Object Color Estimation Using Digital Camera for Noncontact Imaging Applications (Case Study: Teeth Color Estimation)

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ABSTRUCT

There has been a considerable effort in several fields, for objective color analysis and characterization. This paper study the problem of teeth color estimation using the most common color space in current use being the Commission International ed' Eclairage L*a*b* parameters of the captured images were derived from Photoshop software and saved as digital shade guides. A set of ceramic teeth shade was used, Images were captured with high resolution digital camera with LED flash and the data obtained was used to calculate the L*a* and b* values, these values conventionally obtained directly from RGB space. This paper proposed a method to estimating teeth color information from acquired camera data by calculating the L*a*b*values from the device independent color space the CIEXYZ space using transformation matrix which is involve calibration and characterization parts. The results showed significant correlation between data obtained from the digital camera using calibration and characterization process with that obtained from spectrophotometer, also the result showed that the digital camera can be used for color measurements in dental clinic, where the digital imaging could be an alternative for using colorimetric or spectrophotometric methods.

Keywords: Digital camera, digital shade guide, colorimeter, noncontact imaging, camera calibration.

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تخمين لون الجسم باستخدام كاميرة رقمية للتطبيقات اللاتلامسية
(دراسة الحالة: تخمين لون الاسنان)

الخلاصـة

هناك جهد كبير في العديد من المجـالات، بهدف تحليل وتوصيف اللون. هذا البحث يقدم دراسـة
لمشـكلة تقـدير لـون الأسـنان باسـتعمال نطـاق اللـون الأكثـر شـيوعا فـي الاسـتخدام الحـالي وهـو متغيـرات
الـ L *a*b* للصور التي تم التقاطها يتم اشتقاقها من برنامج فوتوشوب وحفظها كمرشد رقمي.

لقد تم استخدام مرشد الأسنان السيراميكي، والتقـاط الصـور بكـاميرا رقميـة عاليـة الدقة مـع فلاش
LED وقد تم استخدام البيانات التي تم الحصـول عليهـا لحسـاب قيم الـ L *a*b* ، هذه القيم يتم الحصـول
عليها عادتا مباشرتا من الفضاء RGB. لقد اقترح هذا البحث طريقة لتخمين المعلومـات اللونيـة للاسنان من
بيانات الكـاميرا بواسطـة حساب قيم الـ L *a*b* من الفضاء CIEXYZ باستخدام مصفوفة التحويل التي
تتضمن على معايرة وتوصيف.

أظهرت النتـائج ارتبـاط كبير بين البيانات التي تم الحصـول عليهـا من الكـاميرا الرقميـة باستخدام
المعايرة وعملية التوصيف مع التي تم الحصـول عليها من Spectrophotometer وكذلك اظهرت النتـائج
امكانيـة استخدام الكـامـيرا الرقميـة للقيـاس اللـون فـي عيـادة لطب الأسـنان، حيث التصـوير الرقمـي يمكن أن
يكون بديلا عن استخدام الأساليب اللونية أو طيفية.

INTRODUCTION

One of many challenges in cosmetic dentistry is to accomplish appropriate and satisfactory reproduction of natural shade of teeth and in that way to make successful restoration [1]. Continuous technological improvements of dental materials and consequent aesthetic enhancement of direct and indirect restorations require trained practitioner able to choose the right shade. Achieving the satisfying morphological, optical and biological form of a restoration is one of the most important goals of esthetic dentistry and dentistry in general [2].

Instrumental assessment of color is considered to be better than subjective visual color matching methods [3]. However, the high cost hinders their common use. In addition to expensive colorimeters, digital images captured with a digital camera and subsequently analyzed using photo editing software has garnered more attention for color assessment [4-8].

Several studies have shown the potential of digital cameras for dental color matching [5-12]. The scene captured by an image sensor of a digital camera can be decomposed into red, green, and blue (RGB) components and translated into digital information. However, the color information received from a digital camera is device dependent. Images produced via a digital camera are usually affected by the light source, reflection spectra of the objects, the photo sensor of the digital camera, and how the image is processed and rendered by the digital camera.

In general, these captured signals are much influenced by the illumination under which the image is taken [8]. To compensate for color differences caused by the colorcast of various light sources, an automatic white balance (AWB) mechanism is usually employed in most high-end digital cameras. Similar to the human eye, digital cameras

provide an AWB function to adjust the color of pixels under different lighting conditions. The most widely used algorithm for AWB is based on the gray world assumption, which seeks to equalize the mean of RGB channels. Another commonly used algorithm incorporates the white world assumption, which states that the RGB values of the brightest point in the image should be the same [13]. However, AWB often fails in situations where the light source has a particular cast or if the captured image does not contain natural white [14]. This is especially important in dental color matching, since various illuminants are used in dental clinics, and the captured images are usually focused in small areas composed largely of a tooth's structure.

