王塚古墳壁画の任意光源下での色彩の認識

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概要

古墳内の壁画について、これらがどのように装飾されたのかということは考古学上重要な論点になっている。通常、暗い古墳内で装飾を施すには、灯明のような灯りが必要だと想像されるが、このような光源環境のもとで豊富な色彩を正確に識別しながら描けたかについては、甚だ疑問である。我々は古墳内部の壁画装飾は、太陽光の下でのみ可能であったのではないかと考えている。

そこで本稿では、太陽光と松明光のもとでの装飾壁画の見えを再現することで、この論点に迫る。複雑な形状を持つ古墳の壁面に直接描かれた古墳や洞窟などの壁画の全体的な見えを厳密に再現するためには、壁面の三次元形状が必要不可欠である。我々は古墳内部の三次元形状と装飾のスペクトル情報を取得し、これらを用いて装飾壁画の任意光源下での見えをコンピュータグラフィックス上で再現したので、その経緯を報告する。

キーワード: 三次元モデリング・光源シミュレーション・色再現

Color Appearance Recognition of Mural in Ozuka Tumulus in Sunlight and Taper Light

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Abstract

Archaeologist have paid much attention to how ancient artists painted murals inside the tumulus. They believe that ancient painters worked inside the cave using artificial lights such as a taper. In contrast, we argue that there is a possibility that they used natural light such as sunlight.

This paper investigates whether the color difference could be recognized with a taper light, inside the dark tumulus, or not. Our approach for the investigation of color difference recognition is to accurately reproduce colored patterns painted on the wall by comparing spectrum data with 2D texture images taken by a digital camera, which are mapped on the 3D model of a tumulus. By using this technique, we successfully reproduce the appearance of mural colors under an arbitrary illumination. Our target is the Ozuka tumulus, located in the Kyushu Island, inside which the various patterns are painted using six colors.

Keywords: 3D modeling, Illumination simulation, Color appearance restoration

1 Introduction

In the research of such cultural assets as wall paintings, archaeologists have paid much attention to the appearance of the painting at that time it was created and have argued about the color recognition by reproducing the color appearance in various ways. In previous works, they analyzed the spectrum of each color or the 2D information of pictures taken by a camera [1] [2]. But we argue that the 3D shape information is essential in order to restore the whole appearance of a mural with complicated 3D shape that is painted on a wall.

We reported our research for the appearance restoration of rock carvings of the Fugoppe Cave by using its 3D shape model [3]. As we described in [3], we think ancient artists could not decorate the walls inside the tumulus at all times. If the tumulus was built with wall stones that were already decorated, we imagine that these stones were painted under the natural light of sunshine. But if the wall was decorated after it was built, we might suppose that the paintings was done under artificial light, such as light from taper. In the latter case, it is doubtful whether ancient artists could recognize their decoration by the taper light. In [3], It was argued that the appearance of carvings depended on the shade and shadow caused by the sun's position on its orbit, and we verified the possibility that the ancient artists worked inside the cave without an artificial light by choosing the optimum season and time for their working.

In this paper, we verify the same possibility focusing on investigating the recognition of colors used for wall painting under sunlight or taper light. Our target for this study is the Ozuka tumulus, a typical decorated tumulus in Kyushu.

The Ozuka tumulus is a burial mound with a square front and a round back (Figure 2), located in the town of Keisen in Fukuoka prefecture in Kyushu Island (Figure 1). It is said to have been built in the middle of the six century A.D., and has been designated as a Special Historic Site because of its brilliantly painted inside wall (Figure 3). Six colors are used for the painting, namely, red, yellow, white, black, green and gray are used for the painting[4]. These paintings are supposed to have done in commemoration of those who are buried in the tumulus, and thus they are valuable as ancient burial accessories (Figure 3).

In order to verify the color recognition, we would need to take the tumulus to pieces, and to burn a taper for light inside the cave, but these actions are impossible because they would interfere with the preservation of the tumulus. Instead in this paper, we use 3D techniques to restore the appearance of the painting in sunshine and taper light in computer graphics.

