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A color calibration method between different digital cameras

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ABSTRACT

In order to achieve the same color information for any digital cameras under the same environment, a color calibration method for adjusting the digital inputs between different digital cameras was presented and then verified by an experiment. This method is based on the accurate prediction of color information via colorimetric characterization modeling. In the process, the tristimulus values XYZ of the ColorChecker colors are obtained from their spectral reflectance and the spectral power distribution (SPD) of a lighting condition. Afterwards, these tristimulus values XYZ are converted to the coordinates in the CIELAB color space using the white point of test lighting condition, i.e. (L^*, a^*, b^*). The relationships between (L^*, a^*, b^*) values and digital inputs for individual digital cameras are described mathematically by the forward and inverse colorimetric characterization models, respectively. Thus, by the proposed procedure, any designated digital camera could get its calibrated color information that is the same as that from a target digital camera, involving the forward colorimetric characterization modeling for the designated test camera and the inverse colorimetric characterization modeling for the target camera. The method can overcome the influences of various environments on color information achieved by different digital cameras.

1. Introduction

There are no doubts that digital imaging is a fascinating and challenging field and digital cameras have become the most popular devices to generate digital images, which give full play to visual information communication and multimedia enjoyment in our daily lives [1].

For digital cameras, their digital inputs (r, g, b) are introduced to record multiple channels of color information in a single exposure, which is actualized by the Bayer pattern with the arrangement of red, green and blue filters placed over individual detectors in a sensor [2]. Most digital cameras adopt 8 bit to record color information for each channel, so that the maximum value of digital inputs for single channel is 255. Though the color information of a scene can be represented by the (r, g, b) values, different digital cameras would certainly achieve dissimilar digital inputs when capturing the same scene under the same lighting condition, which is caused by their parameter differences on filters, sensors, and image processing mechanisms [3,4]. Moreover, even for one digital camera, it may acquire diversities on (r, g, b) values at different settings such as aperture and white balance.

The above mentioned fact existed for most cases, the root of this problem lies in that, the digital inputs (r, g, b) are device-dependent data to represent the color information of captured scenes for individual digital cameras, while a device-independent way is more suitable to describe colors and to transform color information [5]. The device-independent way is usually based on the colorimetric parameters, such as the tristimulus values XYZ, as well as its corresponding values linked to visual perceptions, i.e. the CIELAB color space coordinates (L^*, a^*, b^*) [6,7]. Generally, the colorimetric characterization modeling is often employed to build a mathematical link between the device-dependent digital inputs (r, g, b) and the device-independent parameters such as the tristimulus values XYZ or CIELAB coordinates (L^*, a^*, b^*). These years, many experiential models have been proposed progressively by scholars on color and imaging science, which can give successful experiences to our study [8–10]. These colorimetric characterization models supply a potential way of calibrating the color information between different digital cameras via a device-independent medium, by which their digital inputs could be modified.

There from, to overcome the influences of image record process on color information, and to ensure that different digital cameras get the same color information under the same environment, this study was concentrated on the calibration method for adjusting color information between individual digital cameras, which was based on the forward and inverse colorimetric characterization modeling to link the CIELAB coordinates (L^*, a^*, b^*) with the digital

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inputs (r, g, b) [5]. Using the proposed method and procedure, any designated digital camera could achieve the same color information with the target digital camera when capturing the same scene under the same environment, so that when the images captured by these digital cameras are shown on other devices such as displays, projectors, they will bring about the same color appearance perception. This method provides an efficient and accurate way for calibrating digital cameras, which is beneficial to applications of the digital imaging technologies.

2. Method

The conception of the calibration procedure comes from the superiorities of describing colors by device-independent information such as colorimetric parameters, e.g. the tristimulus values XYZ, and the CIELAB color space coordinates (L^*, a^*, b^*). Since the digital inputs (r, g, b) are device-dependent that cannot represent coincident colors for different imaging devices, an appropriate color space should be selected as a medium to transmit color information between different digital cameras, while the colorimetric characterization modeling is employed to make a convention between the device-independent colorimetric parameters and the device-dependent (r, g, b). In this study, the CIELAB coordinates (L^*, a^*, b^*) are used for transmitting color information rather than the tristimulus values XYZ, because the CIELAB color space is considered as the simplest color appearance model that can express the influences of lighting conditions on the color perception [11]. Besides, the application of (L^*, a^*, b^*) in color information transformation can be regarded as a peculiarity of this study.

