Illumination-independent Color Reproduction in Medicine and Its Evaluation

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Abstract

A system of illuminant-independent color reproduction has been developed for practical use in medicine, and its performance was subjectively evaluated by a group of healthcare professionals of various specialties. For medical diagnosis, it is important to archive image data of diseased skin for the purpose of visually reviewing its chronological changes. However, sufficient color reproduction quality has never developed for this purpose. First, the illuminant conditions at various locations in a university hospital were measured and it was found that illuminants used in the hospital have a wide range of colors and that some of them have color rendering index (Ra) values that are too low for ordinary colorimetric color reproduction. Therefore, the multi-spectral imaging technique was applied for the illuminant-independent color reproduction to correct the color adaptively to the various kinds of illuminant. The healthcare professionals group evaluated the reproduced skin color by comparing the images with real skin. The results verify the effectiveness of the developed system and also expose the medical need for shading reproduction in addition to averaged color reproduction.

Introduction

Morphological diagnosis, which requires reliable color reproduction, plays an essential role in medicine. It is also important to archive diseased skin image data for the purpose of monitoring chronological changes visually. However, most physicians currently evaluate therapeutic effects by comparing a real skin lesion not with its picture recorded before treatment, but with their memory of the image. Therefore, the medical demand for high accuracy color reproduction does not seem to be prominent in this current practice [1]. This is because no digital imaging device is currently available that sufficiently reproduces the skin color quality, which could be applied in dermatology or nursing [2], and medical doctors have given up believing the colors recorded by digital imaging systems. The same situation is observed for oral mucosa and teeth in dentistry.

Many steps are necessary to calibrate and record skin colors and to reproduce them accurately on a display. First, a camera and a display should be calibrated accurately. Then, illuminant conditions should be managed so that the colors are also dependent. Since it is difficult to calibrate every illuminant in practical medical applications, reproduced colors should be adjusted to each illuminant under which they are observed. This adjustment can be done through measurements of various color patches. However, these steps are too complicated for practical use in medicine. Therefore, a color reproduction system that has sufficient quality and practicality for medical applications has never been developed, and no practical evaluation has yet been made on the effectiveness of accurate color reproduction in medicine.

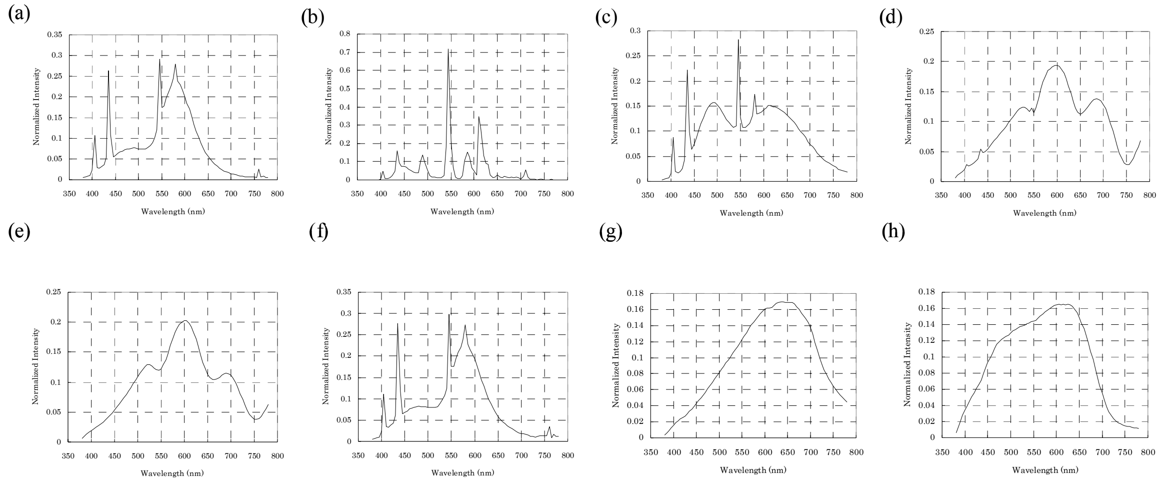
This paper introduces a developed system of illuminant-independent color reproduction for practical use in medicine. As the first step of the development, the illuminant conditions at various locations in a university hospital were measured thoroughly. After comprehensive analysis of this data, a multi-spectral imaging technique for the illuminant-independent color reproduction was adopted. In this paper, the proposed system and the results of subjective evaluation of its performance made by a group of healthcare professionals of various specialties are presented.

