Calibration for Color Measurement of Lean Tissue and Fat of the Beef

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Abstract: In the agricultural field, a machine vision system has been widely used to automate most inspection processes especially in quality grading. Though machine vision system was very effective in quantifying geometrical quality factors, it had a deficiency in quantifying color information. This study was conducted to evaluate color of beef using machine vision system. Though measuring color of a beef using machine vision system had an advantage of covering whole lean tissue area at a time compared to a colorimeter, it revealed the problem of sensitivity depending on the system components such as types of camera, lighting conditions, and so on. The effect of color balancing control of a camera was investigated and multi-layer BP neural network based color calibration process was developed. Color calibration network model was trained using reference color patches and showed the high correlation with L*a*b* coordinates of a colorimeter. The proposed calibration process showed the successful adaptability to various measurement environments such as different types of cameras and light sources. Compared results with the proposed calibration process and MLR based calibration were also presented. Color calibration network was also successfully applied to measure the color of the beef. However, it was suggested that reflectance properties of reference materials for calibration and test materials should be considered to achieve more accurate color measurement.
Keywords : Beef, Color Evaluation, Color Calibration, Machine Vision, Neural Network

Introduction

Color of a beef is one of important factors in grading meat quality and most customers buy the beef that shows good color appearance. In Korea, grades of lean tissue and fat are divided into 7 categories respectively based on their colors. Each carcass has been graded manually by an expert using standard color plate or color patch. However, human evaluation of color status is very subjective and varies with the observer's visual perception and lighting environment. Moreover, color evaluation results have a problem of reproduction because of the different characteristics of the human vision system.

In general, a colorimeter can be used to measure the exact beef color. However, since it can measure the small local area of a beef to be measured, measuring process should be repeated in a sample basis and analyzing process is also required to evaluate the color of the whole meat.

A machine vision system using color CCD camera has an advantage of covering whole beef carcass area at a time and also can measure other quality factors such as size of lean tissue, thickness of fat, status of marbling, and so on. However, measurement using machine vision used to be affected by system components and lighting conditions. Colors of an object measured using a vision system under different lighting sources are different each other. These results are caused by the difference of color temperatures among lighting sources. In order to acquire true color values of an object, machine vision system should be calibrated prior to measurement.

To minimize the effect of system components in measuring the color of an object using machine vision system, many researchers have introduced the color reference. Singh (1993) reported the un-uniformity of standard color paper for peach, and proposed a new standard color paper which were equally spaced in color space. Also Ng (1998) developed a color calibration method by correcting color temperatures of lighting sources.

Objectives of this study were to develop a color

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calibration process that is robust to various types of camera and lighting sources. Color calibration process and developed model were tested in evaluating the color of a beef.

Materials and Methods

1. Beef Samples

Since this study was conducted to develop the automatic quality grading system of the beef carcass, beef samples were taken at the livestock auction market. 10 samples of lean tissue and fat were collected among carcasses that were cooled for 24 hours after being slaughtered. Samples were put into a vinyl-pack and sealed to prevent the color change. To minimize the variation of the beef color, samples were measured immediately using machine vision system and colorimeter. Table 1 shows color characteristics of beef samples.

2. Image Acquisition

Hardware: A color machine vision system was constructed. To investigate color characteristics of machine vision system, three kinds of cameras (JVC TK SONY XC-711, LG Honeywell GC-305) and four kinds of illumination sources (three-wave fluorescent lamp, incandescent lamp, tungsten-halogen lamp, and incandescent & three-wave fluorescent lamp) were used. To get the uniform intensity of lighting, eight lighting sources were equally spaced from the center of measurement plate. A color frame grabber (FlashBus MV-PRO, Integral Tech) was used to acquire digital color images. The grabbed images have 24 bits color information and 640×480 spatial resolution and were saved in BMP file format.