Here, a brief description of the calibration procedure is given, and Fig. 1 depicts its technological workflow in detail. On the whole, the ColorChecker colors under a standard lighting condition could be used as ancillary data in the calibration, in this way for any scene under other lighting conditions which are captured by one digital camera (denoted by test camera), its digital inputs could be manipulated to the same as another digital camera (denoted by target camera). The requisite data for the ColorChecker colors should be collected from two aspects, one aspect aims to get its corresponding device-independent information, i.e. (L^*, a^*, b^*) values, while the other aspect is the acquisition of digital inputs (r, g, b) via the image capture process for the test camera and target camera, respectively. Afterwards, for these two digital cameras, colorimetric characterization models could be built as a bridge connecting (L^*, a^*, b^*) values with (r, g, b), by which two mapping matrixes have been obtained. From this, the mapping matrix $\mathbf{M_t}$ can fulfill the forward conversion for the test camera, i.e. from (r, g, b) towards (L^*, a^*, b^*), whereas the mapping matrix $\mathbf{H_s}$ corresponds to the inverse conversion from (L^*, a^*, b^*) towards (r, g, b) for the target camera. Therefore, for colors of any scene under any lighting condition, we can predict their device-independent information by the matrix $\mathbf{M_t}$ from the digital inputs of the test camera, then convert them into the manipulated digital inputs which are the same as those of the target camera. Like this, the two digital cameras will keep the same color information

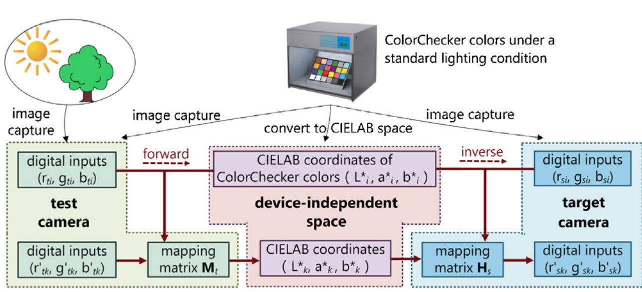

Fig. 1. Workflow of calibration procedure between two assigned digital cameras.

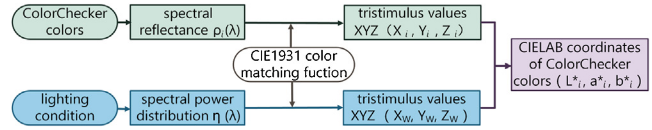

Fig. 2. Calculation process of getting device-independent color information for ColorChecker colors.

when capturing the same scene under the same lighting condition, in other words, the color information has been calibrated between these two assigned cameras. In the following, all the technological processes of the above workflow are described step by step.

(i) To obtain the CIELAB coordinates for the ColorChecker colors.

The method of calculating (L^*, a^*, b^*) values is demonstrated in Fig. 2. Combined with the spectral power distribution (SPD) of a standard lighting condition $\eta(\lambda)$, the spectral reflectance for each ColorChecker color $\rho_i(\lambda)$ is converted to tristimulus values XYZ by the CIE1931 color matching function, i.e. $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, according to the following equation [12,13].

$$\begin{cases} X_i = k\sum\limits_{\lambda=380}^{780} \rho_i(\lambda)\eta(\lambda)\bar{x}(\lambda)\Delta\lambda \\ Y_i = k\sum\limits_{\lambda=380}^{780} \rho_i(\lambda)\eta(\lambda)\bar{y}(\lambda)\Delta\lambda \\ Z_i = k\sum\limits_{\lambda=380}^{780} \rho_i(\lambda)\eta(\lambda)\bar{z}(\lambda)\Delta\lambda \end{cases} \tag{1}$$

where

$$k = \frac{100}{\sum_{\lambda=380}^{780}\eta(\lambda)\bar{y}(\lambda)\Delta\lambda} \tag{2}$$

The superscript '*i*' in $\rho_i(\lambda)$ and (X_i, Y_i, Z_i) stands for the number of the ColorChecker colors, suppose there are N colors in the ColorChecker, $i = 1, 2, \ldots, N$. Meanwhile, for the spectral power distribution of the lighting condition $\eta(\lambda)$, its corresponding tristimulus values XYZ (X_W, Y_W, Z_W) are derived by a similar process, as shown in Eq. (3). There from, the CIELAB coordinates (L^*_i, a^*_i, b^*_i) of the N ColorChecker colors could be calculated from (X_i, Y_i, Z_i) and (X_W, Y_W, Z_W), on the basis of the Commission Internationale de L'Eclairage (CIE) publication [7] on CIELAB color space.

$$\begin{cases} X_W = k\sum\limits_{\lambda=380}^{780} \eta(\lambda)\bar{x}(\lambda)\Delta\lambda \\ Y_W = k\sum\limits_{\lambda=380}^{780} \eta(\lambda)\bar{y}(\lambda)\Delta\lambda \\ Z_W = k\sum\limits_{\lambda=380}^{780} \eta(\lambda)\bar{z}(\lambda)\Delta\lambda \end{cases} \tag{3}$$

(ii) Image capture of the ColorChecker colors for two digital cameras.

As for the N ColorChecker colors under the standard lighting condition, via the image capture process, their device-dependent color information will be recorded as the digital inputs (r_{ti}, g_{ti}, b_{ti}) and (r_{si}, g_{si}, b_{si}) for the test camera and the target camera, respectively.

(iii) Forward colorimetric characterization modeling for the test camera.

For the test camera, a model can be established to mathematically predict the CIELAB coordinates (L^*_i, a^*_i, b^*_i) from its digital