Quantitative Color Appearance Evaluation of Agricultural Products Based on Natural Lighting Information

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ABSTRACT

We developed a quantitative color appearance evaluation method of crops and agricultural products using a digital camera. By analyzing the relationship between the color appearances of the images of a standard color chart with the plain Red, Green, and Blue color sections taken under the various natural lighting conditions and the illuminating spectral information, the photosensitive characteristics of the digital camera were experimentally studied. In addition, the color parameters of the Red, Green, and Blue sections on the virtual standard color chart calculated using the two parameters of a power function with the natural lighting spectral information consistently agreed with those of the standard image taken in the standard color acquisition system. Furthermore, the color calibration for the tomato fruit images taken under the natural lighting using the evaluated color parameters of the virtual color chart was performed. The developed color calibration method showed very successful results as well as the conventional calibration results. Consequently, these results suggested that the surface color images of the agricultural products which have the dynamic color distribution and the complicated geometrical structure could be evaluated based on the irradiance information of the natural lighting.

Keywords: Color calibration, Visible spectrum, Illumination, Agricultural fields, Agricultural products, Tomato.

1. INTRODUCTION

Color of agricultural products is practically used as a quality index in agricultural process such as cultivation, harvesting, sorting and packing, since the color could be reflected by the pigment components, which are some of the final productions through the primary and secondary metabolic process, and by the geometrical structure such as the shape and the surface conditions. There are various machine vision studies on the color of agricultural products after the processes such as drying and radiation have been reported (Brosnan and Sun, 2002; Abdullah et al., 2006). The color measurements using a colorimeter and a digital camera respectively based on the L*a*b* or RGB color coordinate system are usually performed for the quantitative color evaluation of agricultural products (Ergüneş et al., 2006; Hajare et al., 2007). We had adopted the HSL (*H*: Hue, *S*: Saturation, *L*: Lightness) color system based on the CCD camera

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(Kameoka et al., 1994; Motonaga et al., 1997), since the color analysis had the advantage that it easily acquired the surface information and the color distribution. Additionally, the color changes were analyzed by transforming the RGB color system of the CCD camera to the HSL color system in a way similar to human perception, because *H* and *S* are not affected by the quantity of light, uneven illumination, or an uneven surface shape.

The color appearance of the image acquired in the agricultural fields is seriously influenced by the illuminating conditions, and it has been still too difficult to quantitatively evaluate the color appearances of agricultural products. We also studied the quantitative color evaluation method of agricultural products in the agricultural fields (Motonaga et al., 2004; Hashimoto et al., 2001). Additionally, we developed the continuous and quantitative remote monitoring method of the surface color changes of agricultural products data during the cultivation using the Field Server (Fukatsu & Hirafuji, 2005) equipped with a digital camera (Hashimoto et al., 2012). However, there was the problem about the discoloration of the standard color chart for the color calibration in the above methods.

The objective of this study is to develop a quantitative color appearance evaluation method of agricultural products using the simple illuminating information of the natural lighting by developing the analysis on the relationship between the color appearance of the image taken by a digital camera and the spectral feature information of the lighting in our previous study (Hashimoto et al, 2012). Tomatoes cultivated in a greenhouse were then prepared as the experimental samples, since the surface color had dynamically changed from green to red through the post-ripening process.

2. MATERIALS AND METHODS

2.1 Materials

The tomato plants (Momotarou) cultivated in a greenhouse located in the Experimental Farm of the Field Science Center of Kii-Kuroshio Life Area, Graduate School of Bioresources, Mie University, Tsu, Japan, were prepared for the experiments. We also made the standard RGB color charts (Hashimoto et al., 2012) for the color calibration of the images in the outdoor conditions. The standard RGB color chart contains plain red, green and blue sections.

