Determining Tone Conversion Characteristics of Digital Still Camera from Pictorial Images Without the Gray Scale and Its Application to Color Management

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Abstract

Tone conversion characteristics of the digital still camera is not only one of the most important characteristics, but also used for a transformation from raw red, green and blue digital values to colorimetric values. Tone conversion characteristics are produced usually from measured digital values as a function of known luminance or reflectance of subject from the images including a gray scale. Instead, we developed a new method, which is based on working values of subject exposure calculated on the basis of the digital values of digital still camera of two images of the same subject formed at two different exposure levels whose ratio is known. Digital value between digital value pair, which are digital values for two image corresponding to same cumulative frequency, is calculated as a weighted average, and log relative exposure is integrated from digital value pair. Thus, log relative exposures and corresponding digital values are calculated, i.e. tone conversion characteristics are obtained without a gray scale. The calculated tone conversion characteristic by the new method was compared to a characteristic obtained conventionally from the gray scale. Again, a comparison of the two tone conversion characteristics demonstrates that they are almost identical except in the region of lower luminance where flare is effective and that the new method performed accurately. Using the tone conversion characteristic and a gray scale included in subject scene, influence of flare can be eliminated. Colorimetric values for color patches are calculated from the new process, in which the tone conversion characteristic determined by the new method was used and flare was eliminated, and the conventional process by using an analytical model. Average color difference for the new process was less than that for the other. From our studies, the new process has proven to be accurate and practical.

Introduction

The digital still camera is more widespread in many fields. The issues on the color reproduction of the digital still camera have been arisen. Conventionally, color calibration of digital devices is accomplished with three dimensional LUT (Look up table) and three dimensional interpolation. On the other hand, analytical models are used to the calibration in which tristimulus values X, Y and Z can be calculated by linear combination of values calibrated with tone conversion characteristic under the Luther condition. Calibration of display is usually accomplished with such a method. By using analytical models, calculation time becomes fast and nonexistent systems can be simulated at system design steps.

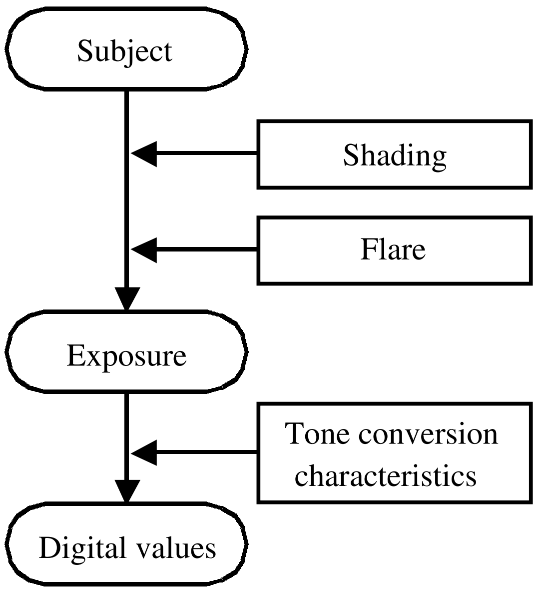

Figure 1. Imaging with the digital still camera

The imaging scheme with the digital still camera is shown in Fig. 1.

Tone conversion characteristic of digital still cameras is not only one of the most important characteristics, but also used for a transformation from raw red, green and blue digital values, R, G and B, to colorimetric values, X, Y and Z; or L^*, a^* and b^*. Tone conversion characteristics of digital still cameras are determined from measured digital values as a function of known luminance of object from the gray scale included in the scene. Tone conversion characteristic is also called as characteristic curve in the field of photography, gamma characteristic in the field of television, and OECF (opto-electronic conversion function) in ISO 14524.[1]

There are many problems to take images of the gray scale. For example, more gray patches to get precise tone conversion characteristic, non-uniformly illumination on the gray scale, and optically decreasing of surround illumination with 4th power of cosine law and vignetting factor.