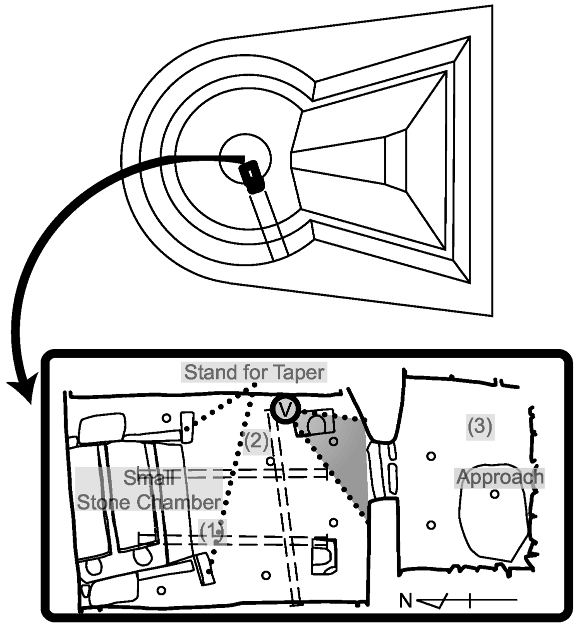

Figure 1: The projection map of the Ozuka tumulus. The lower figure is the enlarged view of the thick line area in the upper figure.

This paper is organized as follows. We describe researches similar to ours briefly because we have already explained them in [3]. Next, we explain how to accurately restore the color of texture images taken by a digital camera. After that, we show and analyze our simulation result. Then, we present the conclusion and the future work of our study. Finally, in the Appendix, we describe the exhibition of the simulation result of our research at the Kyushu National Museum.

2 Related Works

In research similar to ours, Sellers et al.[5] measured the Kitley cave in England by using an ultrasonic sensor. Beraldin restored the 3D textured model of Byzantine Crypt at Santa Cristina in Carpignano, Italy [6], which has many frescos that are preserved in good condition. Brown et al.[7] measured the frieze of the Cap Blanc in France, and Deblin et al.[8] used their data for the ar-

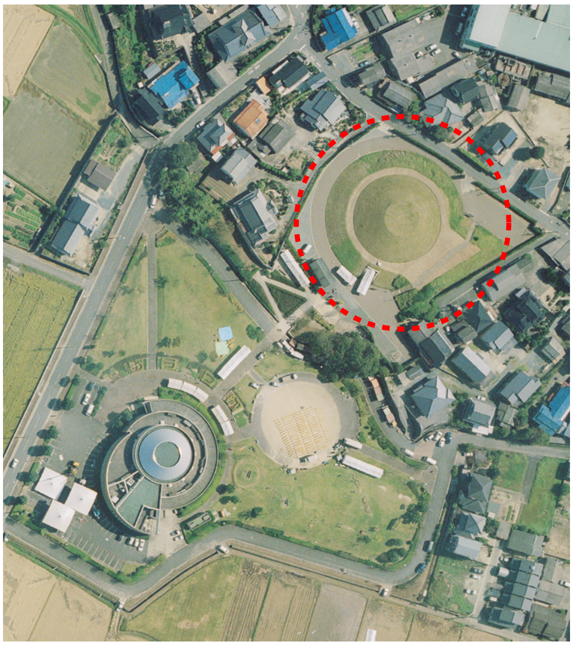

Figure 2: The aerial map of the Ozuka tumulus. The tumulus is located at the circular area.

Figure 3: The mural inside the Ozuka tumulus. Various patterns were painted in the tumulus to decorate the tombs of those buried there.

chaeological study. Sandin et al.[9] developed the projection system, called “CAVE” in order to express the atmosphere unique to the inside space of the cave as virtual reality contents. Similarly, Toppan printing Co., ltd. used its theater for an interactive virtual reality display of cultural assets and world heritage objects [10].

3 Acquisition of Photometric Information

Our aim is to investigate the difference in appearance of paintings in sunlight and in taper light, so that the color appearance can be theoretically restored. We explain the details of their color tone correction in this section.