To make a successful restoration, the purpose of this study is to find a non contact method to calculate teeth color using digital camera.

THEORETICAL BACKGROUND

Whenever a picture for tooth samples is captured, a light is incident on the tooth surface this incident light is reflected by the tooth onto the camera sensor as a function of the reflectance spectrum of the target then the R, G, B values measured by the camera. This model is illustrated in the Figure (1).
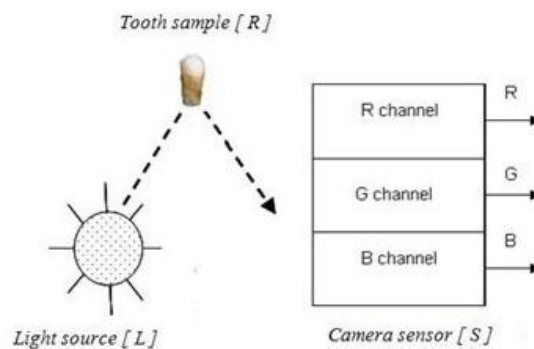

Figure (1) Light source – Reflectance - Sensor model.

As shown [L] is a diagonal matrix represents the normalized light source spectrum values. The reflectance matrix [R] is a matrix with the normalized reflectance spectra on the camera sensor, and the [S] sensor sensitivity function matrix of the camera sensor. If [K] is the response matrix which contains the RGB values, it is given by:

$$[K]^T = [R]\,[L]\,[S] \qquad\qquad \text{…….. (1)}$$

Where

$$\mathbf{K}^T = \begin{bmatrix} \mathbf{R_1} & \mathbf{G_1} & \mathbf{B_1} \\ \vdots & \vdots & \vdots \\ \mathbf{Rn} & \mathbf{Gn} & \mathbf{Bn} \end{bmatrix} \qquad\qquad \text{…….. (2)}$$

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$$R = \begin{bmatrix} r_1(\lambda_1) & \dots\dots\dots & r_1(\lambda_m) \\ r_2(\lambda_1) & \dots\dots\dots & r_2(\lambda_m) \\ \vdots & \vdots & \vdots \\ r_n(\lambda_1) & \dots\dots\dots & r_n(\lambda_m) \end{bmatrix} \quad \dots\dots. (3)$$

$$L = \begin{bmatrix} l(\lambda_1) & \dots\dots & \dots\dots \\ \dots\dots & l(\lambda_2) & \dots\dots \\ \vdots & \vdots & \vdots \\ \dots\dots & \dots\dots & l(\lambda_m) \end{bmatrix} \quad \dots\dots.. (4)$$

$$S = \begin{bmatrix} s_1(\lambda_1) & s_2(\lambda_1) & s_3(\lambda_1) \\ s_1(\lambda_2) & s_2(\lambda_2) & s_3(\lambda_2) \\ \vdots & \vdots & \vdots \\ s_1(\lambda_m) & s_2(\lambda_m) & s_3(\lambda_m) \end{bmatrix} \quad \dots\dots.. (5)$$

n represents the number of color patches on the target. s_1, s_2, s_3 are the spectral sensitivity functions, r_1 to r_n are the reflectance spectra of n patches and l is the light source spectrum values; defined for each wavelength λ.

FINDING THE CALIBRATION MATRIX T

Matrix [K] contains the RGB values of the camera as predicted by the model just described. However these RGB values belong to a device dependent color space. In order to determine the actual colors that the camera RGB values represent, it is necessary to find a transformation that transforms them to device independent space coordinates as shown in Figure (2):
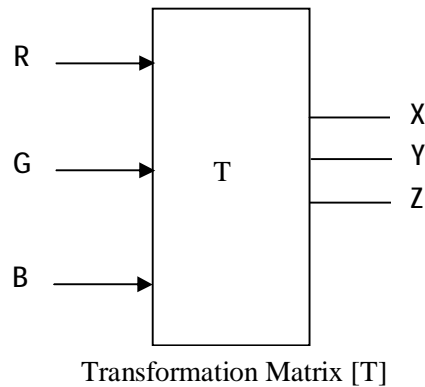

Transformation Matrix [T]

Figure (2) the transformation matrix.

