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Development of the Stool Color Card for Early Detection of - Biliary Atresia using Multispectral Image

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Abstract

The stool color card for early detection of biliary atresia have been developed using multispectral images of stools of newborns. Color and its spectra were measured and analyzed spectrally first in the world and used to design the stool color card. Representative texture was selected by medical specialists from captured multispectral images and spectral information of the images was replaced and edited according to the result of spectral and chromaticity analysis. The stool color card was placed within the Maternal and Child Health Handbook that was distributed to all pregnant women by their respective local government according to the Maternal and Child Health Law in Japan.

Introduction

Biliary atresia (BA) is characterized by a complete inability to excrete bile from the liver to the duodenum as a result of etiology-unknown sclerosing inflammation of the extra- and intrahepatic bile ducts in early infancy [1].

It is the most frequent hepatic cause of death in early childhood. The incidence rate in the USA, the UK, France, Japan, Taiwan and French Polynesia was 0.7, 0.6, 0.5, 1.0, 1.85–1.70 and 2.9 in 10,000 live births, respectively [2-4].

The Kasai procedure (KP) commonly is used as a first-line treatment for all types of BA. Early diagnosis followed by proper KP is essential for the improvement of long-term prognosis for patients with BA. It is increasingly accepted that KP before 30 days of age significantly improves native liver survival rate [1]. According to the recent Japanese Biliary Atresia Registry, however, about 40% of BA patients were operated on at ≤ 60 days of age until 2012 in Japan. "Home-based screening" for early detection of BA is required. It has three main clinical features: pale-pigmented stools, prolonged jaundice beyond 14 days of age and dark urine. Pale-pigmented stools appear within the first 2 months of birth for most patients [1]. Home-based screening using stool color card (SCC) is easier and more cost-effective than office-based screening; however, it may cause some difficulties for families in case of stools with intermediate colors. Screening with SCC in Japan has been implemented in Tochigi Prefecture since 1994. The concept of SCC was introduced from Japan to Taiwan and resulted in nationwide screening with SCC for the first time in Taiwan in 2004, followed by Japan in 2012.

Early SCC was designed and produced via analog image processing (i.e. pictures were taken by film camera and developed chemically, subjective color proofing was conducted with process of trial and error by medical doctors and print engineers). This made it quite difficult to analyze stool's color, modify patches on SCC and control color quality in printing process. Figure 1 shows patches of a precious edition of SCC distributed in Tochigi prefecture since 1994. Textures and its image quality, especially zooming ratio and resolution, varied among patches which affects to observer's assessment.

In this paper, Spectral reflectance and chromaticity of stool of newborns were measured using spectrometer and captured their multispectral images to modify SCC and find new diagnostic criteria quantitatively. First, measured spectral reflectance was analyzed by calculating principal components to show that stool of BA patients can be distinguished from normal using spectral information. Second, CIE-XYZ trichromatic values and CIE-Lab values were calculated from measured spectra and plotted on chromaticity diagram to decide color of patches on SCC. Next, a representative texture was selected by medical specialists from captured multispectral image and their pixel values corresponding to spectral reflectance were replaced and edited based on the results of the spectral and chromaticity analysis. Finally, new designed SCC was printed according to color management procedure using ICC profiles. Spectral reflectance is independent of illumination type (e.g. incandescent lamp, fluorescent lamp, LED lamp, daylight, et al.), which makes us possible to analysis in relate to biochemical. On the other hands, CIE-Lab color space is widely acceptable in printing industry although it depends on illumination spectrum.

Measurement and analysis

Measurement spectral reflectance and chromaticity of newborn's stool

Measurements were conducted in National Center for Child Health and Development in cooperated with hospital division, and Tochigi Medical Center. 196 samples of newborn's stool were captured as six-band images [5] under two lighting geometries (i.e. diffused light for reducing illumination shade and a directional light for accentuating texture). Digital SLR cameras (D200 and D700, Nikon) were used as image sensors. A color chart (color patches of x-rite color checker TM were cut to be smaller and reshaped) was placed beside a sample and captured with every samples to verify estimated spectral reflectance and calibrate spectral sensitivities of the image capturing system. Spectral radiance of 10 points of each sample were measured using spectroradiometer (SR-3, Topcon).

