1. Introduction

Cultural heritage objects are threatened with the destruction caused by decay or damage due to aging, unpredictable natural and man-made disaster such as fire, earthquake, and war. Deterioration or disappearance of any cultural or natural heritage constitutes a great loss to all nations of the world. Due to the precious nature of cultural heritage, it is necessary to choose a proper solution for their preservation and conservation. There are various methods nowadays that can record different information of cultural heritage, such as color, shape, spectral reflectance, etc. Such recording methods also refer to digital archiving which has been gathering increasing interests of researchers in the past few years. The motivation is to ensure that future generations could inherit and admire these amazing works.

A variety of technologies have been applied to the preservation of cultural heritage. Photography is one of the leading techniques which provides a new frontier to the field of archiving. However, due to the limitation of the technique development in the old days, some of the archiving results cannot satisfy all the demands, especially in some exceptional scenarios. For an instance, Horyuji Kondo wall painting, which belongs to UNESCO World Heritage Site under the name Buddhist Monuments in the Horyuji Area, was photographed onto a one-to-one scale glass dry plate with multiband filters (Appearance color: Yellow, Red, Green, Blue) 85 years ago (1935). These glass-based dry plates are the only documentation material that recorded the original appearance of the wall painting during that time, but the coating layer is now fragile and sensitive to storage conditions. A calamitous fire that broke out later in 1949 which resulted in the severe damage to the wall paintings. Fortunately, the color image of the wall painting can be reproduced using the glass dry plates by a traditional technique with the negative-positive process. However, this reproducing process that is known as collotype printing, reproduces the color by a trained craftsman using the glass dry plates manually. The only evaluation criteria for the reproduction is the experience of the craftsman. This is very subjective.

Area sensor-based imaging system is widely used in the digital archiving nowadays. This technique can accomplish the image acquisition work easily and efficiently. Such imaging system offers fairly uniform light distribution, relatively high resolution and relatively accurate color rendering. However, if an area sensor-based imaging system and a linear sensor-based imaging system are compared under an identical imaging setup condition including the same theoretical imaging resolution, the light source, etc., it has some

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**Abstract**  A method for color reproduction of old glass dry plates digitized by a linear sensor camera is proposed. A high-resolution scanner based on linear sensor camera was developed for digitizing glass plates, which is beneficial for high-quality color reproduction. The color reproduction uses filter coefficient calculated from color information of multiband filters. An approach for the calculation of filter coefficient used for color reproduction is addressed in detail. The method was applied to the digitization and color reproduction of a wall painting belonging to World Cultural Heritage Horyuji Kondo, Japan. A verification experiment is conducted to evaluate the accuracy of color reproduction results. Experimental results show that the proposed method is capable of high-quality color reproduction of image details, and there is merit to using this high-resolution digitization techniques for cultural heritage.

**Keywords**: high-resolution scanning, digital archiving, color reproduction, glass dry plate, image processing.
demerits that commonly manifested as geometric image distortion and insufficient resolution. In terms of the imaging mechanism and structure feature, a line sensor-based imaging system has higher detail expressiveness and higher spatial resolving capability than an area sensor-based ones, which makes it more suitable for resolving fine details of cultural heritage. In addition, a line sensor-based camera is a better choice for recording color of cultural heritage with higher color fidelity. The most crucial point is that the line sensor-based camera has less geometrical optic problem for imaging and no issue of pixel interpolation. Since the object employed in this study is a transmissive glass dry plate, which require high resolution, a transmission-type imaging system with a linear sensor is well suited for such objects. It can also cover a bigger area which reduces the acquisition and postprocessing time.

Using high-resolution scanning technology, high-quality image acquisition of the glass dry plate is guaranteed. For high-precision color reproduction, we proposed a method for producing one color image by incorporating the color information of each filter into the multiband images. The color information of the multiband filters is based on the mathematical relationship between the spectral characteristics and different standard color spaces. The RGB information of each filter is used to calculate a parameter named as filter coefficient, which is used in color reproduction together with acquired multiband images. Additionally, a standard IT8.7/2 color chart is captured as a target object to evaluate the accuracy of color reproduction result. The influence of light intensity per filter on color reproduction is also investigated.