Instead, we developed a new method, which is based on working values of exposure to CCD of the digital still camera calculated on the basis of the digital values of digital still camera of two images of the same subject formed at two different exposure levels whose ratio is known. The obtained characteristic is a relationship between relative exposures and digital values to CCD, not an OECF, a relationship between luminances and digital values.

An accurate tone conversion characteristic can be determined by the new method. Using the accurate tone conversion characteristic and a gray scale, flare of the scene can be estimated and eliminated. Such a process produce accurate colorimetric values in the color management system.

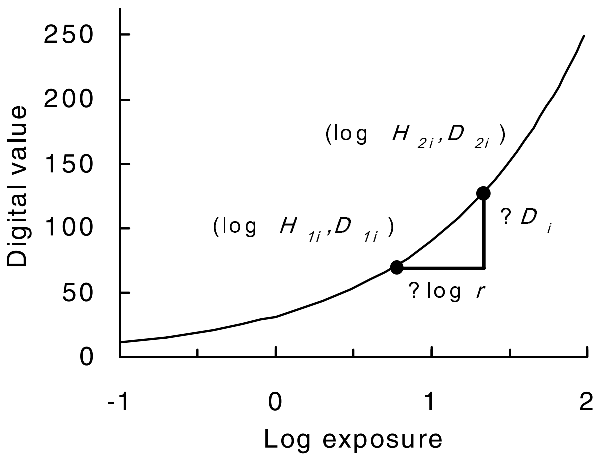

Figure 2. Tone conversion characteristic curve and variables used in this study

Method of Determining Tone Conversion Characteristics

The gradient of a tone conversion characteristic curve of digital still camera is defined as

$$g = \frac{\mathrm{d}\,D}{\mathrm{d}\,\log H} \tag{1}$$

where D is raw digital value of digital still camera, R, G, or B, and H is exposure to CCD. Integrating this equation, the log exposure is expressed as

$$\log H = \int \frac{\mathrm{d}\,D}{g} + C \tag{2}$$

where C is the constant of integration.

In application of Eq. (2), assume that there are two images of a gray scale, Images 1 and 2, and that each image has been produced under the same conditions except for exposure. If r expresses the exposure ratio of Image 2 to Image 1, then

$$H_{2i} = r\,H_{1i} \quad (i = 1,2,3,---,n) \tag{3}$$

where i is the step level and n is the number of steps.

Digital values of the images corresponding to exposures H_{1i} and H_{2i} are D_{1i} and D_{2i}, respectively. An average gradient between these digital value is expressed as

$$\bar{g}_i = \frac{D_{2i} - D_{1i}}{\log r} \tag{4}$$

A digital value D_i, at which the gradient is equal to the average gradient g_i, must exist in the range between the digital values D_{1i} and D_{2i}, and is expressed as

$$D_i = \frac{w_{1i}\,D_{1i} + w_{2i}\,D_{2i}}{w_{1i} + w_{2i}} \tag{5}$$

where w_{1i} and w_{2i} are weighting coefficients. These coefficients are determined as following equations.

$$w_{1i} = 2\Delta D_{1i} + \Delta D_{2i} \tag{6}$$

$$w_{2i} = \Delta D_{1i} + 2\Delta D_{2i} \tag{7}$$

The weighting coefficients are used in order to shift the digital value D_i slightly from the midpoint between D_{1i} and D_{2i} toward the section of the curve having the higher gradient, since the midpoint is virtually always of a slightly different gradient than the average gradient g_i. Then log exposure for step i, log H_i, is calculated as following equation.

$$\log H_i = \log H_{i-1} + \frac{D_i - D_{i-1}}{\bar{g}_i} \tag{8}$$

The digital value vs. log exposure curve can be calculated from a set of D_i 's and g_i 's. i.e. digital values from Eq. (5) and log exposure from Eq. (8). In most cases the constant C in Eq. (2) cannot be determined. It should be noted that, in turn, the actual values of log H also can not be determined: log H here has relative, but not absolute, significance.

