Color reproducibility of skin lesions in multispectral video: Experimental evaluation

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Abstract

The color reproduction accuracy of a multispectral video system was visually evaluated by expert dermatologists to investigate the feasibility of the system in telemedicine applications. The erythema produced by a skin prick test was used as a substitution of real skin lesion, and the dermatologists performed a color matching experiment, in which the color chips were compared with the reproduced images and the real skins. As a result, the mutisperctral video system, consisting of 6-band HDTV camera, 6-primary display and spectrum-based color reproduction, decreased the perceptual color difference between the reproduced image and the real object, as compared with a conventional 3-band HDTV system. It was also shown that the oversights of skin lesions could be reduced in 6-band video reproduction. Through the experiments including multispectral video transmission between the remote hospitals in addition to above skin color matching, dermatologists rated that the natural color reproduction realized by multispectral video is almost satisfactory for the diagnosis of skin disorders.

1. Introduction

In the telemedicine applications such as teledermatology, telepediatrics, and home-care telemedicine, visual communication is crucial, and the color reproduction capability is a critical issue in the video and imaging system for those purposes [1-3]. As the colors of reproduced image in conventional imaging systems are not normally calibrated, which is one of the main reason that the use of visual telemedicine is still limited. Even in the system that complies the color standard, such as sRGB or ITU-R Rec.709, there appears color difference between the reproduced image and the original object, because the camera sensitivity is not equivalent to human vision (i.e., it does not satisfy Luther condition), the illuminant condition is not properly considered, and the accuracy of device characterization is not high enough.

For highly accurate color reproduction in visual communication systems, multispectral imaging technology is promising [4-7]. It has been shown that the color reproduction accuracy can be improved by using spectral image acquisition, and in addition, spectral information can be utilized for the diagnosis support with employing image analysis technique [8-11].

Previous works on the multispectral color imaging is mostly limited in still-image application, but motion picture reproduction is preferable for better understanding of patient condition. Video systems are often used in practical telemedicine applications. The authors have been developed a prototype multispectral video system, which comprises 6-band HDTV video camera, 6-primary color display, real-time color converter, and parallel video encoder/decoder, in the Natural Vision project [7]. The color reproduction accuracy was proved to be superior to conventional HDTV systems, through experimental colorimetric evaluation.

Although colorimetric evaluation is objective and reliable, it is essential to evaluate the color reproducibility from the aspect of medical diagnosis for telemedicine applications. In this paper, we present the results of experiments, in which the color reproduced with the prototype multispectral video system was visually evaluated by expert dermatologists. The main purpose of the experiments is to investigate whether the dermatologists perceive identical color from the reproduced image and the original object, and how the color reproducibility influences the skin lesion diagnosis. As it is not easy to objectively see dermatologist's perception of real skin disorders, we conducted a color-matching experiment between color chips and artificial skin lesions. Among the fields of medical diagnosis, dermatology is most sensitive to color reproduction. The fact that the color reproducibility of the multispectral video system is highly rated by dermatologists indicates the feasibility in other various fields in telemedicine applications.

2. Prototype multispectral video system

The system of prototype multispectral video [6] used in this experiment is shown in fig.1. The 6-channel video signal from a 6-band HDTV camera is converted in a 6to3 color converter to the colorimetric tristimulus values, by using spectrum-based color reproduction technique. In the spectrum-based color reproduction, after the correction of the tone reproduction curve of CCD, the spectral reflectance is calculated for every pixel by Wiener estimation with the spectral sensitivity of the camera and the illuminant spectrum of an image capturing environment measured in advance. A Markov-random field model is used in the Wiener estimation of spectral reflectance. The colorimetric tristimulus values are then generated with using the illuminant spectrum of an observation environment. All these processes can be done by 6to3 matrix multiplication in real-time.