Table 1 Color statistics of lean tissue and fat

Statistics	Lean Tissue			Fat		
	L*	a*	b*	L*	a*	b*
Max.	39.6	27.9	14.1	76.5	6.1	7.5
Min.	30.3	17.2	6.0	69.7	2.2	4.3
Avg.	33.4	22.3	9.8	72.8	3.7	5.9

System initialization: Lighting sources have their own color temperatures and response characteristics of CCD sensors are different from each other. Therefore, system initialization is very important to measure the color of an object. In this study, the color balance of camera was adjusted until RGB color values of colorimeter to white reference showed the similar level (250~255 gray value). And other settings of camera and frame grabber were fixed.

3. Color Calibration

Color coordinate: There are many color coordinates and each coordinate has its own purpose. Generally hue, saturation and intensity (HSI coordinate) values were used in machine vision system. Since L*a*b* coordinate is suitable to measure the beef color and color difference (ΔE) between two objects can be also measured, CIE L*a*b* coordinate was introduced in this study. And meanings of resulting color factors could be easily understood such that L* value represents brightness, a* value represents red greenness and b* value represents yellow-blueness (Jain 1984). Color tri-stimulus values XYZ should be obtained first to get CIE L*a*b* values. XYZ values are computed by NTSC receiver primary using equation (1). And CIE L*a*b* were obtained from equation (2) using computed XYZ values. And reference color values L^*_0, a^*_0, b^*_0 were determined using the white reference plate of a colorimeter.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.117 \end{bmatrix} \begin{bmatrix} R_n \\ G_n \\ B_n \end{bmatrix} \quad (1)$$

R_n, G_n, B_n: NTSC receiver primary

$$L^* = 25\left(\frac{100Y}{Y_0}\right)^{\frac{1}{3}} - 16,\ 1 \le 100Y \le 100$$

$$a^* = 500\left(\frac{X}{X_0}\right)^{\frac{1}{3}} - 500\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} \quad (2)$$

$$b^* = 500\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - 500\left(\frac{Z}{Z_0}\right)^{\frac{1}{3}}$$

L^*_0, a^*_0, b^*_0 : values obtained from the white reference plate of a colorimeter

Utilizing L*a*b* coordinate system, the color difference between two objects were computed from equation (3).

$$\Delta E = \sqrt{(L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2} \quad (3)$$

L*, a*, b*: values obtained from sample

L^*_r, a^*_r, b^*_r: values obtained from the reference

Basic assumption of color calibration: Measuring color values using vision system depends on system components. Optics, CCD sensor characteristics, frame grabbers, and color temperatures of lighting sources affect the measurement values. Though characteristics of some optical components can be obtained from the manufacturer, synthetic effect of these components can not be analyzed actually.

However, if the system environment does not change, color values can be corrected using an appropriate calibration model. In this study, 96 reference color papers (Inki Color Guide) were used as reference colors to train a neural network based calibration model and additional 100 standard color papers were used to verify the model. Reference color papers were selected to represent total color space.

Calibration model: Since a color has 3 dimensional and non-linear characteristics, the multi-layer BP(back propagation) neural network model was suitable to develop the color calibration model. Input data for training the vision system were RGB values of the color patches read by the given vision system, and target values were the NTSC RGB values of the color patches which were measured with a colorimeter. Input and output values were normalized between 0 and 1. Neural network had 3 input and 3 output units. After various trial tests with various network structure, number oh hidden units was decided as 7. Classical back propagation training algorithm was utilized with learning and momentum coefficients of 0.2 and 0.9 respectively. Training was continued until network showed less than 0.0002 RMS error. RMS error was computed using following equation (4).

$$S.E. = \sqrt{\frac{\sum (x_i - y_i)^2}{n-1}} \qquad (4)$$

x_i : actual color value
y_i : measured color value
n : sample number

Model test: Representative RGB color values of patches were acquired by averaging a 10×10 pixel region of each patch. The trained calibration model was validated by comparing RGB values of colorimeter with network outputs using 100 untrained color papers. To test the feasibility of calibration model, measurement experiment was executed in two 2 ways. One was changing camera under the fixed lighting condition (three-wave fluorescent lamp). Another was changing lighting source with the fixed camera (SONY XC-711). The same reference color patches were used for the feasibility test.