For the simplicity, above explanations are based on stepwise images, such as a gray scale. For applying the method to pictorial images, digital values of Images 1 and 2 at same pixel may be used as the digital value pair D_{1i} and D_{2i} above mentioned. But number of these pairs amount to a few millions, and these values contain noise. For avoiding such things, digital values of Images 1 and 2 corresponding to same cumulative frequency are used as the digital value pair D_{1i} and D_{2i}.

The calculation steps for the pictorial images are the following.

(1) cumulative frequency distributions of two images are calculated,

(2) corresponding digital values of two images, D_{1i} and D_{2i} (i = 1,2,---,n), for same cumulative frequency are determined,
(3) digital value D_i between D_{1i} and D_{2i} is calculated as a weighted average,
(4) and then log relative exposure, log H_i, is integrated from digital values D_{1i} and D_{2i}.

Thus, log relative exposures log H_i and corresponding digital values D_i are calculated, i.e. tone conversion characteristic are obtained without a gray scale.

Elimination of Flare

On the translation of the scene luminances into the illuminances incident on the CCD in the digital still camera, the illuminance on each CCD consists of two parts. One part is the image-forming light, which is relative to scene luminance, L, coming from the element of the scene being imaged by the lens. The other part is the nearly uniform flare light, E_f, reflected and scattered from the lens surfaces, the lens mount, the diaphragm and shutter blades, the inner surface of the camera body, and the surface of the CCD. The illuminance, E, on the CCD is the sum of these parts. Thus

$$E = cL + E_f \tag{9}$$

where c is the constant.

The scene luminances are relative to reflectances, ρ, of patches included in a gray scale, and illuminances, E, are relative to exposures, H, which are calculated from digital values from CCD through the tone conversion characteristic. From these variables the following equation holds.

$$H = c'\rho + H_f \tag{10}$$

where H_f is the exposure for flare light, and c' is the constant.

From the experimental data of the gray scale, ρ and H, values of c' and H_f are determined. Then an exposure excluding flare is calculated as a difference of the exposure, H, from the exposure caused by the flare light, H_f.

Then the shading of the exposures excluding flare are corrected by the exposures of white subject.

Application to Color Management

The corrected exposures are those evaluated by the sensitivities of CCD in the digital still camera.

$$R = \int E(\lambda) S_R(\lambda)\, d\lambda \tag{11}$$

$$G = \int E(\lambda) S_G(\lambda)\, d\lambda \tag{12}$$

$$B = \int E(\lambda) S_B(\lambda)\, d\lambda \tag{13}$$

In these equations, E is the spectral energy of the light coming from the subject in the original scene, and S_R, S_G and S_B are the spectral sensitivities of three color components of CCD used in the digital still camera.

If the Luther condition holds, tristimulus values X, Y and Z are related linearly to R, G and B.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \left[M_L \right] \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{14}$$

In the equation, M_L is a 3×3 matrix. If the relationship between R, G and B and X, Y and Z is nonlinear, higher order must be included in the transform equation. Quadratic terms are used in the following equation.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \left[M_Q \right] \begin{bmatrix} R \\ G \\ B \\ R^2 \\ G^2 \\ B^2 \\ RG \\ GB \\ BR \\ 1 \end{bmatrix} \tag{15}$$

In the equation, M_Q is a 3×10 matrix.