For the image display, both 3-primary and multiprimary displays can be employed. The color display is characterized in advance and the parameters are set into the real-time color converter. When using a 6-primary color display, a 3to6 color

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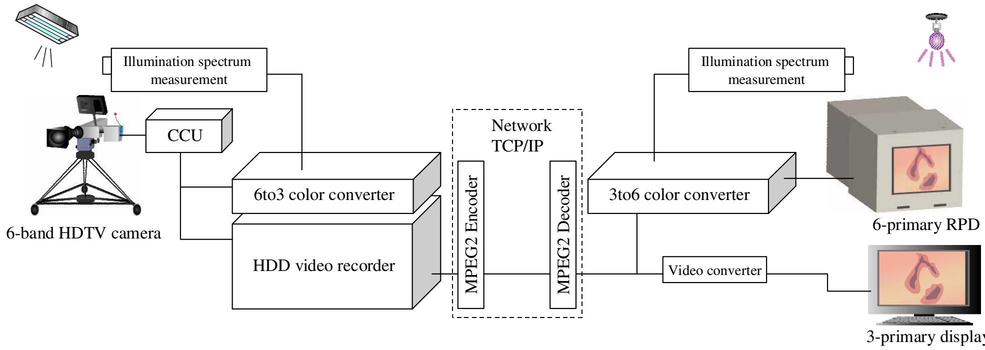

Figure 1 *Schematic diagram of prototype 6-band multispectral video system. CCU: Camera control unit, RPD: Rear-projection display.*

converter consisting of six 3-D LUT's is used to generate the 6-primary color video signal. For multiprimary color conversion, the method based on spectral approximation technique [12] was used in the following experiment. In the method, the spectral radiance of the object obtained from the multispectral image is approximated with the 6-primary color spectra of the display, under the restrictions of a colorimetric match.

In the real-time reproduction, however, direct conversion from 6 to 6 channels is difficult because of the hardware complexity. Thus the spectral radiance of the object is estimated from the colorimetric tristimulus signal, which is an output of the 6to3 color converter, using the linear estimation technique with the illuminant spectrum of an observation environment. Then the estimated spectral radiance is used in the spectral approximation technique. The conversion relationship so obtained is set in the 512bit 3-D LUT's of the 3to6 color converter for real-time processing.

The captured image is recorded in the HDD video recorder with uncompressed format. The data amount is about 3.5Gbps. In the experiment of real-time transmission between remote sites, we used a parallel MPEG-2 encoder/decoder for transmitting video signals through the TCP/IP network, as explained in section 4.4. In the experiment, the data rate of encoded video transmission was 80, 100, and 160Mbps, while the data compression was not the topic for evaluation.

3. Experimental method

3.1 Overview of the experiments

The experiments were carried out at the dermatology department, Yokohama-city University (YCU) Hospital, located at Yokohama-city, Japan. Instead of real patients, the erythema artificially produced by prick test was used, as its color can be considered as a good replication of typical flare such as urticaria. Prick tests of histamine, cedar pollen and mite allergens were performed onto 18 arms from 9 healthy volunteers [Fig.2]. The erythema was evaluated about 15 min after the prick test. Normal skin colors of the same locations were also evaluated and captured before the prick test.

The experiment presented in this paper is composed of following 4 processes;

1) Colorimetric evaluation, in which the colors of target skin and reproduced images were measured by a spectroradiometer (TOPCON, SR-2) to check the colorimetric accuracy.

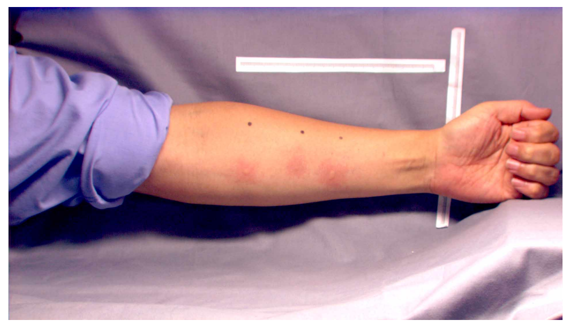

Figure 2 *Photograph of target arm with erythema by prick test.*

2) Visual evaluation by dermatologists. The colors of target skin and reproduced images were visually compared with a set of color chips to find the best-matched color chip. If the tristimulus values of color chips matched to the target skin and the reproduced images are satisfactory close each other, it can be said that the dermatologist perceived almost same color. The results were compared with those obtained from the 3-band system case.

3) The dermatologists were ordered to measure the size of erythema when it found, with using a micrometer caliper, from the real skin and the reproduced image. This experiment was performed to investigate the influence of color reproducibility to diagnosis.

4) Overall evaluation with observing the real-time video reproduction. In the reproduction at local site, the original arm with prick test and the reproduced images by 6-band and 3-band systems were directly compared to check the color fidelity. In addition, to see the feasibility of the system for telemedicine, the multispectral video is transmitted through commercial Metro-Ethernet line (100Mbps´2) between two locations; YCU Hospital at Fukuura (image capture) and YCU Center Hospital at Urafune (image display), which are about 10km apart each other.