Therefore, in this study, a specially designed scanner was developed for the image acquisition of the glass dry plate in high resolution. On the other hand, to ensure that the true color of the wall painting was reproduced systematically and faithfully, much attention was also paid to develop a color reproduction method utilizing the information of multiband filters, which is a solution to maximize the use of the remaining documentation materials. This combination complements each other, so that we can obtain high-resolution and color-accurate digital archives.

2. Method and experiment

2.1 Image acquisition

Scanning technology used in digitally archiving cultural heritage has been developing for many years. Compared with conventional photographic technique, it can offer better uniform light distribution, higher resolution, and more accurate color. However, most conventional scanners are strict with object dimension and some of them need contact to flatten the object surface, which is a severe issue for archiving cultural heritage. Additionally, with the development of display and other output technology such as high-quality printing, increasing demands for high-resolution image and high-fidelity color reproduction have been growing rapidly. For this reason, in this study, a high-resolution flatbed scanner for digitizing large format transmissive object was designed. The scanner provides wide scanning resolution that ranges from 600-3000 dpi, and it is also capable of high-fidelity color reproduction.

All the high-resolution images were acquired by the scanning system shown in Fig. 1. The scanning system mainly includes a line sensor-based camera module, a stepping motor for driving the object stage, a white LED light source group which is well designed for high color fidelity and minimum light irradiation, and a scanner.
The frame structure. The line sensor-based camera module consists of a monochrome CMOS camera TLC-8000CL manufactured by Takenaka which has 8000 pixels for the single channel, and an Apo Rodagon-N 105mm lens with a UV-IR cut filter. The LED light source is a linear light source in which point light sources are arranged in a line. In the transmissive imaging mechanism, transmitted light with very high directionality of the light source is acquired by the camera because the light source is installed facing the camera. As a result, the image shows a clear array of point light sources. To obtain uniform transmitted light with the camera, we experimented on the optimum distance between the light source and the object and installed an acrylic resin panel in front of the LEDs. The panel made of acrylic resin served as a diffuser, and the light from the point light source is diffusely scattered between particles in the acrylic resin, so that the light emitted from the panel becomes diffuse light.

In this study, the scanner was used to digitize the object at 2400 dpi and the scanned image is 8-bit grayscale. The scanning width is around 86mm per scanning stroke. The width of the object was bigger than the scanning width. This means that it required multiple passes to scan the entire width of the object. The scanner head was moved along the length of the object then moved laterally to the next scanning position. This sequence was implemented until the whole object was scanned. The width of glass dry plates of Horyuji Kondo wall painting is 45 cm. One glass dry plate needs nine scans with a 5 cm moving interval along the sub-scanning direction for each scan. Using such a method for scanning is to make it easier to match the position during the post-image stitching process. The image stitching in this study was accomplished by photo merge function inside the Photoshop software firstly, and then adjusted manually according to the result of the stitching.

Before the scanning work, adjusting the light intensity is a necessary process. This is also required for calibrating the uneven distribution of light in image processing. Using the transmission scanning mode, the white point is defined as the light with 100% transmittance in which nothing is placed on the object stage. Additionally, the maximum pixel value of the gradation was set to around 220. The reason for this setting is to avoid causing too much image noise.

The images of the glass dry plates of Horyuji wall painting acquired by the proposed imaging system are as shown in Fig. 2. These images are copies of the original negatives taken through four filters with different extraction wavelength ranges. In this study, the glass dry plates imaged through yellow, red, green and blue filters are defined as glass dry plate black(K), cyan(C), magenta(M) and yellow(Y), respectively. The filters used in the experiment of this study are addressed in detail in the next section.