The MLR (Multi-linear regression) model was developed to compare color calibration results. Dependent variables of the MLR model were R, G, B color values that were obtained from the standard color patches using a color CCD camera. And independent variables of the model were true color values of color patches, which were the same as target values of the neural network. In developing MLR model, the white balance of a camera was adjusted.

4. Beef Color Measurement

Each beef sample was located at the center of measurement plate. The vision system captured an image and saved it as BMP format. And then, each beef sample was measured 5 times using colorimeter and averaged to get the true color value. From the previous experiment and analysis, the green channel of beef image was useful to segment the lean tissue and the fat.

Pixels which had above 160 gray level in G channel were allocated as fat and ones below 160 were allocated as lean tissue. Representative RGB value was obtained by averaging its color values. Finally, L*a*b* values of a beef sample was acquired using trained neural network and compared with values of the colorimeter.

Results and Discussion

1. Color Calibration

Comparison of colorimeter and vision system: CIE L*, a*, b* color values of the reference ranged from 31 to 91, from −43 to 61 and from −39 to 61, respectively. Fig. 1 shows the distribution of color patches in a*b* coordinate. It could be seen that though the same objects were measured, the color values were different with colorimeter and vision system. Particularly, color range of machine vision was narrower than colorimeter values. This represented that color values measured with machine vision system were not similar to those of colorimeter and vision system should be calibrated to get the true color values.

Effectiveness of color balance adjustment: The color values of the color patches were measured under three different lighting sources with and without adjusting the color balance. Table 2 shows the color difference at each measurement setting. The color difference between colorimeter and machine vision was reduced when adjusting color balance regardless of lighting sources. However, even if the adjustment of the color balance enhanced the accuracy of the measurement, the measured values showed much difference from the true color values. To get more accurate color value, machine vision system should be calibrated anyhow.

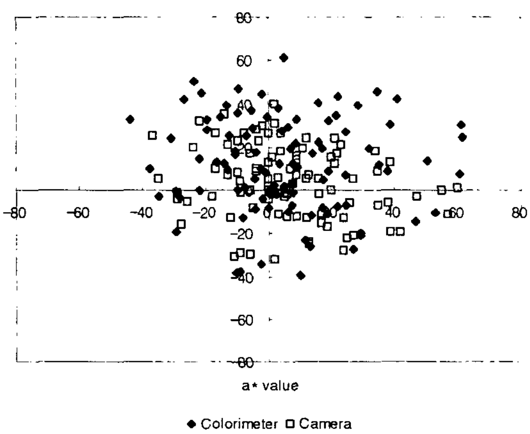

Fig. 1 Distribution of color values measured with colorimeter and color camera.

Table 2 Color difference according to lighting source and adjustment of color balance of camera

Light Source	No Adjust	Color Balance Adjust
Incandescent lamp	21.2	14.4
3 wave fluorescent lamp Incandescent & 3 wave	15.5	14.3
Fluorescent lamp	23.3	19.9

Neural Network for color calibration: The output value of neural network was NTSC RGB and this value was used as input value to get the L*a*b* value. Table 3 shows the relationship between colorimeter and machine vision in L*a*b* coordinate after training was completed. The correlation coefficient at the validation step was as high as 0.99 in all color factors and standard error was below 3.0. The trained neural network learned the color space successfully and it could be used to measure the unknown color precisely.

Table 3 Correlation coefficient and standard error between colorimeter and trained machine vision

Color patches	L*	a*	b*	ΔE
Calibration	0.99/1.0	0.99/2.3	0.99/2.0	0.99/1.5
Validation	0.99/1.9	0.99/2.6	0.99/1.9	0.99/1.8

Table 4 represents results of the accuracy for various measurement conditions. As mentioned previously, the color balancing was effective and neural network model showed better accuracy than MLR model in color vision system. Correlation coefficients were greater than 0.99 and standard error was less than 3.0.