3.1 Texture Image and Color Spectrum

In the 3D textured modeling, we usually use pictures taken by a digital camera as texture images. Though such pictures can be captured in high resolution, they do not represent accurate colors because the color tone changes according to environmental conditions, such as a lighting condition. This effect is formulated as follows.

$$I(\lambda) = E(\lambda)S(\lambda), \quad (1)$$

where

I	:	reflected spectral color signal (measured object color)
E	:	illumination spectral power distribution (illuminated light color)
S	:	surface spectral reflectance
λ	:	visible wavelength.

The appearance of an object is very different if illuminated under a different light, for example, incandescent light vs. fluorescent light.

Moreover, to capture color for each pixel, most cameras record the values of three colors (usually red, green, and blue, RGB) for visible wavelength, but the values depend on the type of camera. This fact is described in a mathematical form extended from Equation 1 as follows:

$$P_k = \int E(\lambda)S(\lambda)R_k(\lambda)d\lambda$$

where

k	:	color channel
P_k	:	camera responce
R_k	:	spectral response curve for each channel.

Namely, R_k changes if a camera changes.

An accurate acquisition method for color information is spectrometry [11], which can obtain color signals of continuous spectrum $I(\lambda)$ independent of the type of camera. Since we can measure illumination spectral color $S(\lambda)$ as spectral color signal of some reference object (usually a white object) illuminated by objective light, we can calculate $I(\lambda)$ from Equation 1. By using spectral color signals, we restore the color appearance of an object under an arbitrary light in computer graphics more accurately than using RGB data because we have more accurate color information [12] [13].

Additionally, these spectral data can be converted to RGB data. However, the resolution of spectrum images does not catch up with that of camera images. So spectrometry takes a huge amount of time to obtain the whole color of objects.

In order to take advantage of both methods, we apply spectrum information to high-resolution camera images. Our method needs the spectrum of an environmental light and an object within the environment, as well as camera images, as input data. The environmental light is an illumination color distribution component, and the reflection component of an object is calculated from the spectrum of the environmental light and the object surface. And the surface spectral reflectance component information is registered into the camera images.

Finally, the color appearance is restored by using the reflection component and illumination component of the environmental light under which the scene is observed.

In our photometric measurement, we obtained about 600 pictures and 21 pieces of spectrum data by using D1x (Nikon) and SpectraScan (Photo Research Inc.), respectively.

3.2 Sunlight and Artificial Taper Spectrum

We used spectrum information of two kinds of environmental light: sunlight and taper light. To obtain the spectrum of sunlight, we measured the white reference illuminated by the sunlight. The spectrum of taper light was measured by a spectrometer. We also measured the spectrum of the white reference illuminated by the fire in the fireplace constructed from bricks in the exhaust system (Figure 4). Figure 5 shows the obtained spectrum.

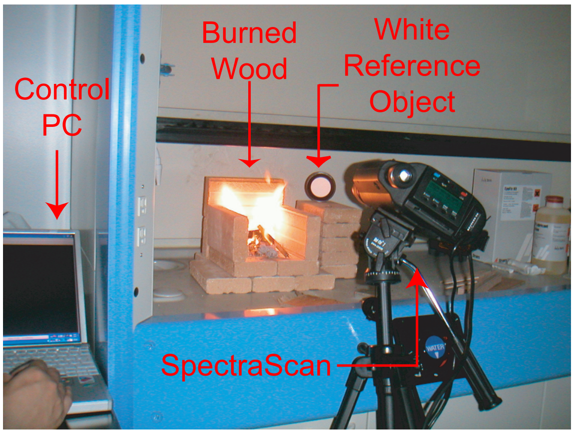

Figure 4: The spectrum measurement of a taper light. In this experiment, we measured the light from burned wood as an artificial light.

4 Experimental Result and Consideration

4.1 3D Shape Acquisition

In the measurement of the Ozuka tumulus, two types of laser range sensors are used. Imager (Z+F) is used for a global area measurement. It can capture the panoramic view in one scanning. In comparison, VIVID 910 (KonicaMinolta) is used for the highly accurate measurement of local area. Figure 6 shows our measurement. In our measurement, 54 pieces of data were obtained by Imager and 117 by VIVID 910.

These multiple measurement data are registered by a fast simultaneous registration method [14], a kind of Iterative Closest Point (ICP) algorithm [15]. This method can reduce the computational cost drastically because its search computation mainly depends on the graphics hardware.

