Measurement Method for Color Capturing Accuracy of Cameras Particularly for High-Fidelity Color Imaging System

Yzuo Hisatake[1], Hitoshi Suzuki[2], Osamu Ozawa[3], Yoshifumi Shimodaira[1]

Hisatake.yuhzo@shizuoka.ac.jp, yuzo.hisatake@gmail.com
[1]Shizuoka Univ. Organization for Innovation and Social Collaboration
3-5-1 Johoku Naka-ku Hamamatsu 432-8561 Japan
[2]Nobuo Electric Inc. , [3]Papalab Ltd.
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ABSTRACT

We have developed measurement methods for fidelity color reproduction with as High-Fidelity Color Imaging System (HFCS) using Programmable Light Emission System, and image color conversion method for the HFCS. This paper introduces our objects and background, technical explanation, and their results.

1 Introduction

Recently, with the rise of IoT, E-commerce via smartphone or PC has been widespread, in addition to conventional mail-order sales using TV or phone call. The problems in "remote shopping" often happen with regard to color difference i.e., what consumers see on their PC display or TV screens and what they actually buy are not same. In the medical field, there are growing needs for telemedicine / tele-surgery, and thus an urgent need for establishing imaging / image output technologies that faithfully reproduces the color of a patient's skin and blood vessels, which contributes to non-contact and safe society under the COVID-19 disaster. In addition, sensory testing related to vision relies on humans at the production site, however test results often vary by tester to tester or due to physical conditions or limitations on working hours. We would like to realize a High-Fidelity Color Imaging system that applies the methods of faithful color reproduction of images from imaging to output, useful as a response to these commercial transactions, remote medical care, and non-contact social transformation. In addition, sensory testing related to vision relies on humans at the production site, but there are problems such as variations due to human physical conditions and limitations on working hours.

Therefore, by automating and mechanizing sensory tests that depend on humans, on-site productivity can be achieved. By providing a means to easily evaluate the excellent color sense of "takumi (artisan)" and realize automate quality control of color in various industries, the technology will lead not only to domestic measuring equipment manufacturers but also to be applicable to outstanding industry technologies such as beer foam texture, cosmetic and car paint color and so on.

This paper introduces the overall of the High-Fidelity Color Imaging System (HFCS), Programmable Light Emission System (PLES) used for the HFCS, measurement methods for fidelity color reproduction, image color conversion methods, and their results.

2 High-Fidelity Color Imaging System Experiment

HFCS is an "image system that faithfully reproduces colors as seeing real things and the output images". From “shooting (camera)” to “projecting (display), this system makes the real thing color and the output color look the same as "seeing the real thing" in site and "seeing the output" on an electric display or printed matter. For fidelity color reproduction, it is necessary to perform color measurement consistently from imaging to display.

-- Photograph in color measurement: HFCS equalizes the color signal (XYZ) for input and output. In the current image equipment, each manufacturer performs its own color conversion (Xi, Yi, Zi ≠ Xo, Yo, Zo non-linear conversion).

-- Display is also colorimetric: HFCS make the displayed color signal equal to the input color signal. (For current equipment each manufacturer has its own color conversion (picture making)).

Figure 1 shows an overview of the HFCS. Prepare an electric color target and measure the chromaticity of each color patch by using colorimeter (catching chromatic dispersion). In the case of Reflective color target, it is measured under several standard light sources, and in the case of electric color target is outputted the light with chromatic dispersion corresponding to some chromaticity (i.e. the color patch).

2.1 PLES: Programmable Light Emission System

Recently, the image quality of electronic displays has been improved, so as to output high-saturated color images, and to display not only object colors but also bright red sunsets and dark blood colors, and so on. In order to realize a high-saturation color target and an infinite number of color patches corresponding to these, an Electric color target that combines a high-saturated-color light source is preferable.

