Development of Gonio Spectral Imaging Systems for Digital Archives

Y. Miyake[*], K. Tonsho[*], T. Ikeda[*], N. Tsumura[*], T. Senzaki[**] and J. Hayashi[**]
[*] Department of Information and Image Sciences, Chiba University, Japan
[**] Mitsubishi Electric Microcomputer Software Co., LTD., Japan

Abstract

In recent years, it is required to develop 3D (three dimensional) imaging systems to capture and reproduce the color, glossiness and shape of the object accurately for digital archives. Our final goal of the research is to construct digital archival systems in museum and Internet or virtual museum via World Wide Web. To archive our goal, we have developed Gonio photometric imaging system to record and estimate reflectance spectra of the 3D object based on principal component analysis and Wiener estimation method. Five-band images of the object are taken under different illumination angles by using developed multi-spectral camera. Dichromatic reflection model and Phong model are introduced to obtain Gonio spectral image. Those obtained images are synthesized with 3D wire frame images taken by 3D camera used laser projection by using Open GL algorithm.

Introduction

The Internet museum, telemedicine, and network shopping on the World Wide Web have increased rapidly in recent years.[1] However, for example in the present Internet museum, color reproduction of the painting and 3D artifact is highly dependent on imaging device such as CCD camera and CRT display. Therefore, it is required to record and reproduce the device independent color of the objects. We have developed[2] high accurate multi spectral imaging systems for recording of reflectance spectra of the object. This system consists of single chip CCD camera (3120x2060 pixels, 14 bits levels) with rotating color wheel comprising five color filters, high quality CRT monitor, and personal computer. This system is controlled by using three software; Image Digitizer, Image Estimator and Image Reproducer.

Image Digitizer controls the rotating of filters, focusing of lens, viewing angle and exposure. After taking image, gamma correction, noise reduction and compensation of pixel defect of CCD camera are also processed by using Image Digitizer software.

Image Estimator is software for estimation of reflection spectra of image based on the principal component analysis and Wiener estimation method from five bands image. Specular and diffuse components of the 3D object are separated on the basis of dichromatic model, and Gonio photometric properties of the object are calculated by Phong model. 3D wire frame images taken and calculated by 3D digitizer are rendered with Gonio spectral images by using Open GL.

3D images with different illuminant, illumination angles and viewpoints are then reproduced by Image Reproducer software, which include the CRT monitor characteristics and color adaptation model. Figure 1 shows schematic diagram of the developed system.

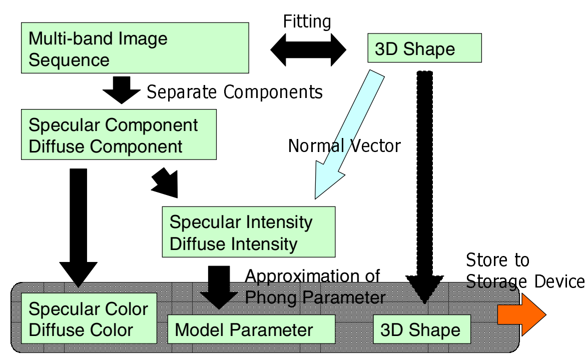


Figure 1. Schematic diagram of the developed 3D Gonio spectral imaging

Multi Spectral Imaging

In the color reproduction system, the camera response v_i (i=1,2 –n) of the object with spectral reflectance $O(\lambda)$ under illumination of $L(\lambda)$ can be represented as :

$$v_i = \int_{400}^{700} L(\lambda) o(\lambda) T(\lambda) f_i(\lambda) S(\lambda) d\lambda \qquad (1)$$

where λ is the wavelength of visible radiation from 400nm to 700nm, $S(\lambda)$ is spectral sensitivity of CCD camera through the lens and filter with spectral transmittance $T(\lambda)$ *and* $f_i(\lambda)$. In a conventional imaging system, i = 3, corresponding to R, G, B. It is clear that the camera response is dependent on the spectral characteristics of all component of imaging system and both taking and viewing illuminant. Many researches on device independent color reproduction have been done which are based on colorimetric color reproduction and color appearance modeling. Our research objective is to record the true spectral reflectance of the object. In the equation (1), we can measure camera response v_i and if we know the spectral characteristics of all components of imaging system and taking illuminant, then it becomes possible to estimate spectral reflectance of the object $O(\lambda)$ with solving the integral equation (1). Usually, dimension of camera response is less than that of $O(\lambda)$, therefore we must solve the ill conditioned equation. Many methods have been proposed to estimate $O(\lambda)$ from v_i. We introduced the principal component analysis and Wiener estimation method.

