Quantitative Evaluation of Surface Color of Tomato Fruits Cultivated in Remote Farm Using Digital Camera Images

Atsushi HASHIMOTO *, Ken-ichiro SUEHARA *, and Takaharu KAMEOKA *

Abstract : To measure the quantitative surface color information of agricultural products with the ambient information during cultivation, a color calibration method for digital camera images and a remote monitoring system of color imaging using the Web were developed. Single-lens reflex and web digital cameras were used for the image acquisitions. The tomato images through the post-ripening process were taken by the digital camera in both the standard image acquisition system and in the field conditions from the morning to evening. Several kinds of images were acquired with the standard RGB color chart set up just behind the tomato fruit on a black matte, and a color calibration was carried out. The influence of the sunlight could be experimentally eliminated, and the calibrated color information consistently agreed with the standard ones acquired in the system through the post-ripening process. Furthermore, the surface color change of the tomato on the tree in a greenhouse was remotely monitored during maturation using the digital cameras equipped with the Field Server. The acquired digital color images were sent from the Farm Station to the BIFE Laboratory of Mie University via VPN. The time behavior of the tomato surface color change during the maturing process could be measured using the color parameter calculated based on the obtained and calibrated color images along with the ambient atmospheric record. This study is a very important step in developing the surface color analysis for both the simple and rapid evaluation of the crop vigor in the field and to construct an ambient and networked remote monitoring system for food security, precision agriculture, and agricultural research.

Key Words : remote, monitoring, color calibration, tomato, cultivation.

1. Introduction

The color of agricultural products is used as a useful quality parameter during cultivation, harvesting, sorting, and packing, since the color appearance is reflected by the pigment components, which are the final products through the primary and secondary metabolic processes, and by the geometrical structure such as the shape and the surface conditions. Various machine vision studies regarding the color of agricultural products after processing, such as drying and radiation, have been reported [1],[2]. The color measurements using a colorimeter and a digital camera based on the L*a*b* or RGB color coordinate system are usually performed for the quantitative color evaluation of agricultural products [3]–[5].

Simple, non-destructive, simultaneous, rapid, and non-chemical evaluation of the quality of agricultural products is very important in order to maintain a stable cultivation. In addition, information obtained in the typical food traceability systems consists mainly of the cultivation, processing, and circulation conditions. There is a lack of sensing evidence about the qualities of agricultural products. Furthermore, cultivators with special skills could sense the delicate change in the plant vigor through their excellent experiences mainly based on visual observations. The authors have adopted the HSL (H: Hue, S: Saturation, L: Lightness) color system based on the CCD camera [6],[7], since the color analysis has the advantage that the surface information and the color distribution are easily acquired.

Additionally, the color change is measured 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 authors also made a color chart of a new grape variety, ‘Aki Queen’ [8], and used it for the evaluation of the tree vigor [9]. Furthermore, they analyzed the color development, which was reflected by the production of the pigments as the secondary metabolites, of the tomato surface during the post-ripening [10] and of carrots with a high carotene content [11].

The cultivation control based on the evaluation of the quality of agricultural products is very important in order to maintain stable production. Therefore, the suitable cultivation management can be performed by having an accurate grasp of the quality change with time in the agricultural fields. Special cultivators have an excellent skill to sense the delicate change in the plants through their excellent experiences, which are mainly based on visual observations. Currently the information visually observed by the experienced cultivator has not been clarified.

Recently, the application of information and communication technologies (ICTs) to agriculture is very active. In many cases, a multi-monitoring system hub equipped with a wireless network server and sensors are installed in farms and paddies, and one of the typical applications of ICTs to agriculture is the remote monitoring of the ambient conditions of the agricultural fields and of the plant images using a network camera via the internet [12],[13]. The ambient data, such as temperature and humidity, are quantitative information and the transmitted data...
The objective of this study was to develop a method for the continuous remote monitoring of the quantitative surface color of agricultural products along with the ambient information during cultivation. Tomatoes cultivated in a greenhouse were prepared as the experimental samples, and the tomato images through the post-ripening process, in which the surface color had dynamically changed from green to red, were taken by different types of digital cameras both using the standard image acquisition system [7] and under the field conditions from the morning to evening. By developing the color calibration method for the image acquired under the field conditions, the surface color change of the tomato on the tree was remotely monitored through the maturing process using the digital cameras equipped with the Field Server [14].

2. Experimental Details

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. The fruits were sampled for the image acquisition taken by a digital camera both using the standard color image acquisition system and under the field conditions from the morning to evening through the post-ripening process. We also made the standard RGB color charts for the color calibration for the outdoor measurement by establishing a color managing system. The standard RGB color chart contains plain red, green and blue sections. Furthermore, we used the whole tomato plants for the remote and continuous measurements of the surface color change in the fruits through the maturing process with the digital camera equipped with the Field Server.