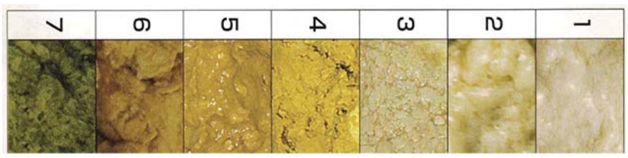

Figure 1. Patches of a precious edition of SCC

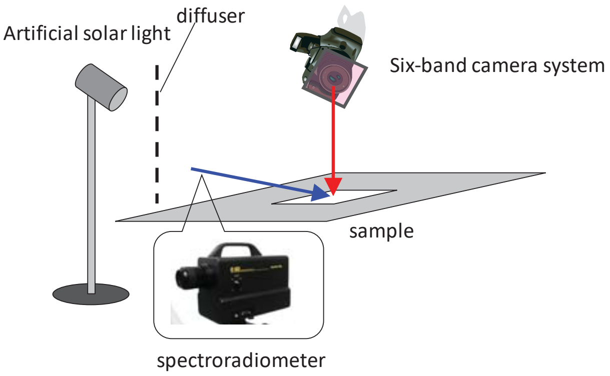

Figure 2. Geometry of measurement and image capturing.

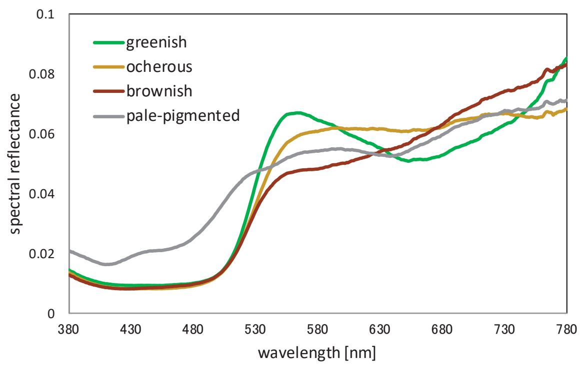

Figure 3. Averaged spectral reflectance.

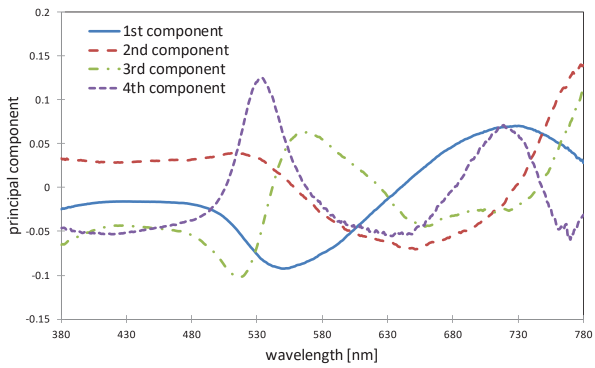

Figure 4. First four principal components.

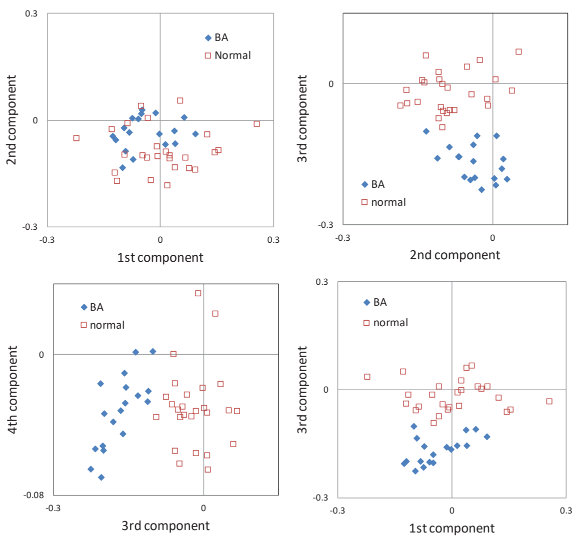

Figure 5. Distributions on hyper-plane.