In a previous paper, we reported that the spectral reflectance of the oil paint can be estimated by the linear combinations of only five eigenvectors.[3,4] On the basis of this experimental result, we have developed five band high qualities CCD camera with 3120x2060 pixels and 14 bits. Figure 2 shows the oil paint image taken by this camera. It is important that each pixel of image shown in Fig.2 has same reflectance spectra corresponding pixel to original oil paint.

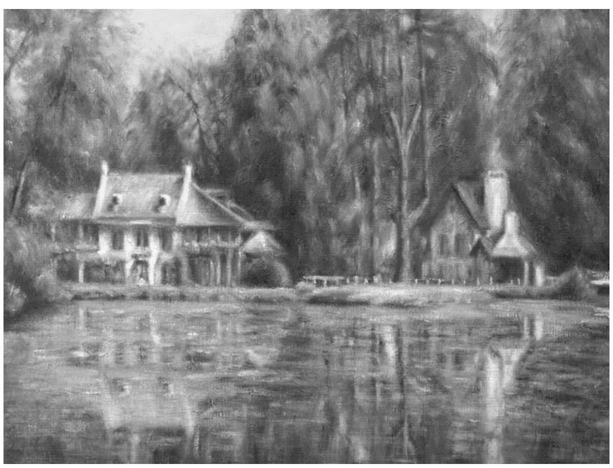


Figure 2. Image of oil paint taken by developed five band camera

Gonio Photometric Imaging System

Dichromatic Model

To record of 3D object accurately, it is necessary to record the reflection spectra, glossiness, texture and shape of the object. In this paper, Dichromatic model was introduced to separate surface reflection and body or diffuse reflection which is corresponding to glossiness and color of the object.

Reflection spectra of the object $\mathbf{f}(\mathbf{r},\theta)$ at coordinate $\boldsymbol{r}$ and illumination angle θ can be defined by Eq. (2) based on the dichromatic model.

$$\begin{aligned}\mathbf{f}(\mathbf{r},\theta) &= k_s(\mathbf{r},\theta)\mathbf{Lo}_w + k_d(\mathbf{r},\theta)\mathbf{Lo}(\mathbf{r}) \\ &= k_s^{(n)}(\mathbf{r},\theta)\mathbf{e}_s + k_d^{(n)}(\mathbf{r},\theta)\mathbf{e}_d(\mathbf{r})\end{aligned} \qquad (2)$$

where, **L** is spectral radiant distribution of the light source and **O**(**r**) is spectral reflectance of the object at coordinate **r** as follows.

$$\mathbf{L} = diag\ [l(\lambda_1), \cdots, l(\lambda_n)] \qquad (3)$$

$$\mathbf{o}(\mathbf{r}) = [o(\mathbf{r},\lambda_1), \cdots, o_n(\mathbf{r},\lambda_n)]^T \qquad (4)$$

$$\mathbf{f}(\mathbf{r},\theta) = [f_1(\mathbf{r},\theta,\lambda_1), \cdots, f_n(\mathbf{r},\theta,\lambda_n)]^T. \qquad (5)$$

$$\mathbf{e}_s = \frac{\mathbf{L\,o}_w}{\|\ \mathbf{L\,o}_w \|},\ \mathbf{o}_w = [1 \cdots 1] \qquad (6)$$

$$\mathbf{e}_d(\mathbf{r}) = \frac{\mathbf{L\,o}(\mathbf{r})}{\|\ \mathbf{L\,o}(\mathbf{r})\|} \qquad (7)$$

$$k_s^{(n)}(\mathbf{r},\theta) = k_s(\mathbf{r},\theta)\|\ \mathbf{Lo}_w \| \qquad (8)$$

$$k_d^{(n)}(\mathbf{r},\theta) = k_d(\mathbf{r},\theta)\|\ \mathbf{L\,o}(\mathbf{r})\|\ . \qquad (9)$$

where, $\boldsymbol{o}_w$ shows spectral reflectance of standard white. K^n_s and K^n_d are the intensity of surface reflection and diffuse reflection which are dependent on the geometry of the illuminant. e_s and e_d(r) represent normal vector representing the color of surface and body reflection, which are function on the wavelength of the illuminant and object. If we can estimate those parameters, surface and body reflection of the object under the arbitrary spectral distribution and angles can be estimated and reproduced.[5]