2.2 Methods

Figure 1 displays the setup of the standard color image acquisition system (Motonaga et al., 2004; Hashimoto et al., 2012) for the acquisition of the standard image. The system is composed of a digital camera (FinePix S3 Pro, FUJIFILM Corporation), six fluorescent lights at a 5500 K color temperature (TRUE-LITE, DURO-TEST Co., Ltd.) and two diffuse reflectors. The use of the TRUE-LITE fluorescent light is based on the CIE (Commission Internationale de l'Eclairage) regulations, and is almost the same as natural light since its color rendering index is 91. The light from the light sources is scattered on the diffuse reflectors placed over the light sources in order to prevent any specular reflection on the sample surface. The illuminance adjusted to 140 lx using the white diffuse reflectors and a dimmer switch was treated as the standard lighting conditions in this study. The visible spectral radiance of the lighting ranging from 380 to 730 nm in 10 nm intervals was measured with spectral measurement device (Eye-One Prophoto, GretagMacbeth Co.).

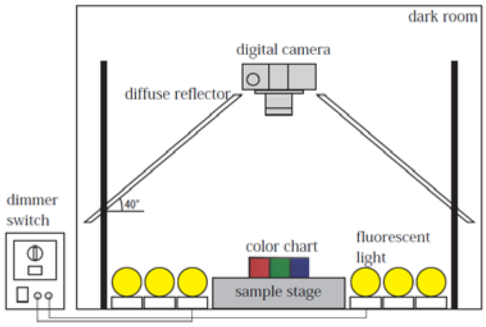

Figure 1. Scheme of standard color acquisition system.

The images were also taken under the field conditions near the window set forward to the southwest direction on the 6th floor of the building of Graduate School of Bioresources, Mie University, Tsu, Japan (north latitude 34.745958333, east longitude 136.522975000) (Figure 2). Additionally, the standard RGB color chart was also placed just behind the tomato fruit, and the image was acquired with it. The geometric relation between the camera and the tomato fruit in the field experiments was the same as that for the standard color image acquisition system. However, the lighting conditions, such as the color temperature and the geometric relation between the color chart and the light source (the sun), were depend on the date, the time and the weather. Figure 3 is an example of the variation of the spectral radiance of the natural lighting.

Figure 2. Scheme of color acquisition system under natural lighting condition.

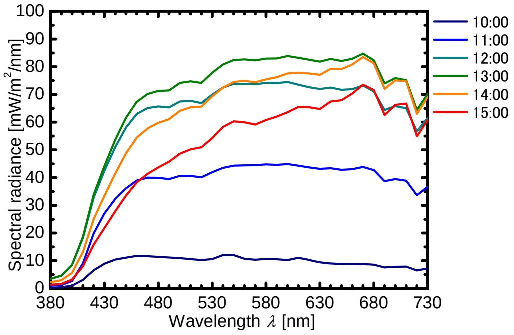

Figure 3. Example of spectral radiance changes of natural lighting.

The images of the tomato fruit section were extracted for the color image analysis. The RGB values were also transformed the color image data into the HSL color space, and then the average values were determined (Kameoka et al., 1994; Motonaga et al., 1997).

3. RESULTS AND DISCUSSION

3.1 Analysis on Color Image Acquisition Properties

The difference of the lighting illumination and exposure adjustment of the camera affect the output values of the color parameter on the recorded image. We then studied the influences of the illuminating and the image acquisition conditions on the color parameters of the acquired image in order to grasp the characteristics of the digital camera as the detector. Figure 4 shows the changes of the average *R*, *G* or *B* value of the standard color chart image under the white diffuse reflectors in the standard color acquisition system. The horizontal axis *Hm* defined by Eq.(1) is the modified focal plane exposure, and relates to the photosensitivity of the camera in consideration of the spectral characteristics of the light exposing the standard color chart and the reflectivity of each color section.

$$Hm = \frac{S \cdot T}{F^2} \quad (1)$$

Here, *F* and *T* are respectively the F-number and exposure time of the camera. *S* defined by Eq.(2) is the integration of the multiplication of the monochromatic intensity exposing the red, green, or blue section on the color chart and its reflectivity with the wavelength, and closely relate to the optical intensity detected by the camera.