2.2 Color reproduction with filter coefficient

Fig. 3 shows the multiband filters used in this study. These filters were the same ones used to photograph the wall painting onto the glass dry plates about 85 years ago. For convenience, we name the filters as filter 1, 2, 3 and 4, where the corresponding glass dry plates are named as glass dry plate black(K), cyan(C), magenta(M) and yellow(Y), respectively.

The calculation of the filter coefficient needs color information of the color filters, which includes spectral transmittance, XYZ value and RGB value of each filter. A spectrophotometer was used to measure the spectral transmittance of four-color filters. The spectrophotometer is C10083M manufactured by Hamamatsu, which is capable of measuring the wavelength of 320 nm to 1000 nm. The light source is a halogen lamp manufactured by Sumita. The measured spectral transmittances of the filters are shown in Fig. 4.

The CIE 1931XYZ color space13) was established by the International Commission on Illumination (CIE) in 1931.
which defined 3 standard primaries named X, Y and Z. The color space can be a quantitative link between distributions of wavelength in the electromagnetic visible spectrum, and physiologically perceived colors in human color vision. Notably, the XYZ color space is an independent color space, and the related mathematical relationships are useful tools when encountering color issue in many applications such as using digital cameras, displays and scanners.\(^{14}\)

Once we have spectral information of the filters, according to the CIE's color matching functions \(\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)\), the XYZ values can be calculated by the following equation. The wavelength range is 400 nm to 700 nm named visible range.

\[
X = k \sum_{400}^{700} S(\lambda)\bar{x}(\lambda)R(\lambda)\Delta\lambda \\
Y = k \sum_{400}^{700} S(\lambda)\bar{y}(\lambda)R(\lambda)\Delta\lambda \\
Z = k \sum_{400}^{700} S(\lambda)\bar{z}(\lambda)R(\lambda)\Delta\lambda
\]

Where \(k\) is a constant and can be expressed by the following equation.

\[
k = \frac{100}{\sum_{400}^{700} S(\lambda)\bar{y}(\lambda)\Delta\lambda}
\]

In this study, we assume that output devices are compliant with sRGB\(^{16}\), which is generally used for many common electronic output devices. Then, to transform from XYZ to sRGB (with \(D_{65}\) white point), the matrix transform is used as shown in Eq. (3).

\[
\begin{bmatrix}
    R_{sRGB} \\
    G_{sRGB} \\
    B_{sRGB}
\end{bmatrix} = \begin{bmatrix}
    3.2406 & -1.5372 & -0.4986 \\
    -0.9699 & 1.8758 & 0.0415 \\
    0.0557 & -0.2040 & 1.0570
\end{bmatrix} \begin{bmatrix}
    X \\
    Y \\
    Z
\end{bmatrix}
\]

After converting from XYZ to sRGB, gamma correction is applied using the following Eq. (4) and output in 8-bit values. \(\gamma = 2.4\) is applied to Eq. (4).

\[
r = floor[(1.055 \times R_{sRGB}^{1/\gamma} - 0.055) \times 255 + 0.5] \\
g = floor[(1.055 \times G_{sRGB}^{1/\gamma} - 0.055) \times 255 + 0.5] \\
b = floor[(1.055 \times B_{sRGB}^{1/\gamma} - 0.055) \times 255 + 0.5]
\]

The CIE 1976 \(L^*a^*b^*\) color space\(^{17}\) was defined by the CIE in 1976. \(L^*\) indicates lightness, \(a^*\) is the red or green coordinate, and \(b^*\) is the yellow or blue coordinate. More specifically, along the \(a^*\) axis, +\(a^*\) direction represents a shift toward red; along the \(b^*\) axis, +\(b^*\) direction represents a shift toward yellow. The center \(L^*\) axis shows \(L^* = 0\) (black or total absorption) at the bottom.