Illuminant Conditions in a University Hospital

Illuminant conditions in Tokyo Medical and Dental University Hospital were measured using a spectrophotometer (CS-1000 Konica Minolta). Spectral radiant distributions were recorded in several locations in five typical rooms utilized for patient care.

Figure 1 shows a portion of the measurement results. The spectral radiant distribution was measured from wavelengths of 380 nm to 780 nm. The wavelengths where the spectral radiant distributions were measured are also listed in Figure 1.

It can be seen that the measured illuminant had a wide range of color. Table 1 shows the correlated color temperatures and the color-rendering index. Because some illuminants generated very low values on the color-rendering index, differences in colors caused by such illuminants should be compensated by some color reproduction technique, and simple chromatic adaptation or color constancy using the von Kries model will not solve this problem [3]. A multi-spectral imaging technique was adopted for illuminant-independent color reproduction, since the operation needs to measure many kinds of color patches that are too complicated to be followed for practical medical use.



Index	Place	Angles of measured plane	Ceiling light	Other lighting sources
(a)	An emergency outpatient unit	45° to the horizontal	on	none
(b)	A treatment room of a dermatology ward	45° to the horizontal	on	none
(c)	An outpatient booth of dermatology	45° to the horizontal	on	windows aside
(d)	A dental chair by the window	horizontal	on	an adjustable lamp
(e)	A dental chair apart from the window	horizontal	off	an adjustable lamp
(f)	A dental chair by the window	horizontal	on	windows aside
(g)	A surgical bed in an operating room A	horizontal	off	surgical lights
(h)	A surgical bed in an operating room B	horizontal	off	surgical lights

Figure 1. Spectral radiance of some illuminations in a university hospital

Table 1. Correlated color temperature and the color-rendering index of illuminants listed in Figure 1 (according to JIS Z 8726-1990)

Lighting source	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
xy chromaticity coordinate (x)	0.3956	0.3699	0.3557	0.4162	0.4189	0.3848	0.4334	0.3753
(y)	0.4018	0.3837	0.3679	0.4108	0.4136	0.3946	0.4150	0.3819
Correlated color temperature (K)	3804	4342	4690	3437	3401	4013	3147	4179
Average color rendering index (Ra)	60.7	80.3	95.6	86.4	87.5	62.8	94.4	96.0

A Color Reproduction System for Medical Use

Figure 2 shows the overall system for the illuminant-independent color reproduction for medical use. Flashes are attached to the digital camera (DiMAGE 7i, Konica Minolta). The types of geometry for the flashes can be chosen to reproduce the appropriate shading for the targets. The obtained image can be saved as raw CCD signal data, and the data is then transferred to a personal computer, which performs the color reproduction process. The captured image is displayed on a high-resolution LCD monitor for medical inspection. The characteristics of the monitor are measured beforehand by a spectrophotometer (CS-1000, Konica Minolta) while a systematic combination of colors are displayed on it [4].

The illuminant-independent color reproduction is performed by a multi-spectral imaging technique shown in Figure 3 [5][6]. The obtained RGB raw image is converted into a spectral reflectance image by employing the Wiener estimation technique. Samples of skin reflectance spectra are used to prepare for the Wiener estimation. The estimated reflectance spectra are converted into tristimulus values by using the spectral radiant distribution of the target illuminant. The spectral radiant distribution of the target illuminant is manually set from a database of values, some of which were measured in the hospital. The useful database was generated to be able to select the appropriate spectral radiant distribution of illuminant by checking the illuminant product number.