3.2 Experimental setup

(1) Illumination lights

The illuminations at the image capturing and observation environments were fluorescent and incandescent lamps, respectively. This can be considered as a possible case of telemedicine applications. In the experiment, the illuminant spectra at both image capturing and observation were measured by using

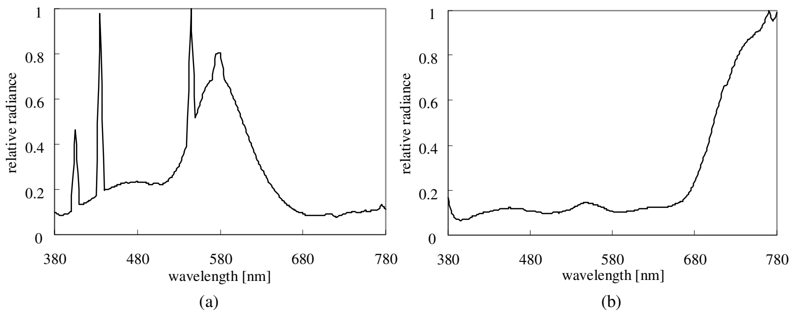

***Figure 3** Illumination spectra at (a) image capturing and (b) observation environment.*

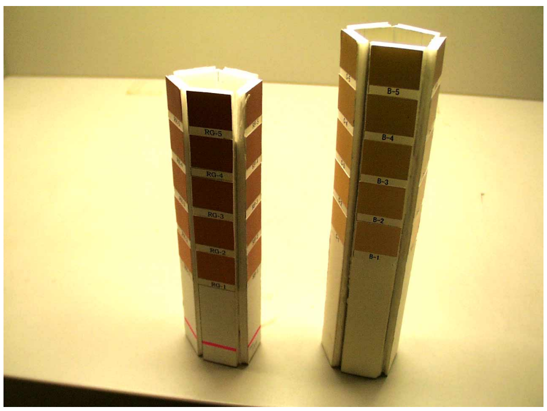

***Figure 4** Skin color chips on pentagonal cylinders used in the experiment.*

SR-2 spectroradiometer, and the measured spectral intensities are shown in fig.3.

(2) Color chips

For the color matching between the reproduced image and the real object, 25 color chips were used. The color chips were printed by an inkjet printer and attached on a handy pentagonal cylinder [fig.4] for easy comparison. The colors were determined from the preliminary measurement of skin colors; distributing around the normal and flare skin colors. The average spacing between the neighboring color chips was $\Delta E^{*}ab$ = 3 - 5 in the CIELAB color space.

(3) Video system

The 6-band HDTV video camera shown in fig.5 was used in the experiment. For comparison, a conventional HDTV system was simulated using the 3-band signal from the 6-band camera, since one-side of the 6-band camera is not modified from the original RGB HDTV camera as shown in fig.6. The uncompressed 3-band signal, where white balance was adjusted with the equipped function of HDTV camera by capturing the white object, was reproduced on a 3-primary sRGB CRT display. This system will be referred as "Conventional 3-band (C-3B) system" in the following.

In the preliminary test at the dermatology environment, we tried to use a 3-primary display (Barco, Model: CCID121) with characterization, but we found the disagreement between the reproduced color and the original object, even though the

***Figure 5** 6-band HDTV video camera used in this experiment.*

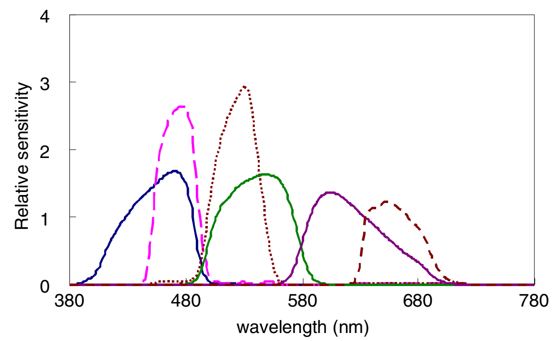

***Figure 6** The spectral sensitivity of 6-band multispectral camera. Dashed and solid curves represent narrow bands and unmodified wide bands, respectively.*