Table 4 Correlation coefficient and standard error of the color values of the reference color patches measured by the colorimeter and those by the camera calibrated or not

Camera status	L*	a*	b*	ΔE
No color balancing	0.98/ 9.4	0.98/ 17.5	0.98/ 9.9	0.83/ 21.2
Color balancing only	0.97/ 6.2	0.95/ 7.2	0.96/ 12.6	0.93/ 14.4
Color balancing + Calibration by MLR model	0.97/ 3.4	0.95/ 7.9	0.97/ 5.4	0.93/ 3.9
Color balancing + Calibration by NN model	0.99/ 1.0	0.99/ 2.0	0.99/ 2.3	0.99/ 1.5

The neural network based calibration model was tested with machine vision system that consisted of different types of cameras at the same lighting condition. As shown in Table 5, the accuracy of the measurement had little difference with different types of cameras. It can be seen that types of camera does not affect seriously to the accuracy of the color measurement.

Table 6 represents the comparison of the accuracy of the color measured with the same color patches under three different lighting sources. The measurement accuracy with trained vision system showed no difference between illumination sources. Developed calibration model learned total color space and showed successful adaptability to the unknown object color. From these experiments, it could be seen that the proposed neural network based calibration process was very reliable and effective.

Table 5 Correlation coefficient and standard errors between color values of color patches measured by colorimeter and those by camera trained at different camera

Camera	L*	a*	b*	ΔE
TK 1074	0.99/ 1.9	0.99/ 1.9	0.99/ 2.6	0.99/ 1.8
XC 711	0.99/ 2.0	0.98/ 3.4	0.98/ 2.8	0.99/ 2.1
GC 305	0.99/ 2.0	0.98/ 2.8	0.99/ 2.4	0.98/ 3.1

Table 6 Correlation coefficient and standard errors between color values of color patches measured by colorimeter and those by camera trained at three different illuminations

Camera	L*	a*	b*	ΔE
Incandescent	0.99/ 2.2	0.98/ 3.8	0.98/ 3.3	0.98/ 2.5
Incandescent & 3 wave fluorescent	0.99/ 2.0	0.98/ 3.7	0.98/ 2.9	0.98/ 2.4
3 wave fluorescent	0.99/ 2.0	0.98/ 3.4	0.98/ 2.8	0.99/ 2.1
Tungsten Halogen	0.99/ 2.0	0.98/ 3.7	0.98/ 2.9	0.98/ 2.5

2. Beef Color Evaluation

Color values of lean tissue and fat were measured using vision system with the developed neural network based calibration model. Average RGB values were put into the neural network and L*a*b* values were obtained.

As shown in Table 7, standard errors of L, a, b color measurement using calibration model were 16.06, 11.31, 2.78 for lean tissue and 16.06, 2.84, 0.99 for fat. These results were far less accurate compared with those for color papers. It might be caused mainly by the difference of the reflectance between the paper used for calibration and meat used for the measurement.

Since values measured using a camera showed a certain bias with respect to those measured using a colorimeter, values measured by camera were compensated through linear regression. After compensating

Table 7 Standard errors of lean tissue and fat measured by colorimeter and those by camera trained with the calibrated model

Statistics	Lean Tissue			Fat		
	L*	a*	b*	L*	a*	b*
Before compensation	16.06	11.31	2.78	16.06	2.84	0.99
After compensation	0.95	3.09	1.21	2.88	0.76	0.78

measurement values, standard errors of measurement results were improved to 0.95, 3.09, 1.21 for lean tissue and 2.28, 0.76, 0.78 for fat. Fig. 2 showed measurement values of neural network compensated with linear regression model and the actual values using a colorimeter. It showed relatively large errors of