Since the exposure value is difficult to control in the present system, a small color patch (10 mm*10 mm, CasMatch, Dai Nippon Printing) was attached on the skin, as is shown in Figure 4. The white and black patch is used to adjust the exposure value and the black level to show the image on the display appropriately.

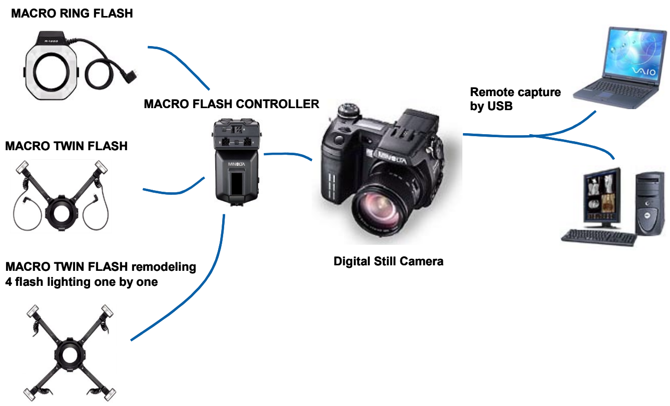


Figure 2. Overview of the color reproduction system

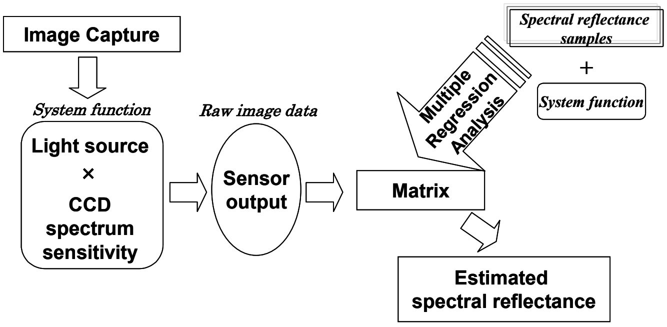


Figure 3. Algorithm for inputting and processing images

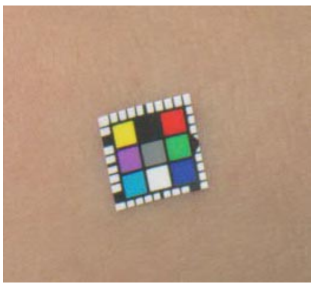
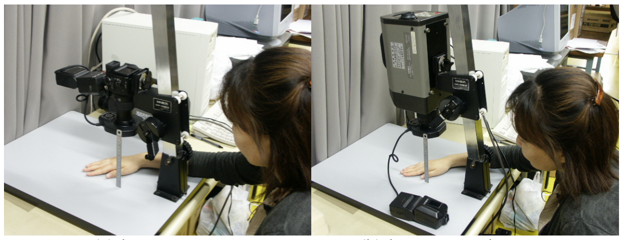


Figure 4. CasMatch

Evaluation of the System Performance

As depicted in Figure 5, the system performance was evaluated by comparing the value estimated by the proposed method and the value measured by the spectral radiometer. For both methods, the same type of flash ring was attached to illuminate the skin. Four real hand dorsal surfaces were measured by both systems. Table 2 shows the evaluation results based on the color difference. The color difference was calculated under illuminant D65. From Figure 2 indicated that the developed system can adequately record skin color under the D65 illuminant. Figure 6 shows the measured and estimated spectral reflectance of the four real skins. It was also found that the developed system can adequately record the spectral reflectance of skin.
A computer simulation was also performed to evaluate the system performance. The spectral sensitivity of the camera system was measured by monochrometer for camera sensitivity measurements (SS-25C, JASCO). Table 3 shows the result of the evaluation. The transformation matrix was created from the samples of 240 color patches and 441 skin reflectance spectra. The reflectance spectra of the color patches are introduced into the samples to reproduce the colors except for the skin to some degree of reproduction accuracy. This is because the strange colors seen in a background will disturb the diagnosis process. Table 3 shows the effectiveness of the developed system in a computer simulation.