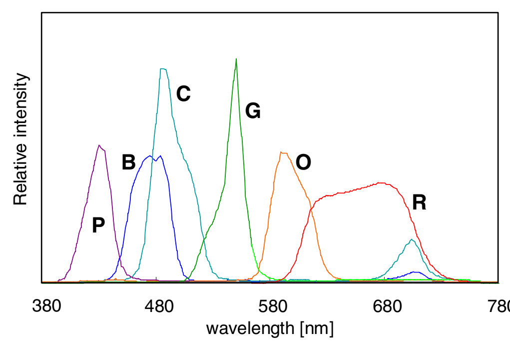

***Figure 7** Spectral radiances of primary colors in 6-primary RPD. Primaries P, C, R, and B, G, O are generated by projector #1 and #2, respectively.*

colorimetric accuracy was enough high. We supposed that it was originated from the observer metamerism effect, since the disagreement was considerably reduced in the 6-primary color reproduction with spectral approximation [12].

This observation does not necessarily mean that 3-primary displays are inadequate for skin color reproduction. The 6-primary display is selected to ensure best results in the relatively difficult experimental condition including various environmental and human factors. We have not tested the validity of a 3-primary display in the skin lesion diagnosis in this experiment.

For the above reason, a 6-primary color display along with spectral approximation was used in the following experiment. The 6-primary RPD (rear-projection display) used in the experiment is

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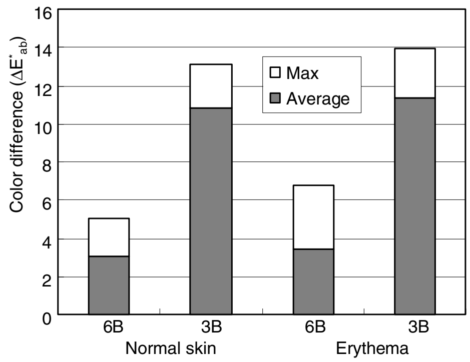

Figure 8 *The result of colorimetric measurement. The average and maximum color differences of corresponding points are shown for 3B and 6B systems.*

assembled with two DLP projectors, in which the spectral transmittance of the filters in the wheel was modified. The spectral intensities of 6-primaries are shown in fig.7. Then the multispectral video system consists of 6-band HDTV camera, 6-primary display, and spectrum-based color reproduction, and called "6-band Natural Vision (6B-NV) system" hereafter.

4. Results

4.1 Colorimetric evaluation

The tristimulus values were measured at manually selected corresponding points on the real skin and the reproduced images by NV-6B and C-3B systems. The CIELAB color differences between corresponding points are shown in fig.8. Note that the color difference includes the error in area selection, but it can be confirmed that good color reproducibility is realized in NV-6B system, i.e., average $\Delta E^*ab = 3.5$, where $\Delta E^*ab = 11$ in C-3B case, for both normal skin and flare regions.

4.2 Visual evaluation

In the visual evaluation, the real skin was observed at first, and a best-matched color chip was determined by the mutual agreement among three dermatologists. However, looking at the colorimetric tristimulus values of selected color chips, large disagreement was found in the results of three arms among nine target arms. Although the reason of disagreement is an issue for further investigation, it is primarily supposed to be the influence of unstable experimental condition. These three cases were excluded in the following evaluation.

Next, the erythema was shot with the 6-band camera and the images for NV-6B and C-3B were prepared. Then each dermatologist observed the images reproduced by NV-6B and C-3B systems, and performed matching with the color chips. The tristimulus values of selected color chips are summarized in table.1. It can be seen that the tristimulus values of color chips matched with 6B system are closer to the direct observation than those of 3B system. The discrepancy in the tristimulus values of the real object and the selected color chips is discussed in section 5.

To see if the dermatologists perceive identical color from the reproduced image, the color difference between the color chips matched with the reproduced image and the real skin is illustrated in fig.9. The color chips selected from the 6B system observation

Table.1 *The tristimulus values of real skin, the color chips selected from direct observation, 6B and 3B system reproductions. The tristimulus values are the average of 1-3 selected color chips.*

