Virtual Reproduction of the Worship Space by Generating Textures based on Spectral Measurements

A Case Study at Mogao Caves in China

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Introduction

The Mogao Caves, a Buddhist site near Dunhuang in Gansu Province, China, span 1600 meters of cliff face and were constructed over 1000 years starting around the 4th century. The site contains colorful sculptures and murals, including the Thousand Buddha wall paintings, which have been the subject of research focusing on their arrangement and color schemes to interpret their impact as a religious space and their psychological effects on worshippers. Over time, these murals have experienced color fading, and efforts have been made to reproduce their original colors through replication and spectroscopic measurements to simulate their appearance under candlelight and twilight conditions. This study reports on the methods and results of recreating the worship space of the Mogao Caves before color fading using VR technology.

Previous Research

Suemori analyzed the visual effects and religious significance of the worshippers' route within the Mogao Caves, focusing on the color schemes and arrangement patterns observed in the Thousand Buddha murals (Suemori, 2020). Additionally, traces of pre-fading colors in areas where sunlight does not reach were analyzed for their production processes, color materials, and techniques, leading to the creation of replicated murals (Fig. 1(I)) (Suemori et al., 2020). Kawaguchi et al. analyzed the spectral reflectance of the replicated murals with high resolution and precision, performing illumination calculations for each pixel based on the spectral distribution of candlelight, and extracted the color characteristics as images by calculating the stimulus values considering the sensitivity characteristics of human eyes and extracted the color characteristics of the object as an image by computing the RGB values (Fig. 1(II)). Furthermore, they output the appearance of the mural under twilight conditions, taking into account the color adaptation of the eye (Fig. 1(III)) (Kawaguchi Suemori and Yasumuro, 2021). This paper integrates the information from previous studies into VR to visually reproduce the cave space with the murals before color fading.

Fig. 1. Replicated paintings and spectral analysis images of the Thousand-Buddha Mural

Methodology

Based on the research of Kawaguchi et al., this study uses the process shown in Figure 2 to recreate the Thousand Buddha murals as textures, utilizing VR display through a game engine to reproduce the caves visually. The spectral reflectance distribution of the replicated murals, measured with high resolution (2761px × 900 px) and high spectral resolution (281 channels), can calculate the reflectance distribution under various light sources. However, this spectral information cannot be directly expressed in a standard CG rendering pipeline, so the spectral calculation results are used as textures. The 3D model of the Mogao Caves, generated from multi-view images, requires the corresponding spectral distribution of the replicated murals to be mapped separately. Orthogonal images generated from the replicated murals and the 3D model of the cave walls are aligned, and this alignment is used as a UV map to correspond with the 3D polygon mesh. The UV map use of orthogonal images allows the RGB-converted textures of the spectral information to be UV-mapped and applied, enabling the representation of the replicated mural colors and light source effects within the 3D CG.

Fig. 2. Process chain of the system

Implementation and Results

Due to the difficulty of conducting on-site 3D measurements at Mogao Caves, this study used online Street-View images of the caves as an alternative method. Specifically, around 40 screenshots were taken from three viewpoints to cover a 360-degree field of view, and these were stitched together using the free software Hugin to create a 360-degree panorama image, as shown in Figure 3. Based on this panorama image, a 3D mesh model of the cave was created using Agisoft Metashape. For the replicated mural images, a vertical line spectrometer was used for scanning while rotating horizontally, causing a slight barrel distortion in the obtained spectral distribution due to reduced scan density towards the periphery from the center (bottom of Fig. 2). In this paper, a bounding quadrilateral region was set for each Buddha statue, aligning the orthogonal images and spectral reflectance images within this region, and correcting the distortion through homography transformation. UV mapping to the 3D mesh model was conducted using the texture projection function of the free software MeshLab. The orthogonal spectral reflectance images of the replicated murals were overlaid onto the orthogonal images of the 3D model, placing the UV maps at appropriate locations.

The created 3D model was imported into a game engine, and the appearance within the Mogao Caves was reproduced in CG. The spectral analysis results of actual candlelight were converted to RGB values and set as the emitted colors of the light source. The color handling with RGB channels allowed interactive VR reproduction of the appearance of the Thousand Buddha murals illuminated by candlelight within the confined cave space based on the recreated mural colors (Fig. 4).

Fig. 3. 360-degree panorama image of the cave

Fig. 4. Reproduced cave scene in Unreal Engine

Conclusion

This study successfully replaced the Thousand Buddha murals within the 3D model with textures representing their pre-fading appearance and expressed the illumination effects of candlelight based on RGB lighting calculations derived from spectral distribution. Future research will verify the differences when using high-resolution spectral information for illumination calculations and conduct visual accuracy validation in VR, leading to psychological experiments on observers' visual perception of observers.

References

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