The XYZ value can be converted to the \(L^*a^*b^*\) value using the equations as follows:

\[
L^* = 116f(Y/Y_n) - 16 \\
a^* = 500[f(X/X_n) - f(Y/Y_n)] \\
b^* = 200[f(Y/Y_n) - f(Z/Z_n)]
\]

where,

\[
f(X/X_n) = \begin{cases}
    (X/X_n)^{1/3}, & X/X_n > 0.008856 \\
    7.787(X/X_n) + 16/116, & X/X_n \leq 0.008856
\end{cases}
\]

\[
f(Y/Y_n) = \begin{cases}
    (Y/Y_n)^{1/3}, & Y/Y_n > 0.008856 \\
    7.787(Y/Y_n) + 16/116, & Y/Y_n \leq 0.008856
\end{cases}
\]

\[
f(Z/Z_n) = \begin{cases}
    (Z/Z_n)^{1/3}, & Z/Z_n > 0.008856 \\
    7.787(Z/Z_n) + 16/116, & Z/Z_n \leq 0.008856
\end{cases}
\]

\(X, Y, Z\) describe the color stimulus considered and \(X_n, Y_n, Z_n\) represent a specified white reference illuminant condition. The equations for calculating the CIE XYZ, sRGB and CIE 1976 \(L^*a^*b^*\) values are addressed above. The obtained color information of 4 filters is shown in Table 1.

When the multiband imaging technique is applied to an object, \(m\) spectral images of the object can be obtained in correspondence with \(m\) filters with specific wavelength range respectively. For reproducing the color of the wall painting, in this study, we proposed a color reproduction method using filter coefficient to synthesize...
one color image by incorporating the color information of each filter into the multiband images.

Let \( r(i), g(i), b(i) \) be the RGB value of the \( i \) th filter, and let \( r_p(i), g_p(i), b_p(i) \) be the ratio of each channel to the total channels in RGB of each filter respectively. Since a total of four filters were used in this study, the value of \( m \) is 4. Then we have following equations:

\[
\begin{align*}
 r_p(i) &= \frac{r(i)}{r(i) + g(i) + b(i)} \\
 g_p(i) &= \frac{g(i)}{r(i) + g(i) + b(i)} \\
 b_p(i) &= \frac{b(i)}{r(i) + g(i) + b(i)}
\end{align*}
\]  

(7)

Now we know the ratio of each channel to the total channels in one filter, then we can calculate the ratio of each channel in this filter to the corresponding channel in all filters. If we define this ratio as, \( r_f(i), g_f(i), b_f(i) \), we can obtain:

\[
\begin{align*}
 r_f(i) &= \frac{r_p(i)}{\sum_{i=1}^{m} r_p(i)} \\
 g_f(i) &= \frac{g_p(i)}{\sum_{i=1}^{m} g_p(i)} \\
 b_f(i) &= \frac{b_p(i)}{\sum_{i=1}^{m} b_p(i)}
\end{align*}
\]  

(8)

The \( r_f(i), g_f(i), b_f(i) \) here is named as filter coefficient.

The filter coefficients are used to calculate with the pixel values of the acquired multiband monochromatic images to obtain the corresponding channel values of the wall painting. If we define the monochromatic image as \( V(i) \) scanned with the \( i \) th filter, and define the calculated corresponding channel value as \( V_r, V_g, \) and \( V_b \), we have following equations:

\[
V_r = \sum_{i=1}^{m} V(i) \cdot r_f(i)
\]

(9)

Through the calculation in Eq. (9), the R, G, B components of the reconstructed color image can be obtained, and the pixel matrix for each component can be created. In a RGB image, each pixel can be represented by a vector \((R, G, B)\) that has three values for the three primary color channels. To visualize the reconstructed color image, the three-dimensional vector is used for representing the reconstructed RGB image as \( V_{\text{recon}} = [V_r, V_g, V_b] \).

Table 2 shows the calculated filter's RGB value, filter's RGB ratio and filter coefficient, respectively.

### 2.3 Evaluation of color reproduction by the proposed method

The mechanism and the related equations for color reproduction are addressed in detail. But how do we verify that the reproduced color is correct or accurate? A reference for checking the accuracy of reconstructed result is necessary.