$$S = \int_{380}^{730} I_\lambda r_\lambda \mathrm{d}\lambda \quad (2)$$

All of the *R*, *G* and *B* values of the images of the color chart taken in the natural illuminating conditions raised to a decimal power In order to study the relationship between the RGB and *Hm* values for the various color lighting conditions, both the RGB and *Hm* values were then standardized based on their maximum values, RGB_{max} and Hm_{max}. All of the standardized values displayed in Figure 4 for the white lighting conditions could be simply on a power function curve, and they were excellently fitted by the power function (Eq.(3)) with the correlation coefficients over 0.999.

$$\frac{RGB}{RGB_{max}} = a \cdot \left(\frac{Hm}{Hm_{max}}\right)^b \qquad (3)$$

In Eq.(3), the parameters a and b respectively could relate to the spectral pattern of the illuminating light and the apparent sensitivity characteristics of the camera as the detector. Additionally, the fitting parameter *b* as the exponent indicated the unique value (0.554) for all illumination conditions and color charts, and the *b* value could be constant. On the other hand, the parameter *a* could be estimated based on the illuminating spectral features. These results might mean that the *R*, *G* and *B* parameters of the images acquired under a specified condition could be converted into those under the standard lighting conditions at 140 lx using the white diffuse reflectors.

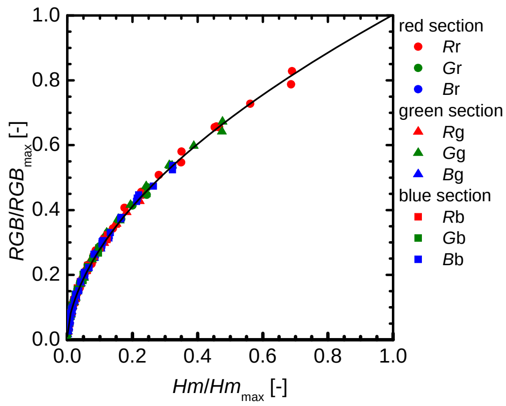

Figure 4. Normalized relationship between *Hm* on RGB values of sample objects under white lighting.

3.2 Color Appearance Evaluation of Virtual Standard Color Chart

In the above analysis, we need the whole spectral information to determine the *Hm* and *a* values. However, in consideration of the application to agricultural fields, it should be easily evaluated using only the simple information of the illuminating characteristics but the whole spectral information. We then tried to obtain the *Hm* and *a* values based on the reflected intensities of the illuminating light on the red, green, and blue sections of the color chart at the wavelength of 490, 550 and 650 nm, respectively (Figure 5), where the illuminating spectral pattern could be characterized.

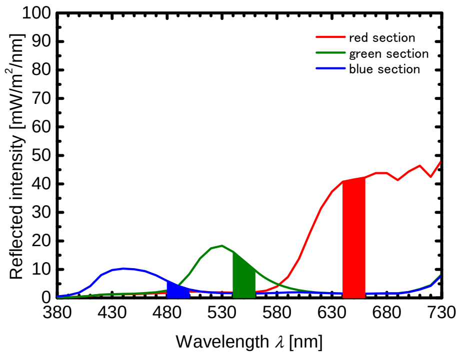

Figure 5. Reflected intensities of illuminating light on red, green, and blue sections of standard color chart and wavelength characterizing natural lighting illumination.

The RGB values of the virtual color charts were calculated using the above parameters *Hm* and *a* on the assumption of the various natural lighting conditions. As shown in Figure 6, the calculated RGB values of the virtual color charts consistently agree with those of the actual images for all color sections.