Finally, the registered multiple data is merged into a single mesh by a consensus merging algorithm. This method converts registered multiple data to signed distance fields, and then a marching cubes method [16] composes a single and uniform polygonal mesh from the signed distance fields again.

4.2 Assumption

On the basis of the above method, we restored the textured 3D model of the Ozuka tumulus. Here we as-

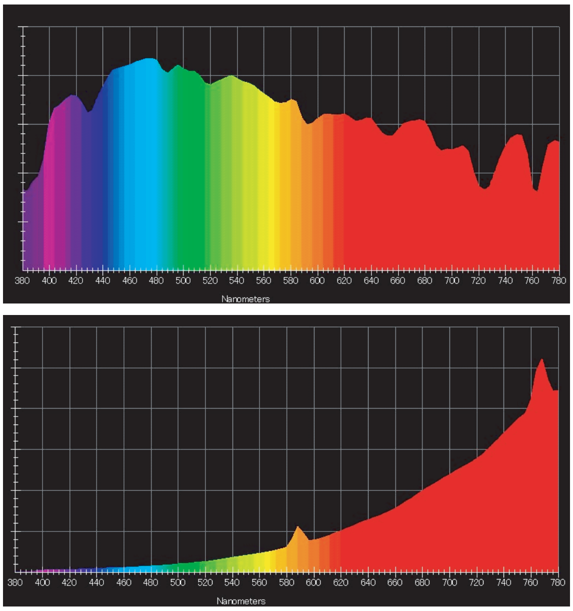

Figure 5: The obtained spectrum data. The upper and lower histogram respectively show the spectrum data of sunlight and a taper light.

sumed that the amount of light of an artificial taper is the same as that of sunlight because we do not know what the ancient artists actually used as an artificial light, so we cannot gauge the brightness of an artificial light. And, there are two stands of tapers inside the cave, so we assumed the ancients used all of them. We measured each relative position between the center of fire and the center of a white reference object illuminated by the fire by burning wood in the spectrum measurement of a taper light. So, for our simulation, we considered the decrement of the amount of light according to the distance from the fire to the object.

4.3 Result

We focused on continuous triangle patterns as typical ones of the Ozuka tumulus. Figure 7 shows the result when the wall was exposed to daylight (no ceiling cover) and also when the wall was illuminated by tapers from the two stands inside the tumulus while the ceiling was covered. In the former case, we can recognize the triangle patterns. But in the latter case, we cannot recognize them.

In conclusion, we consider that it would have been difficult to paint the wall using artificial light inside the dark tumulus, and that the ancient artists worked under the sunshine before building the tumulus. This result provides the archaeological knowledge of the building method of the tumulus, and leads to speculation about the kinds of ceremonies that were held inside the painted tumulus.

5 Conclusion and Future Work

In this paper, we implemented our simulation in computer graphics and verified the possibility that the ancient painters worked in sunlight. We did this by judging the possibilities of recognizing the colors used in the wall paintings in sunlight and in taper light. For our implementation, we developed a novel method to accurately restore color appearance under an arbitrary light. From our simulation result, we found the color difference can be recognized in sunlight only.

Exhibition of Our Result at Kyushu National Museum

Our 3D textured model and the simulation result is exhibited as movie contents at the Kyushu National Museum, that was opened in October, 2005, in Dazaifu-shi, Fukuoka, in northern Kyushu Island. The Ozuka tumulus is the first Special Historic Site of many painted tumuli with burial accessories designated as Important Cultural Property, but visitors cannot enter inside because it must be preserved. However they can experience the atmosphere inside the Ozuka tumulus virtually through our 3D textured model based on highly accurate 3D shape and photometric measurement. Please come to see it!