The device independent color space in this case is the CIE XYZ space and the transformation matrix will be called [T]$_{model}$. These XYZ coordinates corresponding to the color patches are stored in matrix [F]. To determine the transformation from camera RGB to XYZ, the following set of equations in an over determined system was used:

$$[F]^T = [T]_{model} [K] \qquad \text{........ (6)}$$

Where,

$$F = \begin{bmatrix} X_1 & X_2 & ...... & X_n \\ Y_1 & Y_2 & ...... & Y_n \\ Z1 & Z2 & ...... & Zn \end{bmatrix} \qquad \text{........ (7)}$$

$$T = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \qquad \text{........ (8)}$$

The transformation matrix [T]$_{model}$ could be estimated by using the least squares approximation as following:

$$[T]_{model} = [F][K]^T ([K]*[K]^T)^{-1} \qquad \text{...... (9)}$$

After that conversion from RGB to XYZ is performed, the $L^* a^* b^*$ tri-stimulus values from the XYZ is determined using the standard transformation equations [15].

The $L^* a^* b^*$ values have a perceptual meaning: L^* is the lightness which relates to the physical intensity of color, while a^* and b^* are coordinates on the red-green and yellow-blue axis respectively. This scheme is designed such that a constant difference in color, ΔE, is defined by Euclidean distance in the space, thus:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \qquad \text{........ (10)}$$

As given in [1] the transformation can be divided into two parts:

1. Calibration
2. Characterization

Calibration

This process involves determining the nonlinear relation between the camera RGB values measured after gamma and shading correction in the camera and the linear RGB values which represent the response of the camera sensor system. In addition the calibration includes the process of estimation and correction of distortions caused by a camera lens Camera calibration, in general, can involve estimating two types of parameters: Internal and external camera parameters. The internal parameters determine the relation between coordinates of points in the scene and their coordinates in the image,

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while the external parameters characterize the relations between the camera and the scene. Distortion is the aberration that is suffered by the ray that goes through the center of the lens [16]. Mainly two distortions can be considered: radial and tangential distortion.

Tangential distortion arises of misalignment of lens centers in a system of lenses. Moreover Tsai showed [17] that it is the radial distortion that is the most critical non-linear effect of the lens while calibrating a camera. Because of various constraints in the lens manufacturing process, straight lines in the world imaged through real lenses generally become somewhat curved in the image plane. The radial distortion that causes the image to bulge toward the center is called the barrel distortion, and distortion that causes the image to shrink toward the center is called the pincushion distortion. To do this calibration and removes these distortions a matlab functions are written for this purpose.

Characterization

Characterization is the process of finding the transformation from device dependent color space to device independent color space. They are of two types namely, forward characterization and inverse characterization.

MATERIALS AND METHODS

A set of ceramic teeth shade of A1-A3, A3.5, A4, B1-B4, C1-C4, D2, and D3 was used as shown in Figure (3). Images were captured with high resolution digital camera of five Megapixel and Carl Zeiss Optics with dual LED flash.

Figure (3) Ceramic teeth shade.

Six teeth samples were placed on black cloth backing when the digital images were taken as shown in Figure (4). The digital images were taken and saved in TIF format. The resolution used was (2592×1944) pixels.
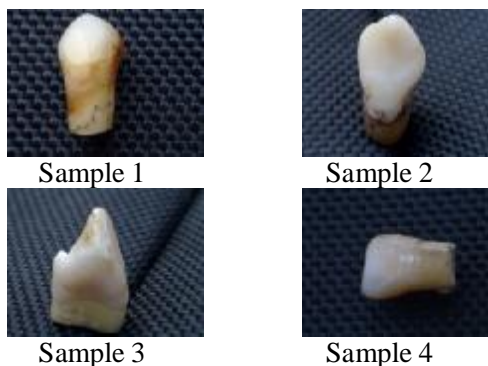

Sample 1

Sample 2

Sample 3

Sample 4

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Sample 5   Sample 6

Figure (4) Teeth samples.

Six different independent images were captured and retrieved on a 24-bit resolution screen then analyzed using Adobe Photoshop CS5.1 and Matlab 8. The color space of the software was set the same as the default color space of the camera. First the image mode was changed from RGB to L*a*b* (Lab$_{dir}$). A standardized square area of 36 mm^2 in area at the center of each sample image was cropped for analysis. The L*a*b* values of theses area were measured six times for each samples, and the mean values were recorded.