		Object			Color chip (direct observation)			Color chip (6B system)			Color chip (3B system)		
		L	a	b	L	a	b	L	a	b	L	a	b
Normal Skin	1	60.3	13.3	20.6	73.8	12.5	21.7	77.8	11.5	20.5	78.0	9.3	12.7
	2	68.1	12.1	17.7	78.9	8.6	17.7	77.5	10.0	15.7	82.4	9.2	11.1
	3	66.3	11.2	18.5	74.9	9.3	15.6	77.5	8.9	16.1	79.4	9.5	11.9
	4	63.6	9.8	20.9	73.3	10.6	21.7	70.4	10.0	19.3	77.1	8.8	14.8
	5	69.1	10.5	15.5	74.9	9.3	15.6	77.2	8.7	15.5	77.9	8.6	13.1
	6	69.6	11.0	17.4	78.0	9.5	12.2	77.9	8.6	12.8	82.2	9.9	10.4
Erythema	1	57.4	17.3	19.1	72.7	25.3	16.9	70.0	26.6	18.1	75.7	23.0	11.7
	2	61.7	17.1	16.0	66.7	28.4	18.8	68.9	25.4	14.9	76.0	22.7	11.7
	3	64.8	16.1	16.8	71.1	27.3	18.6	72.8	25.8	17.6	69.6	23.9	13.5
	4	61.9	15.1	19.1	70.1	29.1	18.5	67.0	27.8	18.3	73.6	25.0	16.0
	5	65.9	15.2	17.3	71.1	27.3	18.6	74.1	24.5	16.0	76.6	22.2	11.5
	6	68.9	15.7	18.5	72.8	24.5	17.8	71.6	27.2	16.3	73.5	24.4	16.2

distribute within $\Delta E^*ab < 4\text{-}5$ range, while in the case of the 3B system observation, the center of distribution is shifted and the color difference becomes about $\Delta E^*ab = 7\text{-}8$.

4.3 Erythema size measurement

No significant difference was found in the erythema size measurement between the C-3B and NV-6B systems. However, in some cases the sizes were not measured from the observation of C-3B system, namely the erythema was not found. Three dermatologists dealt with 60 cases in total, and 8 cases were not judged as flare, in spite that they were found in the direct observation. This means the possibility that the natural color reproduction capability improves the appearance of color difference as well as the colorimetric accuracy.

4.4 Overall evaluation

In the video transmission experiment two configurations were used; real-time and store-and-forward mode. In both modes, the video reproduction was enough smooth and the image and color qualities were satisfactory in NV-6B system for these cases. In the real-time mode, videoconference equipments were concurrently used for easy interaction. The physicians at the two sites could smoothly communicate each other, slight delay was observed in the 6-band system though.

At the time of video shooting, two different illuminants, fluorescent and incandescent lights shown in fig.3 (a) and (b), were used. Then the images were reproduced under the incandescent illumination at the observation site, with applying spectrum-based color reproduction technique. As a result, the color of reproduced image was unchanged even if the illuminant at image shooting was replaced.

In addition, the real-time reproductions by NV-6B and C-3B systems, and the actual skin were directly compared as shown in fig.10. The system shown in fig.1 was used excluding the encoder / decoder.

After these experiments, we have following evaluation comments from the participated dermatologists;

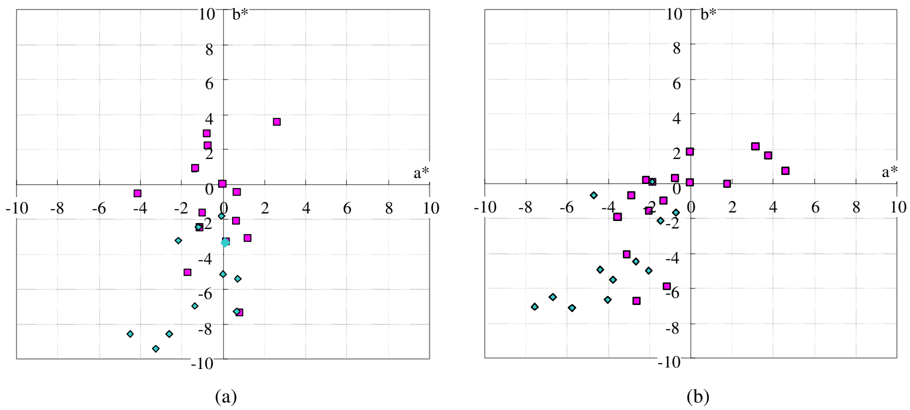

***Figure 9** CIE a^*-b^* color difference between the color chips matched with the real skin and the reproduced images. (a) normal skin, (b) erythema. Square and diamond plots correspond the results by NV-6B and C-3B systems, respectively.*