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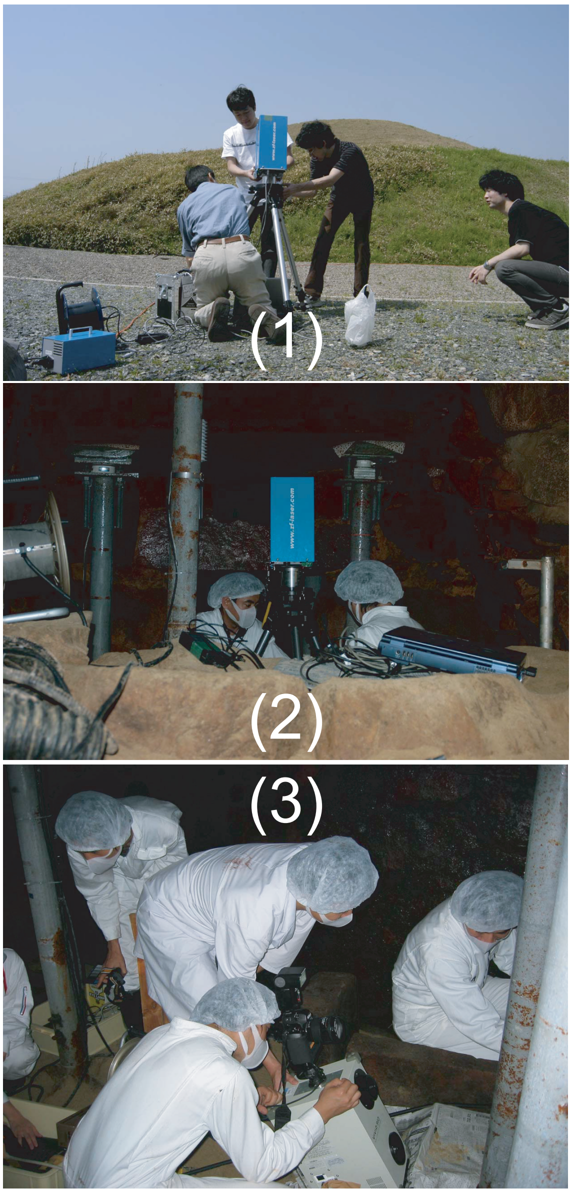

Figure 6: 3D shape measurement. In this figure, (1) and (2) show the measurement outside and inside the tumulus by Imager respectively, and (3) shows the measurement inside the tumulus by VIVID 910 equipped with D1x (Nikon) on the upper.

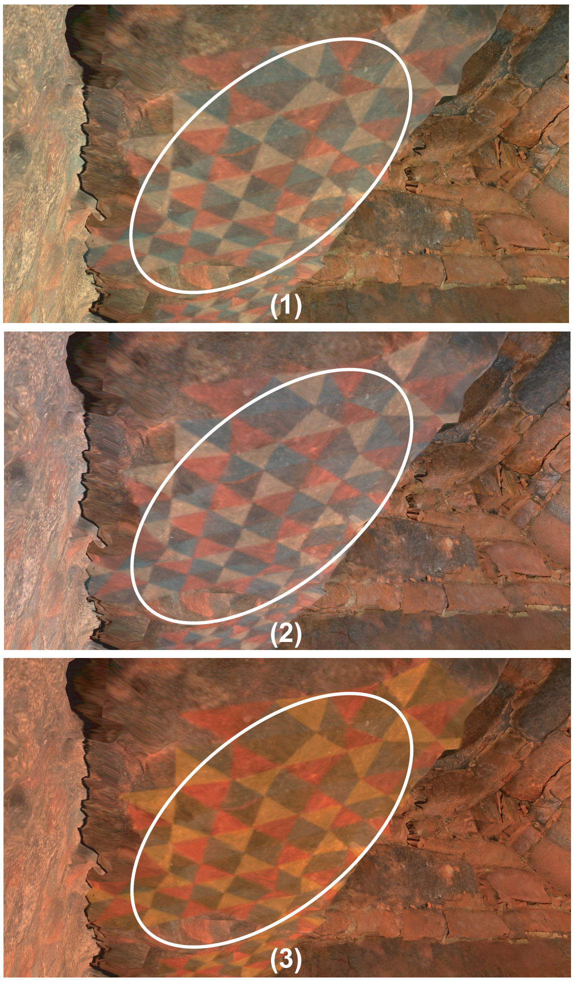

Figure 7: Simulation Result. The color appearance, in the area enclosed by curves in Figure (1), is restored. Figure (2) and (3) show the color appearance restoration under the sunlight and taper light, respectively. We can recognize the pattern in the former figure much more clearly than that in the latter.