Discovery and Extraction of Surface Painted Patterns on the Cultural Relics Based on Hyperspectral Imaging

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Abstract. Hyperspectral imaging, which can non-invasively acquire image and spectrum information on the surface of cultural relics is an efficient and scientific support for heritage conservation. This paper proposed a method that made good use of the imaging results of the hyperspectral system in the infrared band, and used data processing and image processing techniques to enhance and extract the painted pattern on the No.2 Qin Bronze Chariot. The results show that the method can obtain a relatively complete digital image of the painted pattern, which can provide favourable support for the further research and application of the No.2 Qin Bronze Chariot.

1. Introduction
Bronze, as one of the symbols of ancient Chinese civilization, has a high and irreplaceable historical research value. The No.2 Qin Bronze Chariot unearthed from the Emperor QinShihuang’s Mausoleum site has rich and beautiful painted patterns, which enrich data for the study of the politics, economy and burial customs in Qin Dynasty [1]. However, due to the collapse of the tomb, the bronze chariot was buried for a long time and the painted patterns on the bronze chariot was severely damaged. Therefore, the restoration and protection of its patterns is imminent. But, in order to ensure the integrity of the cultural relics and the accuracy of the information, the sampling analysis or obtaining information by visual inspection is no longer suitable for our acquisition of cultural relics information.

Hyperspectral imaging which developed from the field of remote sensing has great applications in agriculture, medicine, energy [2-4] due to its large spectral range and high spectral resolution. Hyperspectral imaging captures hundreds of images in narrow contiguous spectral bands and acquire data containing spatial image and spectral curve [5].

In recent years, thanks to its non-contact operation and high-efficiency detection, hyperspectral imaging technology has become one of the popular non-destructive testing technologies for cultural relics protection. It has good support in the identification of unknown materials, the discovery of hidden information and image enhancement. For instance, Grabowski et al. [6] designed an algorithm for automatic pigment identification based on hyperspectral data. Shi et al. [7] found a few modification traces on the Empress Dowager Chongqing’s 80th birthday 1 by taking advantage of mineral pigments’ special properties in the infrared band. Sun et al. [8] proposed a method to evaluate the flaking degree of murals at the Mogao Grottoes automatically. However, hyperspectral imaging

1 The Empress Dowager Chongqing’s 80th birthday: A famous Chinese painting by Yao Wenhan.
techniques are rarely used in study of painted patterns on the bronzes. This experiment used hyperspectral data and a series of complex data processing processes to extract the damaged patterns on bronze chariot.

2. Material and methods

2.1. Experimental equipment and data collection

The experimental data were captured by a hyperspectral imaging system (Fig.1), which consisted of a hyperspectral imaging camera, a mobile platform, two tungsten lamps and a computer. The hyperspectral camera’s spectral range is near-infrared region (900nm-1700nm) with a spectral resolution of 3.3 nm. Its other characteristics were shown in Table 1.

| Parameters                      | N17E    |
|---------------------------------|---------|
| manufacturer                    | specim  |
| Spectral range(nm)              | 900-1700|
| Spectral sampling(nm)           | 3.3     |
| Number of bands                 | 256     |
| Number of pixels along FOV      | 320     |
| Dynamic Range(bit)              | 12      |

The computer controls the rotation speed, rotation angle and exposure time of the hyperspectral camera through mobile platform and program. The tungsten lamps provide the uniform light source needed for the experiment, which allows the system to obtain higher quality spectral data. In this experiment, the camera was 0.3 m away from the sampling area. After capturing the qualified experimental data, the hyperspectral imaging system obtained the standard white reference data (obtained by a specific white calibration board with high reflectance) and the dark current noise data (obtained by covering the camera with a lens cap) in the same environment, which would be used in dark-white correction.

2.2. Experimental materials and problem description

The “Kuilong” patterns² painted on the outside of the main chariot are chosen as the research data since it appears frequently on the chariot [9]. Six “Kuilong” patterns were captured by hyperspectral system and each “Kuilong” patterns on the chariot is approximately 10 cm long and 7 cm wide (Fig.2).

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² “Kuilong” pattern: A traditional decorative pattern that is very common in Chinese bronzes. “Kuilong” is a creature in Chinese mythology that looks like a Chinese dragon with only one foot.
The six “Kuilong” patterns have the information about three types of damages that exist on the No.2 Qin Bronze Chariot’s painted patterns. These three types of damage are described as following.

- Flaking of the pigment layer. Since the bronze chariot was painted by the “stacking drawing method” [10], some of its pigment layers were flaking off under the influence of external force and structural changes.
- The surface was covered by bronze rust or other mixtures.
- The colour of pattern changed.

2.3. Experimental methods and data processing flow

Fig. 3 illustrates the data processing flow of the proposed method. At first, for reducing the noise and environmental effects, the original data need to be preprocessed with dark-white correction, data screening, principal component analysis (PCA) and inverse principal component analysis. Secondly, the steps of pattern extraction are as follows: 1) Select a band that shows the clearest image of the missing edge. 2) Perform an image correction to make the patterns captured by the hyperspectral imaging system and digital camera consistent. 3) Enhance the pattern’s edge in the hyperspectral image, extract the visible edge from the pattern in both the hyperspectral image and ordinary picture. 4) Fuse the edge information extracted from hyperspectral image and ordinary picture.