Gonio Photometric Imaging

In the Eq. (2), e_s and e_d(r) have spectral information from 400nm to 700nm; therefore at the interval of wavelength 10 nm, they have 31 dimensions. We introduced the Gonio photometric imaging systems to capture the reflection spectra of 3D object as shown in Fig. 3. Namely, e_s is calculated by Eq. (6), and $BaSO_4$ plate was used as reference white. On the other hand, if we assume that the illumination angle in imaging system is varied widely, we may consider that the e_d(r); a vector of diffuse component makes maximum angle from the specular component. Then we can determine the K^n_s, K^n_d. Wiener estimation method was used to estimate the reflection spectra of the object from five band images. In our experiment, five band images were taken with different illumination angles. Figure 4 shows the images of specular and diffuse components of the bottles. Figure 5 shows pictures taken under five different illumination angles (-90, -45, 0, 45, 90 degrees). Phong model was introduced to calculate the Gonio spectral information of the object from those taken images.

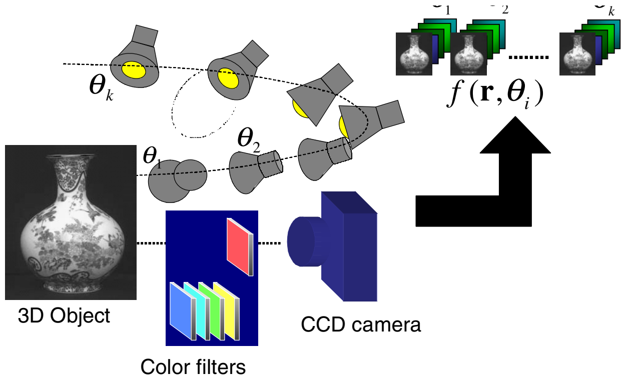


Figure 3. Gonio photometric capturing system

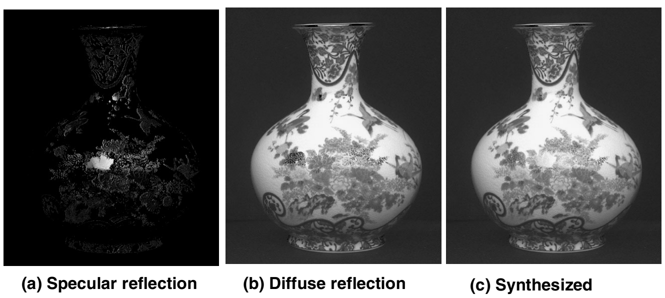


Figure 4. Separation of specular and diffuse components

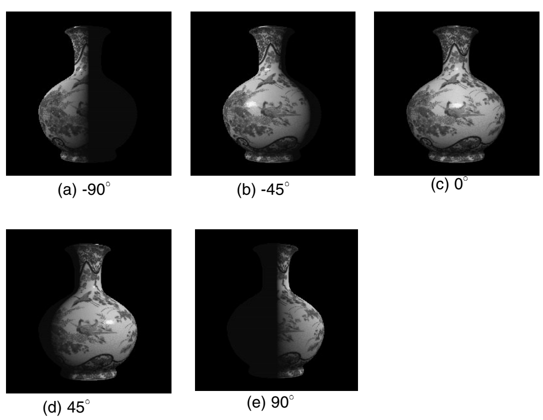


Figure 5. Image from five different illumination angles

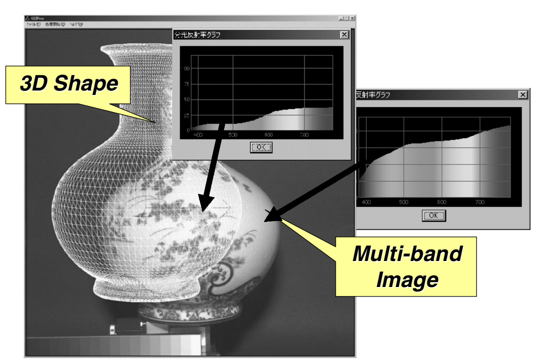


Figure 6. Synthesized image with wire frame and gonio spectral image

Capturing of the Three Dimensional Shape

Many methods have been proposed to record the shape information of three dimensional object.[6] In our experiment, 3D digitizer by laser projection (Minolta Vivid 700) was used for this purpose. In this camera, horizontal stripe of laser beam is projected onto the object and scanned from top to bottom and taken by calibrated CCD camera. 3D coordinate of the object is calculated by triangulate method. Those obtained wire frame images were synthesized with Gonio spectral images which has different illumination angel and view point by using surface model for computer graphics applications as shown in Fig.6. Therefore, we can get complete image with reflection spectra and shape information of 3D object. Figure 7 shows images of bottle from five different view points. Figure 8 shows wire frame image (a), surface image (b) and synthesized gonio spectral image(c).