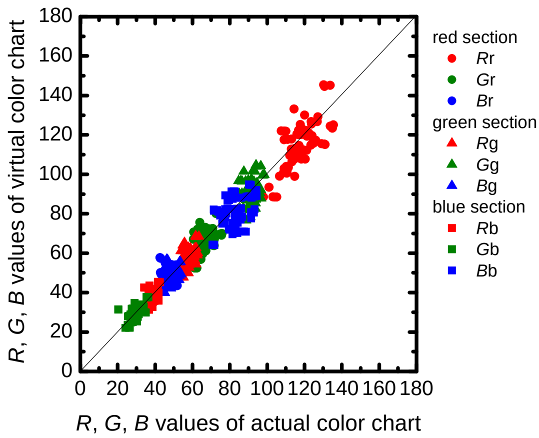

Figure 6. Relationship between RGB values of actual and vertical color charts.

3.3 Color Calibration of Tomato Fruit Image

Using the calculated RGB values of the virtual color chart under the natural lighting conditions, the color calibration developed in our previous study (Hashimoto et al., 2012) was then performed as follows. The 3x3 matrices $\boldsymbol{C}$ and $\boldsymbol{C'}$ in Eq.(4) denote the R, G, and B values of the virtual color chart for the virtual standard image and the sample image, respectively. The color transformation matrix $\boldsymbol{A}$ for the color calibration is calculated as follows.

$$\boldsymbol{C'} = \boldsymbol{A} \cdot \boldsymbol{C} \tag{4}$$

$$\boldsymbol{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}, \quad \boldsymbol{C} = \begin{pmatrix} Rr & Gr & Br \\ Rg & Gg & Bg \\ Rb & Gb & Bb \end{pmatrix}, \quad \boldsymbol{C'} = \begin{pmatrix} R'r & G'r & B'r \\ R'g & G'g & B'g \\ R'b & G'b & B'b \end{pmatrix}$$

The matrix $\boldsymbol{A}$ for each sample image was determined using Eq.(4). The color calibration image is obtained by multiplying the matrix $\boldsymbol{A}$ with the column vector of *R*, *G*, and *B* values corresponding to each pixel that composes the sample image:

$$\begin{pmatrix} r' \\ g' \\ b' \end{pmatrix} = \boldsymbol{A} \cdot \begin{pmatrix} r \\ g \\ b \end{pmatrix} \tag{5}$$

where, *r*, *g* and *b* are the *R*, *G*, and *B* values of a picture element of the sample image. *r*', *g*' and *b*' are the *R*, *G*, and *B* values of the picture element after the color calibration. After the calibration, the RGB values were transformed the color image data into the HSL color space. In the calibration, we developed a new correction method for Lightness based on the RGB values of the color chart. Figure 7 shows the Hue values of the tomato fruit images during post ripening calibrated by the developed method, and more consistently agreed with those of the standard images than those calibrated by the conventional method. Therefore, these results of the excellent color calibration suggested that the surface color images of the agricultural products could be evaluated based on the monochromatic irradiance information in the agricultural fields.

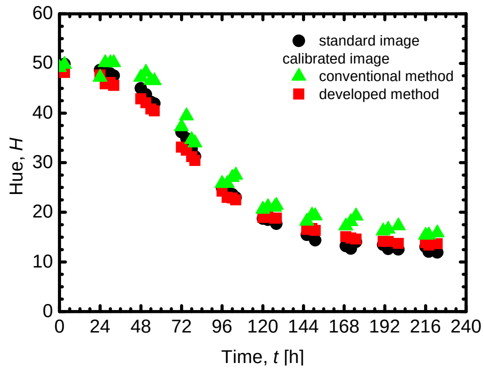

Figure 7. Relationship between RGB values of actual and vertical color charts.

4. CONCLUSIONS

By analyzing the relationship between the color appearance of the image taken by a digital camera and the spectral feature information of the lighting, the color parameters of the virtual standard color chart were simulated, and the color calibration using the simulation results were performed. In addition, the new correction method for Lightness based on the RGB values of the color chart was developed, and was applied to the color calibration. As the result, the color calibration for the images taken under the natural lighting using the estimated color parameters of the virtual color chart was very successful. The surface color images of the agricultural products could be then evaluated based on the natural lighting information. Consequently, this study plays a very important role in developing the surface color analysis for both the simple and rapid evaluation of the crop vigor in the field and the agricultural research interests.

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