A color reference chart is commonly used to evaluate the color reproduction accuracy of a digitization procedure. The color chart is intended for color comparison or measurements. It is used for checking the color reproduction accuracy of and color management. Typical example charts are the IT8.7/2 and Color checker charts. These are flat physical objects with different color samples. A reference for checking the accuracy of reconstructed result is necessary.

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The accuracy and effectiveness of the proposed system was quantitively evaluated using an IT8.7/2 color chart. Firstly, the chart was digitized by the proposed imaging system with the same type of four-color filters used for
photographing the original wall paintings. Then, the acquired chart images were processed with the proposed method to reconstruct its color. Lastly, the reconstructed color image was used to calculate the color difference to evaluate the accuracy of color reproduction.

The chart images scanned with the four-color filters were obtained using the proposed high-resolution scanner in reflective mode. Fig. 5 is the schematic representation of the scanner. The scanner consists of a monochromatic line CMOS camera unit as the one described in previous section, a flat-bed frame and a white LED light source which can focus the illumination at the target region using a cylindrical lens. Additionally, a UV-IR cut filter was used on the camera lens since only the visible light range is involved in this study. The scanning conditions used for acquiring the images of the reference color chart were set to mimic the conditions during the initial photographic documentation of the wall paintings taken 85 years ago.

After the image acquisition of IT8.7/2 color chart, the obtained images were used to rebuild its color using the proposed method.

Various well-known formulas for calculating color difference (Delta E) were established based on device-independent color spaces. The CIE1976 color difference formula\(^{(19)}\) is one of the most widely used in related fields since the formula provides high accuracy and computational simplicity.

The color difference is calculated based on the CIE1976 color difference formula in Eq. (10):

\[
\Delta E_{ab} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad (10)
\]

where the colors are represented in CIE L’a’b’ color space; \(L_2^*, a_2^*,\) and \(b_2^*\) are the actual values of the colors measured from each color patch and \(L_1^*, a_1^*,\) and \(b_1^*\) are the reference values of the colors provided by the chart manufacture.

The calculated data and detailed analysis would be discussed in the next section (Section 3).

### 2.4 Experiment for light amount settings

Moreover, the four-color filters have different light transmittance attributes, which can cause the acquired images to show different brightness. Therefore, it is necessary to adjust all the images to be at same level. However, if the images are acquired under low light conditions, the adjustment may cause a lot of image noise that affects the color reproduction. An experiment was conducted to investigate the effect on color reproducibility due to the difference in exposure adjustment for each filter in the imaging procedure. Table 3 shows the lighting conditions and setting methods used in the experiment. When the scanning of the color chart was conducted as shown in Fig. 5, the filters were changed in order depicted in the figure. There were three methods employed in adjusting the amount of light for each filter: 1) changing light intensity; 2) changing lens aperture; and 3) changing camera sensitivity. Before any actual scanning, all devices were set to factory settings. These three methods were used individually or in combination to create three different conditions for adjusting the light intensity. For condition 1, the light amount of filter 1 was adjusted by changing light intensity only. When the value of sensor response comes to the reference value shown in Table 3, the adjustment would be accomplished. The scan with the rest of filters would follow the above setting without

| Light amount of each filter | Condition 1 | Condition 2 | Condition 3 |
|-----------------------------|-------------|-------------|-------------|
| Reference value for sensor response (Range from 0 to 255) | Filter1: 220 | Filter1−4: 220 | Filter1−4: 220 |
| Auto | Filter2−4: 220 | Filter2−4: 220 |

| Adjustment method | Light intensity and camera sensitivity |
|-------------------|---------------------------------------|
| Light intensity   | Camera sensitivity                     |
any adjustment. For condition 2, the adjustment for each scan with each filter were performed as what was described in condition 1 at first. During the adjustment, if the value of sensor response cannot fit the reference value, then the lens aperture would be changed to match the reference value. For condition 3, the light amount of each filter was adjusted by changing the camera sensitivity only.