RESULTS

The standard L*a*b* values of ceramic teeth shade measured by spectrophotometer as shown in table1. The L*a*b*color values first obtained directly from the RGB (Lab$_{dir}$) from the photoshop program for each sample, then these L*a*b*color values (Lab$_{Cal.}$) obtained from XYZ after calibration and characterization process.

**Table (1) The standard L*a*b* values of ceramic teeth shade
Measured by spectrophotometer.**

Ceramic shade	L* value	a* value	b* value
A1	76.25	0.40	10.00
A2	73.10	0.65	12.75
A3	72.50	0.65	13.17
A3.5	69.50	2.80	18.00
A4	67.50	2.00	16.50
B1	76.25	-0.85	8.00
B2	75.00	-0.85	11.00
B3	71.25	0.00	14.80
B4	71.80	1.00	18.50
C1	75.60	-0.40	10.00
C2	70.50	0.85	12.75
C3	70.65	1.00	13.00
C4	66.75	1.30	12.96
D2	73.75	0.00	8.00
D3	70.60	0.65	11.00

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Mean values of L*a*b* of ceramic shade is plotted in Figure (5). Lab_{dir} and Lab_{Cal} derived from digital images were compared. The correlation coefficients as shown in Table (2) below:

Table(2) The correlation between the standard L*a*b* values of ceramic teeth shade and that using direct method and the proposed after calibration and characterization process.

Parameter	Correlation Lab_{dir}	Correlation Lab_{Cal}
L*_value	0.6537	0.9487
a*_value	0.8986	0.9234
b*_value	0.9152	0.9213

The proposed method of obtain digital shade guides using Lab_{Cal} had a greatest mean match than that using Lab_{dir} it is clear that it had significantly high correlations to the standard L*a*b*.
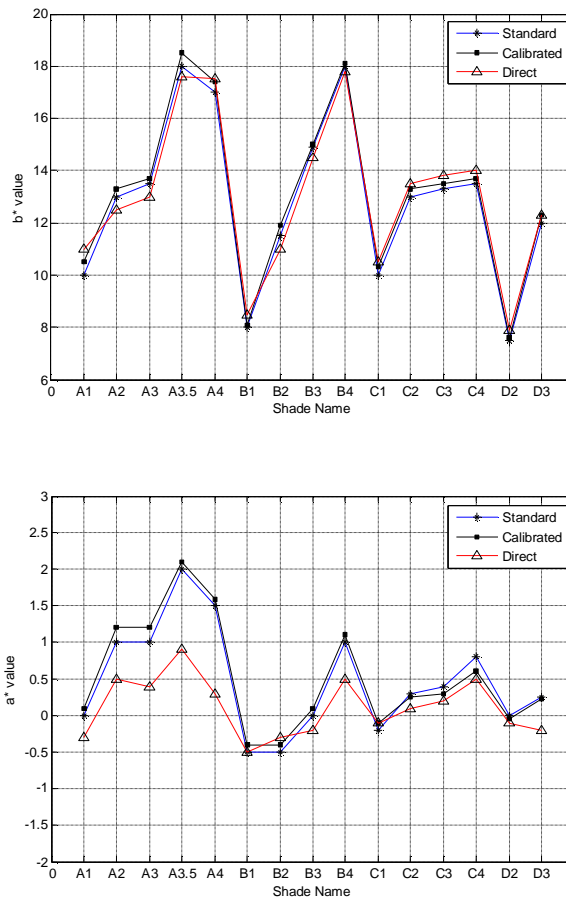

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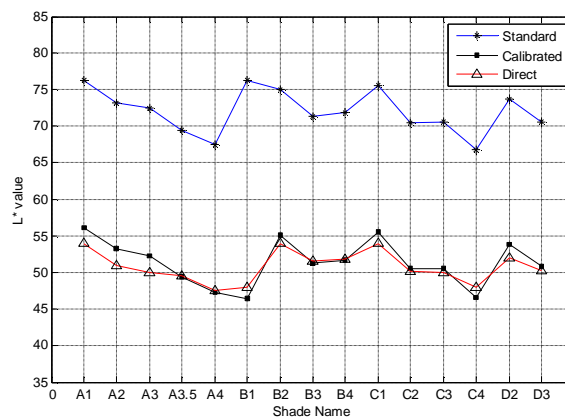
Figure (5) Mean values of L*a*b* of ceramic shade.

CONCLUSIONS

A new method is proposed for finding teeth color using digital camera instead of conventional human visual methods using physical shade gauid. The Lab_{cal} values of tooth image samples shows significantly high correlations to the standard L*a*b* values. The digital camera can be used for color measurements in the dental clinic.

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