Figure 3. One of Photographs used in this study

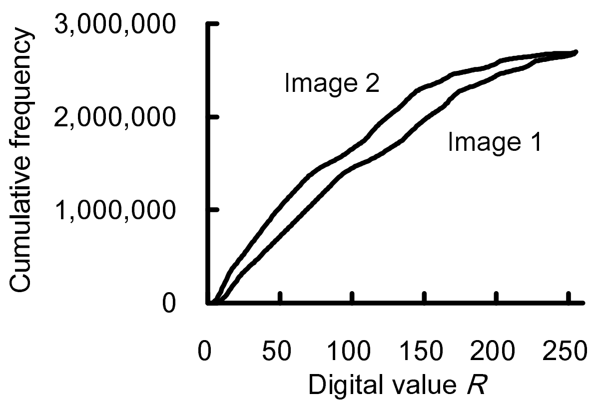

Figure 4. Cumulative frequencies of digital value R *for two images*

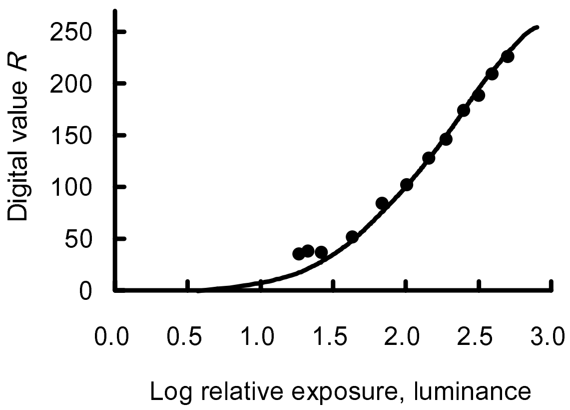

Figure 5. A calculated tone conversion characteristics for digital values R *and measured digital values from a gray scale*

Thus colorimetric values are calculated from digital values of digital still camera through the inverse route of the flow shown in Fig.1. This means that the analytical model of digital still camera has been constructed.

The calculated tristimulus values are then confirmed to these of the color patches taken in the scene.

Experiments and Results

Tone Conversion Characteristic

Two different exposure images for a scene including GretagMacbeth Color Checker DC were taken with Minolta Dimage RD-3000 digital still camera. Exposure time was changed to obtain two images of different exposure, because of accuracy of exposure time. Repeatability of the diaphragm was taken into consideration, the full open diaphragm was used. Because daylight is unstable at both illuminance and color temperature, photographs were taken indoors. To avoid oscillation based on voltage frequency, tungsten lamps, not fluorescent lamps, were used to illumination.

One of the two images, Image 1, is shown in Fig. 3. Cumulative frequency distributions for digital value R of two image are shown in Fig. 4. The digital value pairs D_{1i} and D_{2i} determined from the cumulative frequency distributions for the two images. Then digital values, D_i, and corresponding log relative exposures, log H_i, i.e. a tone conversion characteristic was calculated by Eqs. (5) and (8). The calculated tone conversion characteristic of digital value R is shown in Fig. 5. As the calculated log exposure is relative, the curve was arbitrarily shifted to pass the point of (2.0, 100). The tone conversion characteristics of digital values G and B are also calculated. These are almostly identical to that of digital value R.

In Fig. 5 the relationship between luminances and digital values is also plotted as the dots which were determined conventionally from the gray scale of Color Checker DC in the scene. The relationship is one of the tone conversion characteristics obtained conventionally. The luminance of the gray scale is also relative value which is based on tristimulus value Y, and the dots were shifted to overlap the region of higher luminance of the curve. A comparison of the two tone conversion characteristics demonstrates that they are almost identical except in the region of lower luminance where flare is effective and that the new method performed accurately.

Application to Color Management

Colorimetric values for color patches are calculated from the new process and the conventional process with a gray scale by using analytical model. The tone conversion characteristic obtained with the conventional process, in which eight gray patches in the test chart for digital still camera published by IIEEJ (The Institute of Image Electronics Engineering of Japan) were taken with RD3000 camera, and the spline interpolation was used to make smoothed characteristic, is shown in Fig. 6.