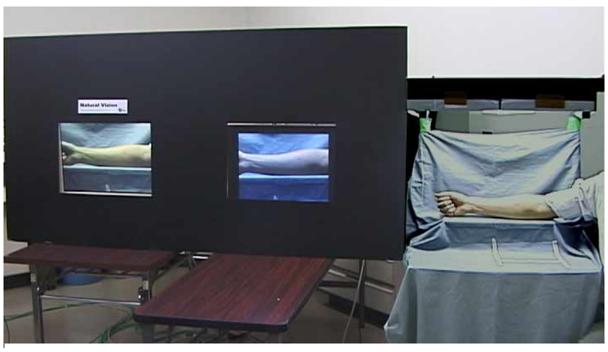

***Figure 10** Setup for the direct comparison of the real skin and the reproduced images by NV-6B (left) and C-3B (center) systems.*

(a) The color reproduction by C-3B system is not sufficient especially in reddish colors, and is not suitable for the diagnosis of subtle flare such as measles, virus infection, and drug allergy.
(b) The image color in NV-6B system looks natural, and the reddish and yellowish colors can be easily discriminated. Then the profile of the erythema is clearer in the image of NV-6B system.
(c) The dilatation of blood capillary can be clearly observed in NV-6B system.
(d) The size and the operability of camera and display need to be improved for practical use.

5. Discussions

The color matching experiment was performed in the environment similar to that of real practice, to evaluate the color reproducibility from the dermatological aspect. This caused a difficulty in the control of environmental setting, such as the distance between the color chip and the object and the illumination intensity at the surface of color chip. Therefore the tristimulus values of real object or reproduced image did not well agree with the selected color chips, due to environmental factors. For example, in the matching of normal skin, the sizes of the stimuli were different, and brighter chips were selected possibly under the influence of the size effect. In the matching of erythema lesion, more reddish chips were selected due to the chromatic contrast with the surrounding normal skin. The influence of these factors should be investigated to confirm the validity of this experiment. Even though these uncontrolled factors caused by the features of human visual system, the chips of almost same color were selected from the real skin and the NV-6B reproduction. We suppose that the environmental factors affect both the real object and the reproduced image, in a similar manner. Therefore we conclude that the observers perceive almost identical color from the reproduction by the NV-6B system.

In addition, in the preliminary experiment, we found that the disagreement of color appearance supposedly due to the observer metamerism. Slightly yellowish color was observed from a 3-primary display even when the colorimetric match was achieved. This indicates that the spectral color matching may be required in this kind of direct comparison of the original and reproduced colors.

As the opinion of the dermatologists participated in the experiment, some valuable applications of a multispectral video system were recommended. For example, monitoring or recording of surgical operation; the physicians outside the operating room can observe the operation and give comments to the surgeons. It is expected to improve the observation of blood circulation or the discrimination of normal and tumorous tissues, which is important for determining the area of ablation. It is impossible to examine them through conventional HDTV system and sometimes the viewers cannot understand the real meaning of the operation. This means that the multispectral video is also advantageous in the educational video of surgical operations.

There are other promising application areas of multispectral video according to the participated dermatologists; (a) The observation of circulatory disorders, such as arterial sclerosis, collagen disease, and Raynaud's disease, (b) The condition and the area of inflammation will be clearly depicted in inflammatory diseases, ex., toxic erythema, eczema, urticaria, and inflammatory keratosis, (c) The diagnosis of Paget's disease and extramammary Paget's disease, types of the intraepidermal carcinoma, in which the subtle color variation is important to determine the extent of tumor, (d) Diagnosis of solar keratosis, precancerous skin disease, which depends on the color appearance of dark or light tan, pink, and red colors. The verifications of these potential applications are the issues for future investigation.

6. Conclusion

Through the objective and subjective evaluation of the multispectral video comparing with C-3B system by the expert dermatologists, the benefit of natural color reproduction has been

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clearly shown. It significantly improves the reproduction of faint reddish colors, where the reproducibility is insufficient in the conventional video. The reproduction of color difference is also superior, resulting the reduction of oversight happened in the C-3B case. The visual information provided by the NV-6B system is almost enough for telemedicine applications.

In the experiments presented in this paper, there were limitations as to the environmental condition and operational procedure, and there remains several issues for further investigation; the effects of surrounding colors, the observer metamerism, and the selection of color chips in color matching with skin lesions. There are other subjects to be addressed; the use of a 3-primary display with proper characterization, the image compression issues, and the influence of environmental setting. Downscaling the system and simplifying the operation are also essential for the practical use.

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