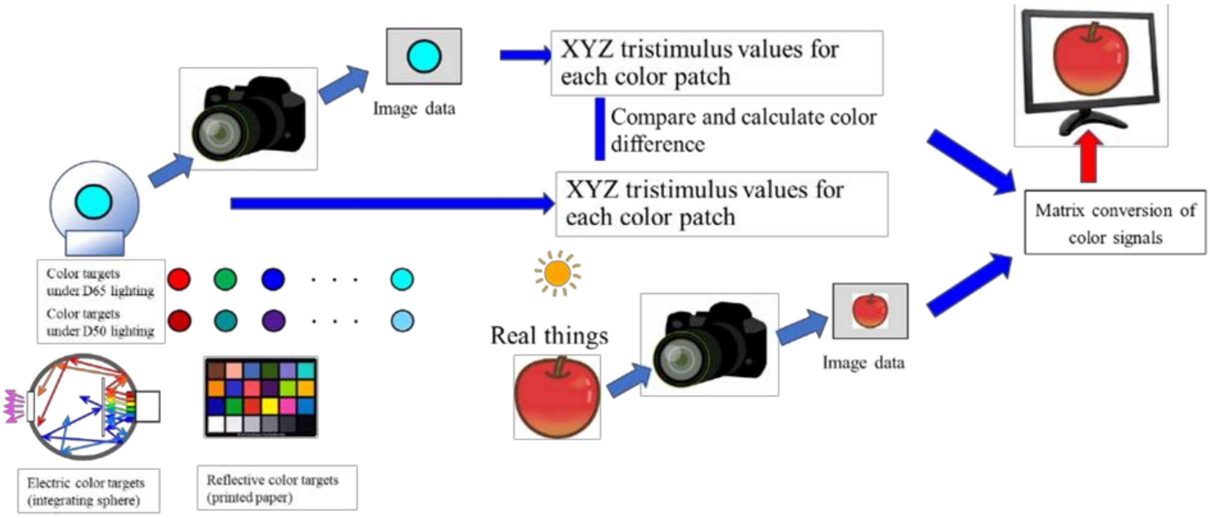


Fig. 1 overview of the HFCS

We have developed an Electric color target using 18 colors of Light Emitting Diode (LED) and developed the PLES [1], [2] using the LEDs. The Electric color target [3], [4] used for the PLES has a wider color reproduction range than the color gamut of ITU-R BT.2020.

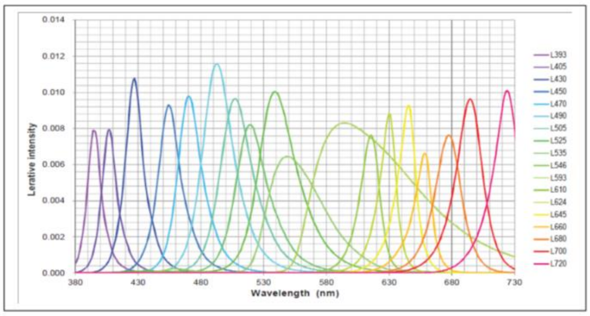


Fig. 2 The emission spectrum of the LED used for PLES

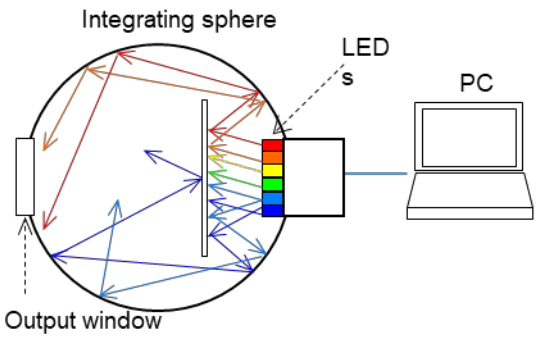


Fig. 3 The Schematic diagram of PLES

Figure 2 shows the emission spectrum of the LED used for PLES, and Figure 3 shows the schematic diagram of the PLES. Various emission spectra can be realized by controlling the light intensity of 18-color LEDs, and Figure 4 shows an example of the emission spectrum of the X-rite color checker using the Electric color target. The chromaticity is a perfect match.

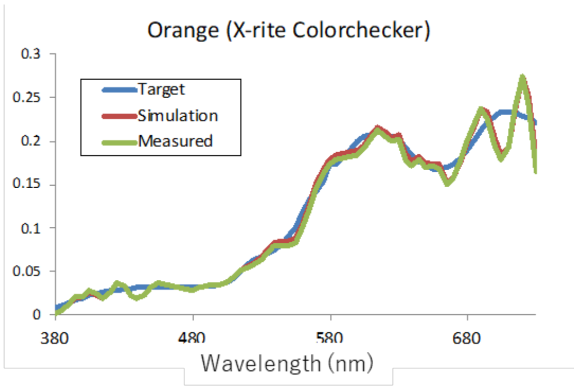


Fig. 4 An example of the emission spectrum of the X-rite color checker using the Electric color target