2.2 Methods

The images of the tomato fruit sampled from the tree were taken through the post-ripening at 298 K using four kinds of digital cameras; i.e., fine single-lens reflex camera with 6.17 million-pixel CCD (FinePix S2Pro, Fuji Photo Film), ordinary single-lens reflex camera with 6.30 million CMOS (EOS Kiss Digital, Canon), fine web camera with 0.38 million CCD (KX-HCM180, Panasonic), and ordinary web camera with 0.30 million CMOS (CG-WLNC11MN, Corega). The image acquisition using the single-lens reflex cameras was carried out under the conditions that the aperture priority automatic exposure (AE) mode was applied and the shutter speed was set at “Automatic”. On the other hand, for the web cameras, the image acquisition conditions were automatically controlled under the standard modes. The acquired images were recorded as JPEG, TIFF or RAW format files. The image acquisition was carried out both in the standard color image acquisition system and under the field conditions.

The setup of the color image acquisition system is displayed in Fig. 1(a). The system is composed of a digital camera, two 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 its color rendering index, which expresses the color appearance by a light source as 91, and is almost the same as natural light. 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 fruit images were also taken under the field conditions as displayed in Fig. 1(b). 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 tomato fruit and the light source (the sun), were depend on the date, the time and the weather. In both image acquisitions, the standard RGB color chart for the color calibration was placed just behind the tomato fruit on the black matte and was taken with the fruit.

Additionally, we remotely monitored the surface color change in the tomato fruits on the tree in the greenhouse located in the Experimental Farm. The images were taken by the four kind of digital cameras during the maturing process for 14 d and were sent to the BIFE Lab. of Mie University via VPN with the field environmental information collected by the Field Server. The standard RGB color chart on the black matte was also placed just behind the cluster of the tomato fruits as presented in Fig. 2 and was taken with them. The geometric relation between the camera and the tomatoes gradually and slightly shifted during the maturing process, and the lighting conditions constantly changed.
Fig. 2 Color image monitoring during tomato maturation process.

2.3 Color Calibration

The color analyses were performed using the images of the tomato fruits. The sample images were extracted from the acquired ones using Photoshop CS (Adobe). We obtained the R, G, and B values in the RGB color space for each pixel of the extracted image and calculated the average values. The values of the standard RGB color charts taken in the fields were calibrated based on the standard color images which had been already acquired in the standard color acquisition system. The detail of the color calibration procedure is as follows [7],[9].

The 3x3 matrices $C$ and $C'$ in Eq.(1) denote the R, G, and B values of the standard RGB color chart for the standard image and the sample image, respectively. The color transformation matrix $A$ for the color calibration is calculated as follows.

$$C' = A \cdot C \tag{1}$$

$$A = \begin{pmatrix}
    a_{11} & a_{12} & a_{13} \\
    a_{21} & a_{22} & a_{23} \\
    a_{31} & a_{32} & a_{33}
\end{pmatrix}, \quad C = \begin{pmatrix}
    Rr & Gr & Br \\
    Rg & Gg & Bg \\
    Rb & Gb & Bb
\end{pmatrix}.$$

For example, $Rg$ denotes the G value of the red section on the standard RGB color chart. The matrix $A$ for each sample image was determined using Eq.(1). The color calibration image is obtained by multiplying the matrix $A$ with the column vector of R, G, and B values corresponding to each pixel that composes the sample image:

$$\begin{pmatrix}
    r' \\
    g' \\
    b'
\end{pmatrix} = A \cdot \begin{pmatrix}
    r \\
    g \\
    b
\end{pmatrix} \tag{2}$$

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.

We also transformed the color image data into the HSL color space, and then the average values of the H, S and L were determined [6],[10].

3. Results and Discussion

3.1 Color Calibration of Plain RGB Color Charts

Figure 3 shows the relationship between the hue and saturation values of the green chart of the images taken by the standard color acquisition system, under the outdoor conditions and after the color calibration using the above method. The symbols and error bars indicate the average values of all pixels over the green chart and the standard derivations, respectively. The color parameters of the acquired images significantly depended on the cameras and the file formats. The dispersions of the color parameters of the images acquired by the web cameras were much more remarkable than those by the other cameras. The color parameters of the images taken by the single-lens reflex cameras and recorded in the RAW format present a very slight difference before and after the calibration, and the saturation values of the images recorded in the JPEG or TIFF format were almost saturated before calibration. For all conditions, both the hue and saturation values after the calibration were almost the same as those of the images taken by the standard color acquisition system, and the calibration could be experimentally satisfied. Especially, for the single-lens reflex cameras using the RAW format, the calibration results were quite excellent. Additionally, the results for the red and blue charts were similar to those for the green one displayed in Fig. 3. These results suggested that the color calibration method would be applicable to materials with a plain structure such as the standard color chart. In the later experiments, as the single-lens reflex camera, we used the ordinary one.