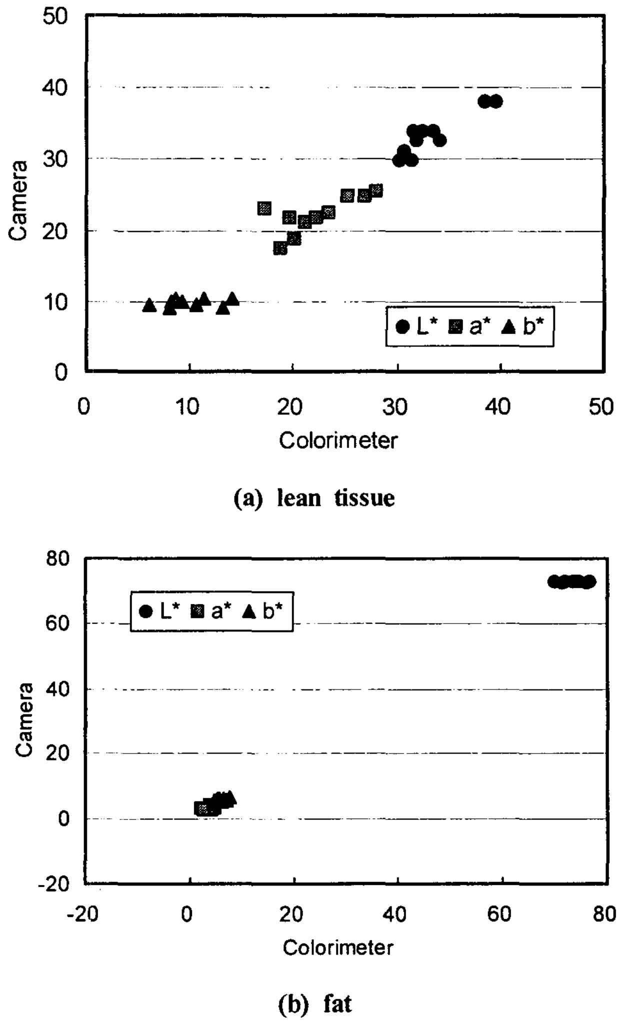

Fig. 2 Results after compensating values of neural network with linear regression model.

a* and L* for lean tissue and fat respectively. And this was caused by the blood spots of the measurement samples. In measuring samples using a colorimeter, areas having blood spots were avoided. In a case of measurement using a camera, total areas were covered without considering blood spots and that might be one of major sources of error. It is suggested that reflectance properties of reference materials for calibration and test materials should be considered to achieve more accurate color measurement.

Conclusions

In the agricultural field, a machine vision system has been widely used to automate most inspection processes especially in quality grading. Though machine vision system was very effective in quantifying geometrical quality factors, it had a deficiency in quantifying color information. In this study, in order to develop the automatic quality grading system of the beef carcass, the robust and effective way of the color measurement of the lean tissue and the fat of the beef carcass was proposed.

Though quality factors of beef carcass such as size of lean tissue, status of marbling, thickness of back-fat are important, colors of lean tissue and fat are the most stimulus factors to the customer. Though measuring the color of a beef using machine vision system had an advantage of covering whole lean tissue area at a time compared to a colorimeter, it revealed the problem of sensitivity depending on the system components such as camera and lighting conditions. To overcome this limitation of vision system, the effect of color balancing control of a camera was investigated. And neural network based robust and effective color calibration process was proposed to cope with various environments in using vision system. Neural network based color calibration model was trained using reference color patches and validated. It showed the high correlation with L*a*b* coordinates of a colorimeter and the successful adaptability to various measurement environments such as various camera types and lighting sources.

Color measurement model based on the neural network and linear regression model gave successful results in color measurements of lean tissue and fat. However, it did not give as accurate results as those with color papers. Major errors were difference of reflectance between the reference papers and test beef samples and blood spots over meat samples. Some way of calibration method covering reflectance ratio of reference and sample material may guarantee more accurate color measurement.

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