### 2.5 Image registration

For restoring the color image of the wall painting in the case of this study, the initial step is digitizing the four glass-based dry plates. Then, the image registration was performed on the images which is processed and ready to be overlapped into a color image. In order to accomplish the image registration, feature point detection and feature matching is necessary. Various feature detection techniques and algorithms have been developed in the field of computer vision\(^{20}\). In addition to some widely used feature detection methods such as Scale-Invariant Feature Transform (SIFT)\(^{21}\), there are many methods for specific application and scenario. For instance, Damon M. Conover showed a technique for automatic registration and mosaicking of technical images of old master paintings\(^{22}\). The technique can provide accurate alignment of a variety of types of images, even when content differences are present.

However, for the registration of the images of the wall painting in this study, it is hard to make use of such technique. On one hand, the lack of equivalent information in each monochromatic image or channel complicates the registration process; on the other hand, the test samples used in the literature all have a standard or a color image of the original object, which makes the point-based registration algorithms applicable. The wall paintings of Kondo Horyuji Temple no longer exist due to the damage caused by fire, therefore it is impossible to acquire any type of image of the original objects.

Hence, we decided to fulfill this process by making use of the proposed imaging system. With support of the high-resolution imaging system used in this study, the acquired images are detailed enough to find feature points manually. So, a total of 11 feature point pairs is selected from the entire image area. Then, the affine transformation is conducted to accomplish the image registration.

Affine transformation is composed of translation, scaling, homothety, similarity transformation, reflection, rotation, shear mapping, and compositions of them in any combination and sequence\(^{23}\). If we set \(X\) and \(Y\) as affine spaces, since the combination of several transformations is obtained as one linear transformation, then every affine transformation \(f: X \rightarrow Y\) can be represented as \(x \mapsto Ax + b\), where \(A\) is a linear transformation on \(X\) and \(b\) is a vector in \(Y\). Then affine transformation can be described as shown in Eq. (11):

\[
\begin{pmatrix}
  y \\
  1
\end{pmatrix}
= \begin{bmatrix}
  A & b \\
  0 & 1
\end{bmatrix}
\begin{pmatrix}
  x \\
  1
\end{pmatrix}
\tag{11}
\]

Since it is a transformation matrix, the equation is equivalent to the following:

\[
y = Ax + b
\tag{12}
\]

which is called affine transformation matrix.

### 3. Result and discussion

#### 3.1 Color reproduction accuracy

The color reproduction of the IT8.7/2 color chart based on the proposed method with three scan settings is shown in Fig. 6. Basically, the allowance for color difference should be judged by the agreement between the relevant parties, and acceptable Delta \(E\) values may vary greatly depending on the exact applications and

![Condition 1 (\(\Delta E_{ab}^*<2.32\))](image1)

![Condition 2 (\(\Delta E_{ab}^*<2.22\))](image2)

![Condition 3 (\(\Delta E_{ab}^*<4.73\))](image3)

**Fig. 6.** Color reproduction results under the three scanning conditions.
environment; the Delta E values listed in 'Example of the allowance by color' are valid universally at ISO regulation or in a variety of industries\(^{24}\). According to the Delta E values and its corresponding description, the Delta E of condition 1 and condition 2 belong to Grade A color tolerance, which can be considered as the same color in general; while condition 3 is a Grade B color tolerance, it means the color difference of this level may catch the attention of relevant skilled practitioners.

Comparing the results of condition 1 and 2 in Fig. 7, it can be found that the coverage of the patch with good reproduction result is similar. This indicates that the adjustment of light amount for each filter does not affect the result of color reproduction significantly. While comparing condition 2 and 3, both of them were adjusted to make the light amount of each filter uniform but in different ways. The adjustment of the sensitivity of camera sensor leads to a larger color difference.