Conclusion

We have developed Gonio spectral imaging system for recording the shape and reflectance property of 3D object by using high accurate multi-spectral camera and 3D digitizer.

Wire frame image is taken by 3D camera and Gonio spectral image is calculated by dichromatic model, Phong model and Wiener estimation method. As a result, we could successfully reproduce arbitrary images from different viewing angles and illumination under different spectral radiant distribution, and also illumination angles. We consider that the developed system is significant to apply digital archives and virtual museum. However, further improvement is necessary for more effective taking picture and accurate color reproduction.

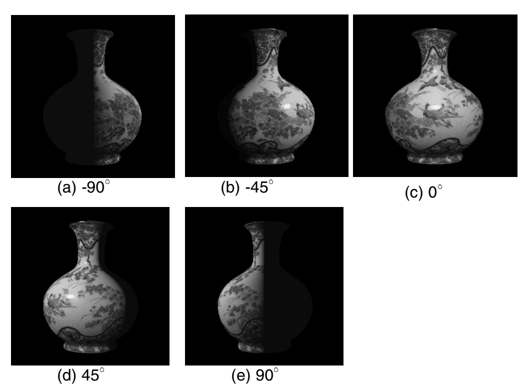
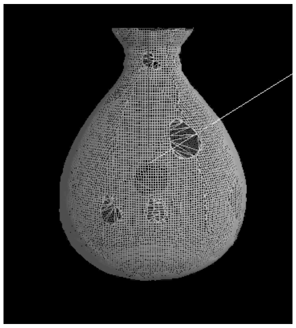
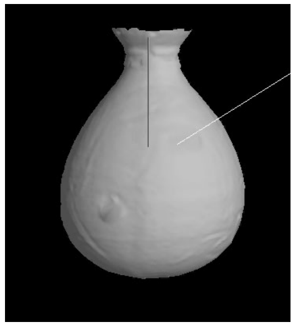


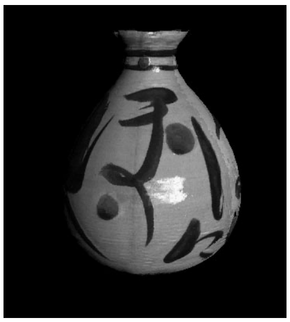
Figure 7. Image from five different view points



(a) Wire frame image



(b) Surface reflection image



(c) Gonio spectral image

Figure 8. Example of Gonio spectral image

Acknowledgments

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Biographies

Dr. Y. Miyake received the B.S. and M.E. from Chiba University. He received Ph.D. from the Tokyo Institute of Technology. He is a professor of Department of Information and Image Sciences, Chiba University. He was served as president of SPSTJ. He is currently vice president of IS&T and a fellow of IS&T.

K. Tonsho received M.E. from Chiba University. He jointed to SONY co. ltd. from April, 2002.

Mr. T. Ikeda is a master course student of Miyake laboratories in Chiba University.

Dr. N. Tsumura received B.S., M.E. and Ph.D. from Osaka University. He is an associate professor of Chiba University.

T. Senzaki received M.S. from Ehime University. He is a research associate of Mitsubishi Microcomputer Software co. ltd.

J. Hayashi received M.E. from Doshisha University. He is currently chief scientist of Mitsubishi Microcomputer Software co. ltd.