2.2 To achieve faithful color reproduction of various colors (corresponding to a wide color gamut)

It is necessary to use a wide color gamut color target to support cameras that can capture a wide color gamut and electronic displays that can output the wide color gamut. An electric color target that can reproduce even the emission color is essential. The HFCS can also be applied to faithful color reproduction using reflective color targets, but it cannot support color reproduction of highly saturated colors such as sunsets. On the other hand, the number of colors of color patches can be obtained infinitely by the combination of multiple primary colors of the PLES. Of course, the color of an object under any light source (i.e., D65, D50) can be reproduced. In other words, the PLES not only covers what can be done with a reflective color target but can also express colors that are not available in a limited number of reflective color targets and can also cover a wide color gamut. Especially, the PLES is indispensable for color reproduction of highly saturated colors. Therefore, we think that it is desirable to use the PLES for the HFCS.

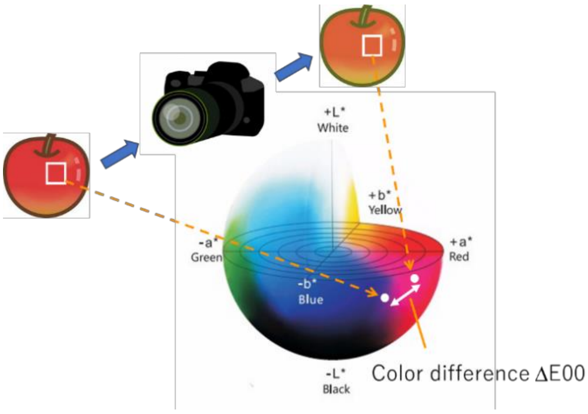


Fig. 5 the differences measure the formula color difference ΔE00 in the Lab color space

3 Measurement method for color capturing accuracy of cameras Results

To achieve fidelity color reproduction, it is necessary firstly to compare the tristimulus values of each color patch and the tristimulus values of photographed with a camera capable of measuring colors, and secondly to calculate the differences between both, and thirdly to obtain a conversion matrix color signals that minimizes the differences. Figure 5 shows the differences measure the formula difference ΔE00 in the Lab color space [5].

The average value of the color differences for a plurality of colors is taken as the color reproduction accuracy of the camera. For example, the average color difference of the 24 color patches in the fig. 5. The closer it is to 0, the more colorimetric (high color fidelity). The distance between the subject color and the captured color in L*a* b* color space.

It is the accuracy that is evaluated here. Of course, precision is also important, but we evaluate how faithful the color reproduction is.

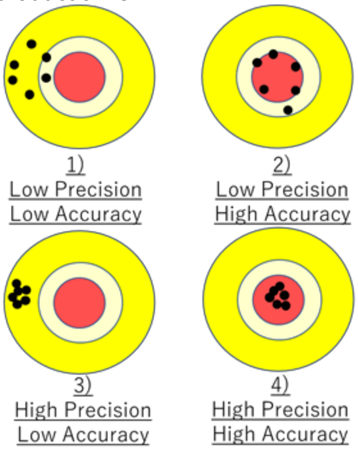


Fig. 6 the differences between accuracy and precision

Figure 6 shows the difference between accuracy and precision. In the figure, black circled symbols are measured values, red circles are within the required specifications, and yellow circles are outside the required specifications (the outside is out of the required specifications). Accuracy is a measure that the value is close to the "true value", and precision is a measure that indicates the small amount of variation between the multiple values. The red circles in Fig. 6 are the required specifications, the center of the circle is the target value, and the range of the circles is the specificity on design value. (Target value ± allowable range). Both 2) and 4) have high accuracy and are almost within the required specifications of the red circle. In addition, 4) has higher precision than 2), and the variation in measured values is small. On the other hand, 3) has high precision but deviates from the target value. 1) has low accuracy and precision. The purpose of measurement is to measure the true value.

Matrix conversion of color signals

Figure 7 shows a method of deciding of Matrix conversion of color signals. The matrix is determined so that the average value of the color difference ΔE00 of each color is minimized, and the average value at that time is used as the color reproduction accuracy of the camera to be measured.

4 Results and discussions

Figure 8 shows the measurement values of the color reproduction accuracy of the color patch of the X-rite color checker for 24 colors. a) is the result of a colorimetric camera calibrated by the PLES, and b) is the result of using a conventional camera. A colorimetric camera faithfully reproduces the color of the color target.