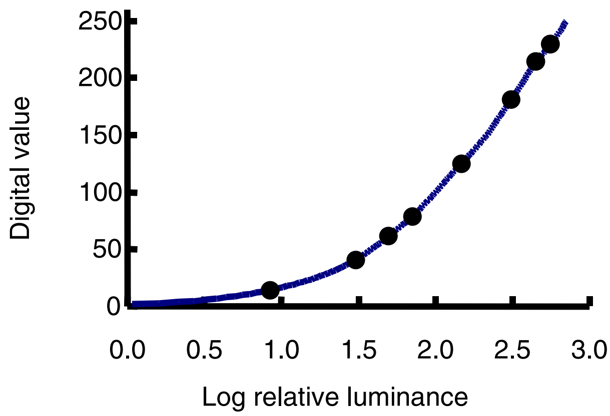

Figure 6. A tone conversion characteristic determined with a gray scale and the spline interpolation

Calculation was accomplished with two processes. In the new process, the tone conversion characteristic was determined with the new method and flare was eliminated. On the other hand, in the conventional process, the tone conversion characteristic was determined with a gray scale in the scene and the spline interpolation, and flare was not eliminated. The following is calculation steps from digital values to colorimetric values.

1) digital values R, G and B are converted to exposures H_R, H_G and H_B by using the tone conversion characteristic,
2) flare is eliminated from exposures in the new process and shading of the exposures are corrected in the both processes,
3) tristimulus values X, Y and Z are calculated from those exposures by using Eqs. (14) and (15) ,
4) L^*, a^* and b^* are calculated from X, Y and Z, and
5) color differences between calculated and original values of L^*, a^* and b^* were calculated

The color differences for the two processes are shown in Table 1. Mean and maximum color differences for the new process were less than those for the conventional process.

Table 1 Color Differences for the Two Processes

Combination		Process	
		New	Conventional
Linear	mean	4.1	4.4
	max	24.4	29.5
Quadratic	mean	2.2	3.1
	max	6.3	10.8

Discussions

As importance of reproduction of gray, the identification on the three tone conversion characteristics of digital values *R*, *G* and *B* had been expected and was confirmed in this study. Then cumulative frequencies of digital values *R*, *G* and *B* were summed up and cumulative frequency of total digital value was obtained. Tone conversion characteristic of total digital value was calculated and compared to these of digital values *R*, *G* and *B*. The characteristic of total digital value showed almostly average of these of digital values *R*, *G* and *B*.

In Table 1 the mean and maximum color differences for the new process were less than those for the conventional process. It was assumed that error of the tone conversion characteristic decreased and nonlinearlity between *R*, *G* and *B* and *X*, *Y* and *Z* decreased. From our studies, the new method determining a tone conversion characteristic has proven to be accurate and practical.

Summary

A new method determining the tone conversion characteristic of digital still camera was developed. Only digital values of two images of the same subject formed at two different exposure levels whose ratio is known are used, but a gray scale which is conventionally used is not used in the method. Using the tone conversion characteristic and a gray scale included in subject scene, influence of flare can be eliminated. Then the tone conversion characteristic was applied to color reproduction model of digital still camera and used to not only convert digital value to exposure but also eliminate flare. Color differences expected from the new process, in which calculated tone conversion characteristic was used and flare was eliminated, were less than those of conventional process. The new process has proven to be slightly accurate and practical.

References

1. ISO 14524:1999, Photography - Electro still picture cameras - Methods for measuring opto-electronic conversion functions (OECF's)
2. Masao Inui, J. Soc. Photgr. Sci. Tech. Jpn, 43, 22 (1980)

Biography

Masao Inui received his M.Eng. from Chiba University in 1973 and joined the University staff there in the same year. In 1986, he joined Konica Corporation, where he advanced to the position of Chief Research Associate. In 1993, he received his D.Eng. from Chiba University, and in 1998, Dr. Inui took a professorship at Tokyo Institute of Polytechnics. He has served as an expert member of ISO/TC42/WG3 (1990 to 1998), and also served on the Executive Committee of the Society of Photographic Science and Technology of Japan (SPSTJ). Dr. Inui was awarded the SPSTJ's Paper Award in 1977 and its Technology Award in 1991. His special interests include image analysis, evaluation, design, and processing, especially color management, color reproduction and micro image structure.