(a) by camera (b) by spectrophotometer

Figure 5 Measurement of skin color

Evaluation of Healthcare Professionals

A group of healthcare professionals was asked to evaluate the reproduced skin color compared to the real skin. The arm of a medical doctor is captured by the developed system, and the captured image is transformed into the calibrated color based on the illuminant in the experimental room. The illuminant in the experimental room was a Three-band Day-white Fluorescent Lamp. Figure 7 shows examples of the images used for the evaluation in the experiments. A white patch is used for the adjustment of the camera exposure level instead of CasMatch.
The following six questions asked to the group: (1) is the color reproduction correct or not, (2) will you use this system for medical diagnosis or not, (3) comments on user interface, (4) comments on the camera system, (5) comments on the display system and (6) other comments. The specialties of the participants are laboratory medicine and preventive medicine (MD#1), dermatology (MD#2), dentistry (MD#3) and nursing (MD#4).

Table 2. Color differences obtained by measurement.

Sample	Estimation			Measurement			ΔE*94
	L*	a*	b*	L*	a*	b*	
skin 1	65.4	9.4	20.6	65.2	9.0	20.5	0.4
skin 2	63.8	7.8	18.9	64.0	8.3	19.4	0.5
skin 3	66.3	10.7	22.0	66.2	10.6	21.8	0.2
skin 4	60.8	9.7	19.9	61.4	9.4	19.7	0.6
					ΔE*94 max		0.6
					ΔE*94 average		0.4

