論文の内容の要旨

REFLECTANCE ANALYSIS OF LAYERED SURFACES USING A MULTISPECTRAL IMAGE

（マルチスペクトル画像を用いた層状表面物体における反射率解析）

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Despite great public interest in cultural assets, knowledge of these assets is often restricted because of deterioration and collapse. Consequently, it has become an important goal in the computer science community to model and record such assets. This digital data is then used to create digital media such as, computer graphics (CG), and virtual reality (VR) content. Furthermore it is also used for restoration and preservation analysis.

For modeling cultural assets, it is important to understand how to preserve the important information about them, including shape and surface color. Usually, shape information can be obtained by a laser range sensor, and this information has become more accessible with improved data processing algorithms. On the other hand, current color imaging systems like digital still camera (DSC) are usually represented with the traditional red, green, blue (RGB) color model. RGB cannot always provide accurate color information. The color of images captured with DSC is dependent on both the characteristics of the device and the condition of the illumination environment, making it difficult to accurately represent color appearance in the real world. Consequently, we need to capture surface spectral reflectance as ultimate color information in order to preserve the accurate color of cultural assets.

Spectral reflectance is inherent in the nature of objects. Object analysis using the fact that different materials have different spectral reflectance is performed in many fields, such as medical imaging, agriculture, archaeology, and art. However, in the real world, it is difficult to obtain and handle a multispectral image effectively. Cultural assets are often found in an outdoor environment or in a dark environment can pose different problems. In an outdoor environment for instance the temporal alteration of the illumination environment changes greatly. This causes effects of saturation and underexposure when measuring the spectra. Moreover, most cultural assets have at their surface complex reflection, absorption, and scattering, with a color mixture between the top and bottom layers, making material segmentation impossible. This paper targets analysis of cultural assets having such multilayered characteristics.

Our goal is development of novel multispectral imaging systems for modeling cultural assets, proposing reflectance analysis methods using a multispectral image, and applying them in practice. The paper proposes the following three tasks related to preservation, release, and analysis.

First, in order to make VR contents by using 3D data, texture images by DSC are generally used as color information. However, the color of images captured with DSC is dependent on both the characteristics of the device and the condition of the illumination environment. A fundamental problem here is that the color information is not accurate. In a narrow environment, such as a tumulus, compact mobility is necessary to measure spectra. For these circumstances, we propose a color restoration method that uses both high resolution images captured by DSC and spectral information captured by a conventional spectrometer. This is a practical method from the viewpoint of automation and computational cost.

Second, we propose an efficient acquisition and segmentation method of multispectral images in outdoor environments. A conventional multispectral imaging system may have two kinds of cameras. The first is a multiband camera, which is mainly used in the color reproduction field and does not have high spectral resolution, but has high image quality. The second is a hyperspectral sensor, which is mainly used in the aerial remote sensing field and does not have high image quality, but has high spectral resolution. Compared to these systems our solution has not only high image quality and sufficient spectral resolution for object analysis but also a wide capture angle. The multispectral image segmentation method can handle object surfaces having complex reflection based on a statistical procedure.

Finally, many object surfaces such as wall paintings are composed of layers of different physical substances, and are called "layered surfaces." Such surfaces have more complex optical properties than a diffuse surface and are generally unable to be segmented. Our method proposes a novel physical model we call the Spider model, which decomposes optical properties.

The main contribution of this thesis is that the author proposes two multispectral imaging methods and two reflectance analysis methods which are applied not only in theory but also in practice to show their viability. The contribution can be specifically summarized by the five following points: First, we have developed a practical color restoration method based on spectral information for making VR contents, have actually produced VR contents by using restored images, and have also released them in Kyushu national museum. Second, we have developed a multispectral imaging system that can efficiently acquire spectra in a wide field. Third, we have proposed a multispectral image segmentation method based on statistical procedures. Fourth, we have proposed the Spider model as a physical model for layered surfaces, and have also proposed decomposing complex reflection components of a layered surface. To our knowledge, there are no methods sharing our goals and techniques. Finally, we have applied our methods to both the reflectance analysis of tumuli and the spectral analysis of bas-relief in the Inner Gallery of the Bayon Temple. These methods are specifically designed for modeling cultural assets, but they can be used in other fields as well.