Since PLES can output colors of an arbitrary spectrum, it is possible to selectively output multiple colors in the range required by users and improve the accuracy of color proofing of cameras.

5 Conclusions

We are convinced that these methods will contribute to the well-being of humankind. Currently, we are working on preparing for an International Standard of these technologies.

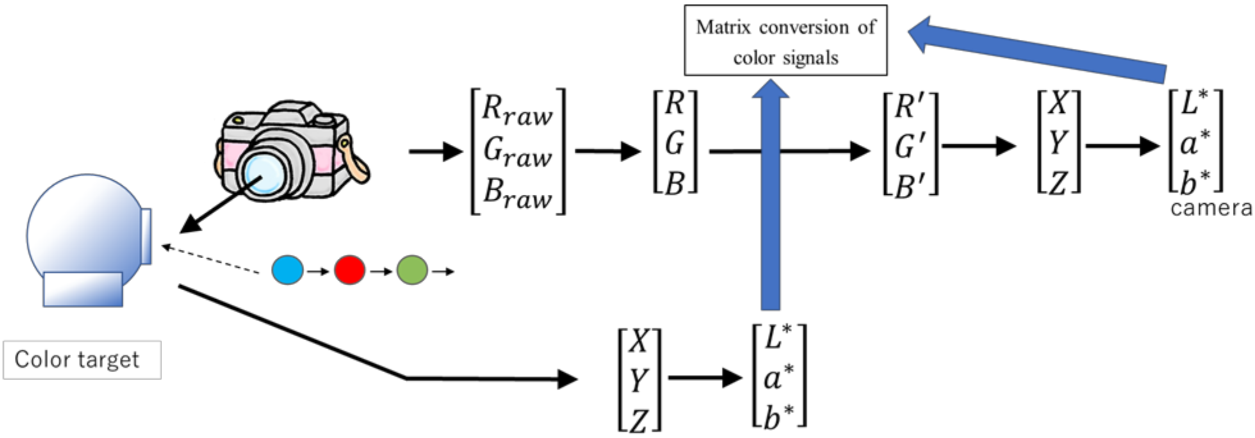
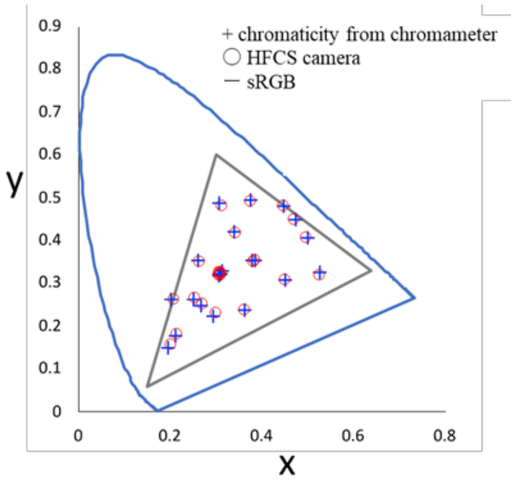
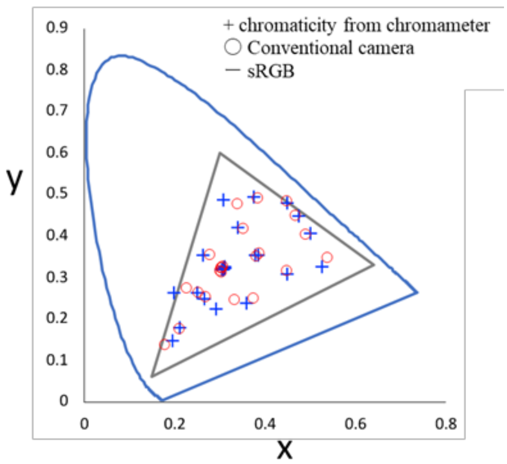


Fig. 7 A method of deciding of Matrix conversion of color signals



a) The result of a colorimetric value using the HFCS



b) The result of a colorimetric value using conventional camera

Fig. 8 Measurement values of the color reproduction accuracy of the color patch of the X-rite color checker for 24 colors

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The authors would like to express their appreciation for the standardization of high-fidelity color imaging system sub working group (HFCS-SWG) under JIIA standardization committee and the Japanese national committee for standardization of next-generation high-color-fidelity imaging-system of Shizuoka University (HFCS-committee) for offering valuable advice and discussions.

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