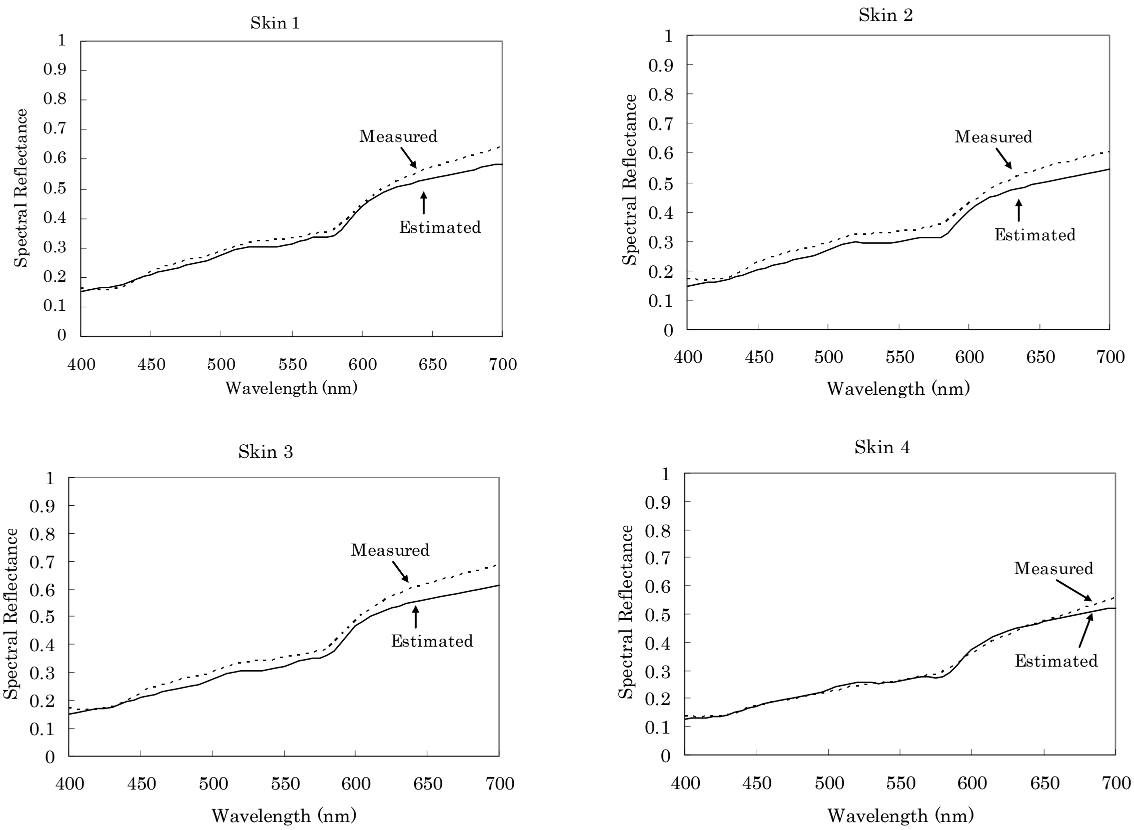


Figure 6. Estimated reflectance spectra of human skin

Table 3. Color differences obtained by simulation.

(a) in D65

Sample color	Simulation			Measurement			ΔE*94
	L*	a*	b*	L*	a*	b*	
blue	36.0	22.8	-55.0	37.7	24.9	-51.4	2.6
white	90.9	1.2	-5.5	92.8	2.2	-3.5	2.8
cyan	67.3	-32.7	-28.5	65.1	-36.3	-24.5	3.9
purple	55.4	50.5	-37.0	55.2	48.2	-37.5	1.1
gray	58.8	-2.6	-1.9	56.5	-0.1	-1.2	3.4
green	68.6	-64.7	38.7	67.9	-62.5	40.5	1.4
red	52.0	71.2	52.6	50.7	73.7	41.4	4.9
black	18.4	0.1	-0.3	16.8	1.7	-4.7	4.7
yellow	88.4	-11.7	79.5	88.0	-11.3	82.9	0.9
					ΔE*94 max		4.9
					ΔE*94 average		2.8

(b) in white fluorescent

Sample color	Simulation			Measurement			ΔE*94
	L*	a*	b*	L*	a*	b*	
blue	28.9	20.2	-67.6	35.0	18.1	-56.4	6.9
white	90.8	-0.1	-6.2	92.6	0.9	-4.2	2.5
cyan	64.3	-24.8	-32.4	59.5	-26.3	-32.7	4.9
purple	51.7	41.0	-45.6	54.3	38.9	-40.2	3.2
gray	57.5	-2.0	-3.1	56.5	-0.5	-1.4	2.3
green	67.6	-46.0	37.8	66.3	-45.2	40.1	1.8
red	53.2	57.8	53.4	48.8	60.5	37.4	8.2
black	17.4	0.2	-1.0	16.7	0.8	-5.3	4.0
yellow	91.4	-10.9	84.0	90.2	-8.3	88.0	1.9
					ΔE*94 max		8.2
					ΔE*94 average		4.0

Figure 7. An example of a human hand image

Question (1): Is the color reproduction correct or not? The group answered as follows.

MD1: “Almost satisfactory. The red color of gingival under three band fluorescent lamps is different from the red color under illuminant A.”

MD2: “Satisfactory results were obtained under the white fluorescent lamp, but scattered green artificial dots were observed under three band fluorescent lamps. Under these two illuminants, a significant difference was observed in the appearance of pigmented or hypopigmented patches. The difference in the reproduced contrast may cause this result. Superficial veins were clearly observed. Observation of skin pores and wrinkles required the reproduction of three-dimensional features.”

MD3: “Satisfactory results were obtained under the white fluorescent lamp. I don't say 'no', but the appearance of the red color was thought to be poor under other illuminants.”

MD4: “A real arm is more yellowish than the reproduced picture, but the boundaries of an erythema for the latter were clearer.”

Question (2): Will you use this system for medical diagnosis or not? The medical specialists answered as follows.

MD1: “It will be possible in limited cases. It can be used in screening for cases that should be consulted to specialists, e-learning, and home care, which will be the practical applications.”

