L^*, hue angle, and chroma are shown in Figure 4 [7, 8]. The $CIEL^*a^*b^*$ parameters for any individual measure skin color as it would have been visually perceived. The skin of the lower forearm has characteristics determined by both hereditary skin color and environmentally induced melanin pigmentation. The ventral forearm, however, is relatively infrequently exposed to ultraviolet radiation and provided a readily accessible site to place over the viewing port of the spectrophotometers. The distribution of $CIEL^*a^*b^*$ parameters for the eighty male subjects represents objectively the ventral forearm skin color phenotype of the group. The range of each color space parameter within
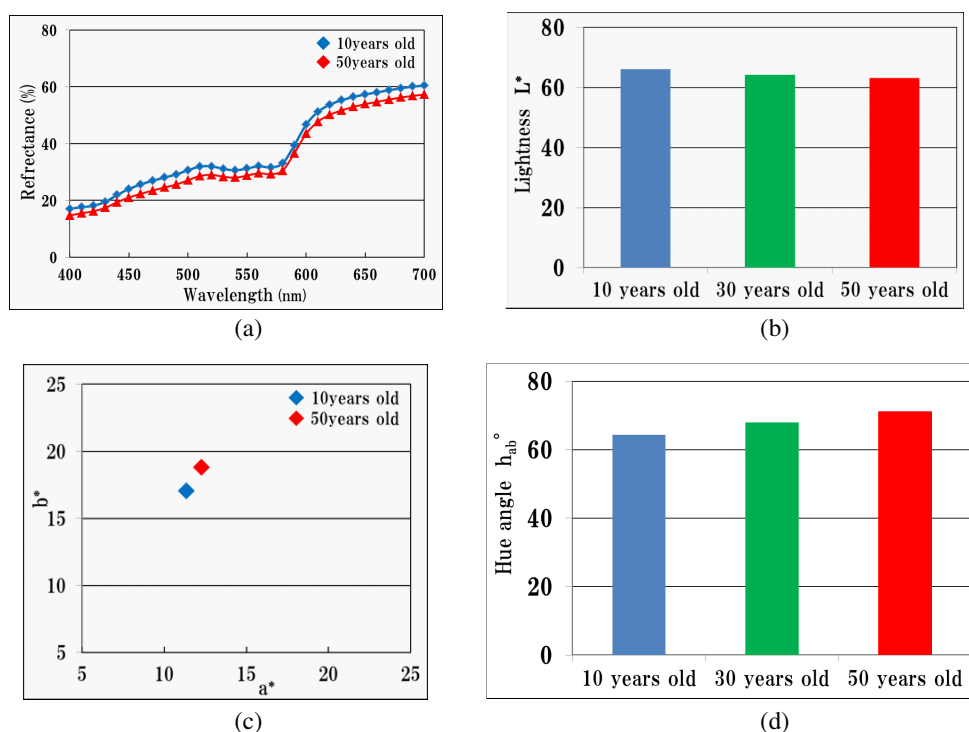

Figure 4: Distribution skin colors of 200 subjects expressed as the measured values of CIE-$L^*a^*b^*$ color space, refrectance spectra, L^*, $a^* - b^*$, metric hue angle h°_{ab}.

the group provides a numerical specification of the distribution of the corresponding color attribute as it would have been visually perceived. The L^* values ranged from 59.0 to 75.0. The apparent asymmetry of the distribution within the group was confirmed by a goodness of fit test showed that the hypothesis that the L^* values were normally distributed about a mean of 68.2 could be rejected at the 95% level of confidence. This meant that there were a few individuals whose skin was much lighter than would be expected from a normally distributed range of L^* values. The hue angles (h°) ranged from 54.0° to 78.0°. A difference in hue angle was noted between some subjects as the only color attribute that distinguished them because they were otherwise similar with respect to L^* and C^*. Differences in the skin color between individuals could be identified where both the L^* and h° values differed but the values for C^* were similar, or where the values for both the C^* and h° differed but the L^* values were similar. A further possibility was identified where differences in both L^* and C^* were evident but the hue angles were similar. For many randomly selected pairs of individuals all three $CIEL^*a^*b^*$ values were different. It was found to be suitable for representing skin color hue angle can be directly assessed the degree of red-yellow. For example, inflammatory skin lesions becomes stronger to red direction, normal skin becomes stronger yellow tone to reverse. Hue angle of normal skin color of Japanese is present in the range of 55 to 75 degrees.

6. CONCLUSION

Dermatologists or cosmetologists have long tried to quantify skin color and had few results until the advent of colorimetry. With the image colorimeter, quantification of skin color has become a simple matter: skin color can be measured rapidly, non-invasively, and reproducibly. The instrument, which can be used by paramedical staff, provides data that lend themselves for comparison, irrespective of where they are collected. The instrument has enabled definition of the range of physiologic values of skin color, and has revealed marked variations between exposed and non exposed skin. Constitutional skin color characterizes an individual's phenotype better than facultative skin color and is highly indicative of vulnerability to sunlight. On the practical level, colorimetric skin color values can be used to study pigmentation capacity, to program photo chemotherapy, and to predict the risk of, and prevent, actinic cancer. Colorimetry can be used to quantify the intensity of erythema of spontaneous and experimental lesions. Metric hue angle were found to correspond well to the appearance of skin color. However, the subjects are too few to make a general conclusion, and the authors would like to add additional observers in the not-too distant future.

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