Artificial solar light (XELIOS, SERIC Ltd) was used for illumination. 48 spectral data (including 18 samples of BA and cholangitis) were selected for analyzing principle component and chromaticity. The geometry of spectral measurement and image capturing and a captured image are shown in Fig. 2. Wavelength range was 380 nm to 780 nm with 1 nm interval.

Spectral analysis

Selected 48 samples were categorized into four types of color: greenish, brownish and ocherous as normal (corresponding to images No. 4-7 in Fig. 1), and pale-pigmented as BA (corresponding to images No. 1 -3 in Fig. 1). Averaged spectral reflectance of each color category are shown in Fig. 3. It seems to be categorized statistically.

Principle components were calculated using 28 reflectance of normal patient's samples. Cumulative proportions of first four, six and nine are 98.26 %, 99.36 % and 99.90 % respectively. This result indicates that at least four components are required for representing spectral feature of nowborn's stool. Let us consider the case of first four principle components below. First four principle components shows in Fig. 4. Using this result, 48 spectral reflectance including 18 of BA were projected onto the space defined using principal components of 1st and 2nd, 2nd and 3rd, 3rd and 4th, and 1st and 4th (Fig. 5). These results shows that the 1st and 3rd components seems to be correlated with BA: all samples of BA have negative value corresponding to the 3rd component. This shows the trend that reflectance in wavelength shorter than 540 nm relatively increases and stool color of BA patient becomes pale-pigmented in progression. Figure 6 shows a measurement result of spectral reflectance of a patient after surgery. Reflectance in wavelength range 540 and shorter have increased and come close to the distributions of normal stools. Figure 7 shows another cases compared before and after surgery on the space spanned by the 1st and 3rd components. Concerning with the 1st component, values were changed from positive to negative before and after surgery. This indicates a possibility of the 1st component to be a barometer of recovery of liver function.

Chromaticity analysis

CIE-Lab values of measured spectra data were calculated and plotted onto a*-b* color plane (Fig. 8). BA (square) and normal (cross) seems to be separate, and cholangitis (triangle) were distributed between BA and normal.

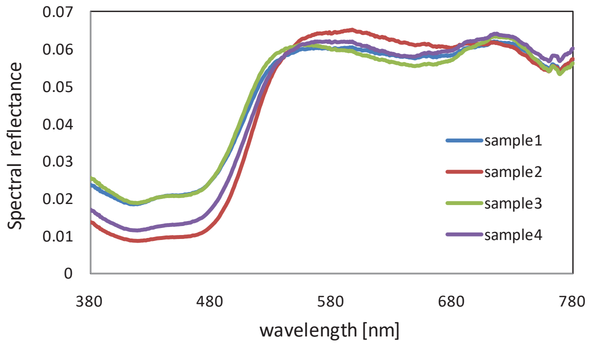

Figure 6. Spectral reflectance of a patient after surgery.

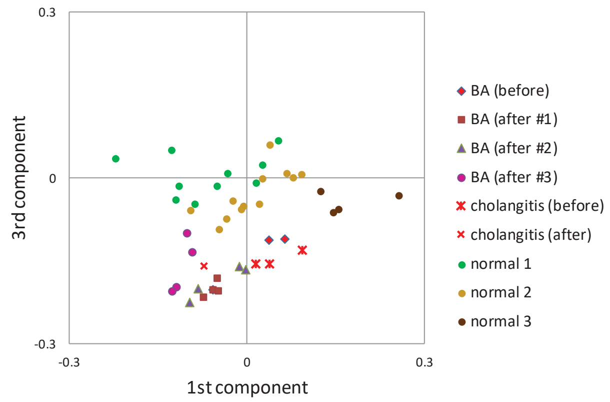

Figure 7. Distribution on the plane spanned by the 1st and 3rd components.

Designing patches of stool color card

New stool color card was designed using multispectral images as follows:

Step. 1: Capture six-band images and reproduce its accurate color on a LCD monitor.

Step. 2: Select an image as a representative texture.

Step. 3: Select ten representative colors of stool by medical specialists (including doctors) and extract six-band pixel values of each representative color.