MD2: “Although exact estimation cannot be made without directly observing diseased skin, a more precise color reproduction than printed pictures is achieved. It will be applicable to neoplastic lesions, but further investigation will be required for inflammatory lesions.”

MD3: “Yes, I agree. If three-dimensional appearance is successfully reproduced, skin lesions will be visible more exactly. It will be applicable to the diagnosis of caries of teeth or inflammation of gingiva, namely, the diagnosis of periodontitis.”

MD4: “Appearance of erythema is satisfactorily reproduced for nursing use. Subtle histological difference observed in skin and swelling observed at gingivitis lesions are well reproduced also. Nearly flat objects like skin are OK, but the appearances of objects with greater depth are not able to be reproduced properly.”

Question (3): Comments on the user interface. The group answered as follows.

MD1: “Pursue user-friendliness through repeated prototyping.”

MD3: “Limit functions to minimum requirements, aiming at a simple system. Although sufficient experience will minimize any inconvenience, rarely-used functions should be omitted.”

MD4: “Make it easy to use.”

Question (4): Comments on the camera system. The group answered as follows.

MD1: “An inexpensive, light, portable system is better.”

MD2: “Focusing this camera is not easy. A single-lens reflex camera would be better. Mount type flashes are more easily broken by accident than built-in types. Such accidents occurred very often in my university.”

MD3: “About the shape of the flash power module, a horizontally long shape is preferred to present one because it can be stored more easily.”

MD4: “Make it small and simple.”

Question (5): Comments on the display system. The group answered as follows.

MD1: “A small, inexpensive, light system is better.”

MD3: “A notebook equipped with a flat panel display that has enough performance for color reproduction should be manufactured.”

Question (6): Other comments. The group answered as follows.

MD2: “Real skin can be palpated and observed from multiple angles, but pictures on a display can not. Reproducing a three-dimensional appearance would effectively compensate for these limitations. Although taking a photograph using "the four flashes system" is not suitable for the methods currently established in dermatology in which a picture with minimum shadows can be taken, it helps obtain more suitable pictures for some diagnostic aspects. A major purpose of image recording in dermatology is not to record its appearance, but its location. Appearance of a skin lesion is only remembered by physicians and reproduced through their narrative explanation.”

MD3: “Because the three-dimensional appearance of gingival swelling and that of gingival stippling are poorly reproduced, they may be overlooked. And because the surface of a tooth is curved, a point-source light cannot appropriately show its precise shading. A linear-source light may be appropriate. In this experiment, the color appearance of teeth was reproduced satisfactorily. If color appearance of artificial teeth and that of post crowns are also well reproduced, this system will allow a dentist to choose them by observing their colors on a display. This method will provide a lot of advantages to dentists, denturists and patients.”

The developed system has been evaluated as a system that can be used in limited cases. Through the experiments, valuable comments from the medical doctors were obtained. As MD#1 mentioned, this technique can be used for screening in cases that should be consulted to specialists, e-learning, and home care applications. As an example of limited cases, MD#2 mentioned that it can be applied to neoplastic lesions. However, he also mentioned that further investigation is required to examine inflammatory lesions. MD#3 and #4 also mentioned that it is necessary to reproduce three-dimensional appearances.

In summary, the system is deemed a great step up from the conventional system. However, it is also recognized that the illuminant independent color reproduction is just one method for aiding medical diagnosis. General illuminant independent reproduction is necessary to reproduce shading under the desired illuminants.

Conclusion

The result of evaluation clearly identified the significance of the proposed color reproduction system for medical applications. It suggested that such system could be used by medical doctors for practical diagnosis and archiving if a user-friendly system were available.

Although flash photography captures stable color information for the adequate estimation of spectral reflectance, it loses shading information that reflects the surface irregularities of objects. Because this drawback is considered to significantly affect diagnosis on skin and mucosal lesions, establishing an alternative method for obtaining stable color information without a flash will be another important target of future investigation.

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