Fig. 3 The workflow of the proposed method

3. Data processing and results

3.1. Data preprocessing

To reduce the impacts of the ambient light and noise on the experimental data, data preprocessing is necessary. The dark-white correction is mainly used to avoid the influence of ambient light and dark current noise, and it is achieved by formula (1):

$$ P = \left( \frac{P_0 - D}{W - D} \right) \times 100\% $$

where $P_0$ is the original data and $P$ is the corrected data. $D$ is the dark reference data (approximately 0% reflectance) and $W$ is the white reference data (approximately 99.9% reflectance).

Data screening removes the first 40 bands and the last 15 bands of the hyperspectral data since they have too much noise. PCA is a common method for data dimensional reduction and decorrelation [11]. After PCA, the most information (about 99.83% information) in the hyperspectral data is transferred to the first 10 principal components (PCs) (Fig. 4) and the last PCs have little useful information but high noise. The inverse PCA based on the first 10 PCs can further reduce noise, get a better spatial image and smoother spectral curve.
3.2. Pattern extraction

3.2.1. Band selection based on spectral features. The hyperspectral images captured from the near-infrared are likely to find the information that is not visible to the naked eye [7, 12]. As shown in Fig.5(a) and Fig.5(c), the “Kuilong” pattern on the No.2 Qin Bronze Chariot is incomplete, and its edge is blurry or has disappeared. The main reason for the disappearance of “Kuilong” pattern’s edge in (a) and (c) are the flaking of the pigment layer and being covered by a brown material. While, in the corresponding hyperspectral image (Fig.5(b) and Fig.5(d)), almost all of the invisible edges are completely displayed, which is of great significance for restoring the complete pattern.
3.2.2. Image correction based on Moving Least-Squares. The hyperspectral image contains the edge information that is invisible to the naked eye. Nevertheless, it loses some details due to low spatial resolution. The ordinary picture taken by digital camera is a JPG image (Fig.7 (a)) can make up some of the details. The image correction algorithm based on the Bicubic interpolation [13] and the Moving Least-Squares (MLS)[14] was used to make the location, shape and size of the “Kuilong” pattern in the ordinary digital image consistent with pattern in the hyperspectral image.

Two point sets P and Q were established on the ordinary picture and hyperspectral image, where P (Fig.7(a)) means the position of the points before the transformation and the Q (Fig.7(b)) is the position where they should be moved. The transformation function is determined by minimizing the value of the Moving Least-Squares formula (formula (2)):

$$\sum w_i |l_v(P_i) - Q_i|^2$$  \tag{2}

$$w_i = \frac{1}{|P_i - v|^2 \pi}$$  \tag{3}

where $P_i$ and $Q_i$ are the row vector, $v$ is the deformation point, $l_v()$ is the transformation function, and $w_i$ is the weighted value. Formula (3) is the weighted function, which implies that the value of $w_i$ is related to the distance between $v$ and $P_i$. By using the rigid transformation to constrain the transformation matrix, the transformation function will be acquired. The corrected result of the ordinary picture is shown in Fig.7(c). The “Kuilong” pattern’s edge on the corrected ordinary picture coincides with the “Kuilong” pattern’s edge in the hyperspectral image.

3.2.3. Edge enhancement and extraction. High-pass filter is a kind of frequency domain filter that is commonly used to sharpen images and enhance edge. Its principle is to filter low-frequency signals while passing high-frequency signals [15]. In this experiment, the high-pass filter uses a 3x3 core with a center pixel value of 8 and an external pixel value of -1. The Fig.8(a) fuses the image from the high-pass filter’s result and the 40% original hyperspectral image. It can be seen that when other information of the pattern is weakened, the edges are enhanced. The Fig.8(b) is the edge information extracted from the enhanced image (Fig.8(a)). The Fig.8(d) is the edge information extracted based on...
corrected ordinary picture (Fig.8(c)), it has a large gap from a complete pattern but has a better detail information for the tail of the pattern. Then, the edge in Fig.8(e), which fuses the edges in (b) and (d) is 48.59% more than the edge that human see at visible light. It well shows more complete composition of “Kuilong” pattern, and provides more detailed and scientific information for the experts and scholars to better study the No. 2 Qin Bronze Chariot.

Fig.8 (a) The hyperspectral image enhanced by a high-pass filter (b) The extraction of the edge in the hyperspectral image (Fig.8(a)) (c) The ordinary picture after image correction (d) The extraction of the edge in the corrected ordinary picture (Fig.8(c)) (e) The fusion of edges in Fig.8(b) and Fig.8(c)

4. Conclusion
With the advantages of non-contact, wide spectral range and large spectral resolution, hyperspectral imaging technology provides more efficient and scientific support for the detection, restoration and protection of painted bronzes. In this study, the “Kuilong” pattern on the No.2 Qin Bronze Chariot was discovered and extracted by comprehensive processing and analysis of the hyperspectral data. From the research results, on the one hand, the extracted patterns can be used for deeper research and application of the No.2 Qin Bronze Chariot; on the other hand, this research also proposed a feasible method of restoring painting pattern on bronze and proved the application potential of hyperspectral imaging technology in restoring bronze painting. In future research, the spectral information in the hyperspectral data and dozens of mineral pigments determined by researchers at the Emperor QinShihuang’s Mausoleum site museum will be used in identifying the original color of the painted pattern. It makes that possible to digitally reproduce the original looking of the No.2 Qin Bronze Chariot.

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