Step. 4: Calculate CIE-Lab values of selected each images

Step. 5: Replace pixel values of the representative image with extracted pixel values with keeping brightness of each pixel to generate ten patched images.

Step. 6: Reproduce color of generated ten images and convert each image to CIE-Lab and RGB images.

Step. 7: Select three representative image as BA and four representative image as normal from selected ten images by medical specialists.

Step. 8: Adjust their color by modulating six-band pixel values according to suggestions of medical specialist with keeping analytical trend shown in Fig. 8.

Step. 9: Generate seven color patches by averaging each representative image.

Ten images selected in step.3 and their averaged spectral reflectance are shown in Fig. 9. Images of No. 2, 3, 8 and 9 correspond to BA. Fig. 10 shows seven patches finally designed. Patches corresponding to BA are No. 1 to 3 and patches corresponding to normal are No. 4 to 7. Color of stool between No. 3 and 4 is suspected with BA.

Summary

Color saturation control method by changing SPD of illumination was proposed. Color enhancement factor was newly introduced, which enables us to easily control SPD of illumination while keeping metameric white by varying few parameters. In experiments, the proposed method was implemented on a multi-color LED lighting system. Color shift variations were evaluated using color patches of a color chart and possibilities for applying this method to virtual restoration of cultural heritage like discolored old paints or wood-block prints were shown.

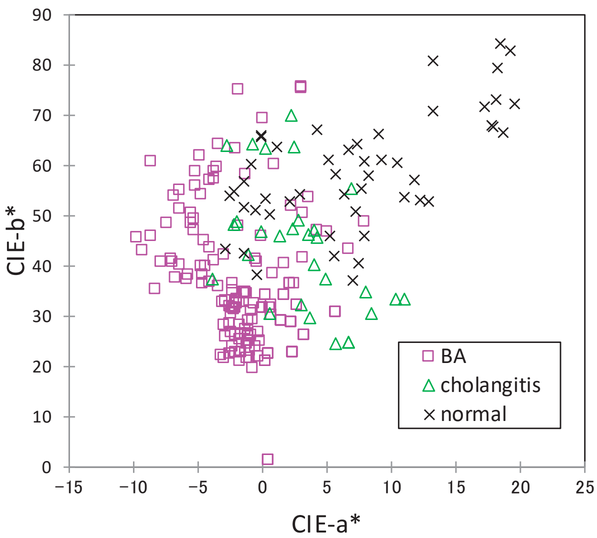

Figure 8. Distributions on CIE a*-b* plane.

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Author Biography

Masaru Tsuchida received the B.E., M.E. and Ph.D. degrees from the Tokyo Institute of Technology, Tokyo, in 1997, 1999, 2002, respectively. In 2002, he joined NTT Communication Science Laboratories, where his research areas included color science, three-dimensional image processing, and computer vision. His specialty is color measurement and multiband image processing. From 2003 to 2006, he worked as a researcher at the National Institute of Information and Communication Technology (NICT) for the "Natural Vision" project.

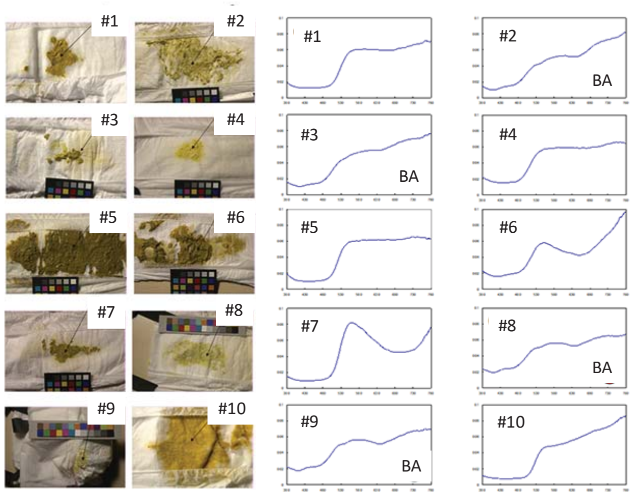

Figure 9. Selected ten images and their averaged spectral reflectance.

Figure 10. Current stool color card distributed in Japan. (No. 1 to 3: BA, No. 4 to 7: normal).