Based on this analysis, it was found that the way of adjusting the light amount in correspondence with each filter can affect the accuracy of color reproduction using the proposed method. Among three adjustment methods, condition 2 gives the best result of color reproduction.

### 3.2 Color reproduction result of the wall painting

The proposed method is used to digitize the dry glass plate negatives of the Horyuji Kondo wall painting, which belongs to UNESCO World Heritage Site under the name Buddhist Monuments in the Horyuji Area. The digital archiving of the plates was performed by the Advanced Imaging Technology Lab at Kyoto University in Japan in 2015. Since Horyuji Kondo wall painting no longer exists and there is less authoritative literature for quantitatively evaluating the quality of the reproduction, in this study we just list the reconstructed color image (Fig. 9(b)) and a photo of a replica of the wall painting drawn by a professional painter before it was burned down (Fig. 9(c)), and then have a rough visual comparison of the reconstruction result.

As mentioned previously, the light amount in correspondence with each filter can affect the accuracy of color reproduction, so we needed to adjust the brightness of multiband images properly before applying the proposed color reproduction method. Fig. 9(a) shows the positives of the negatives shown in Fig. 2, which are adjusted with proper brightness setting and available for reproducing color with the calculated filter coefficient. In this study,
the negative-positive process was accomplished by a color inversion method available in Photoshop. Fig. 9(b) shows the reproduced color image of the wall painting using the proposed method. Finally, Fig. 10(a) shows the stitched image of the wall painting.

Several regions of interests (ROI) shown in Fig. 10(b)-(d) were enlarged show the level of detail that can be achieved from the high-resolution scans and the color reproduction of details. A comparison between the 2400 dpi image acquired in this study and the 300 dpi image acquired by conventional commercial scanner is conducted (Fig. 10(b')-(d')). The size of each ROI is approximately 5mm × 5mm. It can be observed that the 2400 dpi images can represent fine outlines and colors even with a magnified view of more than 10 times larger than its actual size. The enlarged images also demonstrate that the color reproduction is well accomplished without misalignment or displacement issue.

From the above results, the high-definition color reproduction for Horyuji Kondo wall painting is accomplished. However, it is difficult to set a conclusion that the color reproduction result is completely accurate. Because all the conditions and settings for the photograph used in this study are based on the limited amount of relevant literature found in historical records. The attempt for estimating and representing the photographing condition of such a precious cultural heritage could be a subject of research in the future.

4. Conclusion

In this paper, a line sensor camera-based digital archiving method for high-precision color reproduction of traditional glass dry plate is proposed and experimentally verified. The experimental equipment used in this study, a high-resolution scanner for digitizing large format transmissive object, was carefully designed and implemented. The acquired images demonstrate that the imaging system is capable of high-precision image acquisition. With support of high-resolution imaging system, image registration can be accomplished simply. Because the glass dry plates were scanned at a very high-resolution of 2400 dpi, even though the acquired images are monochromatic, feature points can be selected by the naked eye. As a result, it is possible to perform accurate alignment and to eliminate misalignment and color blur. An approach for recovering color information of Horyuji Kondo wall painting using the filter coefficient is addressed in detail. A spectrophotometer is employed to measure the spectral transmittance of the filters that is used to acquire further color information including XYZ value and RGB value of each filter. These acquired color information are then utilized to calculate the filter coefficient used in the color reproduction of the wall painting. On the other hand, to verify that the proposed method is correct and effective is also a vital issue. We used a standard IT8.7/2 color chart with known color information as a scan object in the experiment to verify the correctness of reproduced color. The results showed that the proposed method can provide good accuracy in color reproduction that belongs to grade A color tolerance. The digitization and color reproduction result of the wall painting also indicates that the proposed method is capable of high-quality image acquisition and color reproduction even in image details. The application to the real cultural heritage indicates the great potential of the proposed method to digitize similar kinds of precious documentation material with high-quality color. Using the method presented in this study, it is possible to archive them with high resolution, high color fidelity and less geometric distortion issue.

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