3.2 Color Calibration of Post-Ripening Tomato Fruits

We studied the color calibration effects of the tomato fruits during the post-ripening process. Figure 4 represents examples of the tomato fruits images. The images taken under the outdoor conditions are quite different from the standard images that were taken by the standard color acquisition system; these differences in the color appearances could be due to the spectral patterns of the sun-light that would vary by the climate or something like these conditions. On the other hand, as shown in Fig. 4 (c), the color appearances of the tomato images after
the color calibration using the method presented above are very similar to those in the standard images.

Figure 5 displays the time courses of the hue values of the tomato fruit images during the post-ripening process and the color calibration effects. For the images acquired using the single-lens reflex camera, the calibrated values consistently agreed with those taken by the standard color acquisition system, and the color dispersions among the images were negligible. On the other hand, for the images acquired using the ordinary web camera, significant differences between the calibrated values and those taken by the standard color acquisition system were observed especially during the period when the hue value was dynamically changing, and the color dispersions among the images were remarkable.

Additionally, the curve fitting for the time courses of the hue values displayed in Fig. 5 were performed using those fitted by the Boltzmann equation (Eq.(3)) that can express the surface color change in the tomato fruit from green to red based on the pigment production and consumption [7],[10].

\[
H(t) = H_{ini} - H_{fin} \frac{1}{1 + \exp\left(\frac{t - t_0}{w}\right)} + H_{fin}
\]  

(3)

In Eq.(3), \(H\) and \(t\) are the hue value and time, respectively. The parameters \(t_0\) and \(w\) denote the inflection point of the time course and the time constant ticking its curve, respectively. The subscript ini and fin indicate the values at the initial and final stages, respectively. The lines drawn in Fig. 5 are the fitting results, and the determination coefficients (\(R^2\)) were all very high as listed in Table 1. Both the fitting results and the \(R^2\) values were obtained by Origin 6.1 (OriginLab Corporation).

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>After</th>
</tr>
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<tbody>
<tr>
<td>single-lens reflex camera (RAW)</td>
<td>0.999</td>
<td>0.996</td>
</tr>
<tr>
<td>single-lens reflex camera (JPEG)</td>
<td>0.999</td>
<td>0.994</td>
</tr>
<tr>
<td>fine web camera (JPEG)</td>
<td>0.998</td>
<td>0.944</td>
</tr>
<tr>
<td>ordinary web camera (JPEG)</td>
<td>0.998</td>
<td>0.986</td>
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The determination coefficients, which could be one of the uncertainty indexes, after the color calibration were different for each acquisition condition. The value for the ordinary single-lens reflex camera by the RAW format recording was the highest among all the acquisition conditions and was 0.996. Also, the determination coefficients for the web cameras were relatively low. Additionally, though the color was excellently calibrated using the developed method, the absolute values and the fitting results of the hue changes significantly varied. Moreover, for the ordinary single-lens reflex camera using the RAW format recording, the time course before the color calibration roughly agreed with that after calibration, and this experimentally indicated the possibility of a quantitative color analysis in the field. Furthermore, the developed calibration method could be applicable to the quantitative evaluation of the surface color change of the tomato fruit through post-ripening, under the conditions that the lighting conditions were constantly changing, as...
3.3 Color Monitoring of Maturing Tomato Fruits

The remote monitoring of the surface color change of the tomato fruits on the tree in the green house located in the Experimental Farm was performed along with the field environmental information collected by the Field Server (Fig. 2). The acquired images and ambient atmospheric records were sent from the Experimental Farm to the BIFE Lab. that was approximately 10 km away via VPN. Figure 6 shows the time courses of the hue values of the maturing tomato fruit color after the color calibration along with the field environmental information shown in Fig. 7. As well as the results in Fig. 5, the calibrated hue values for all the measuring conditions were consistently fitted by the logistic function (Eq.(3)) and the variations in the calibrated and fitted results were observed among the acquisition conditions. For the images acquired using the single-lens reflex camera, the color dispersions among the images were also negligible. Thus the color calibration was experimentally effective for the quantitative and long-term remote monitoring under the conditions that the geometric relation between the camera and the tomatoes was gradually shifting. The above results indicated the color of agricultural products cultivated at a distant place could be quantitatively measured via the internet using the developed method.

Fig. 6 Time course of average and dispersion of hue value of tomato surface color during maturing process.

Fig. 7 Time course of atmosphere conditions of tomato during maturing process.

4. Conclusion

We developed a continuous and quantitative remote monitoring method of the surface color changes in agricultural products along with the atmosphere condition data during the cultivation. By applying the color calibration to the image acquired under the field conditions, the influence of the sunlight could be eliminated, and the calibrated color information consistently agreed with those acquired using the standard color acquisition system through the post-ripening process. In addition, the surface color change of the tomato on the tree was remotely monitored through the maturing process using a digital camera equipped with the Field Server. As the images were sent from the Experimental Farm to the BIFE Lab. via VPN along with the field environmental information, the quality as one of the final stages of the overall metabolism of the agricultural product could be evaluated by analyzing the environmental antecedents during cultivation. Furthermore, this also suggested the possibility to construct a database for the color in order to determine the quality of the agricultural products along with the antecedent cultivation conditions. 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.

References

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