MULTISPECTRAL IMAGING

The Influence of Lighting Condition on Spectral Reflectance Reconstruction and Image Stitching of Traditional Japanese Paintings

Jay Arre Toque, Yuji Sakatoku, Julia Anders, Yusuke Murayama and Ari Ide-Ektessabi

Advanced Imaging Technology Laboratory, Graudate School of Engineering, Kyoto Univeristy

Yoshida-honmachi, Sakyo-ku, 606-8501, Kyoto, Japan

Keywords: Multispectral imaging, Analytical imaging, Spectral reflectance, Image stitching.

Abstract: Illumination condition is one of the most important factors in imaging. Due to the relatively complex interaction occurring when an incident light is irradiated on the surface of an object, it has been a topic of researches and studies for quite a while now. In this study, its influence on the reconstruction of spectral reflectance and image stitching was explored. A traditional Japanese painting was used as the target. Spectral reflectance was estimated using pseudoinverse model from multispectral images captured with seven different filters with spectral features covering 380-850 nm wavelengths. It was observed that the accuracy of the estimation is dependent on the quality of multispectral images, which are greatly influenced by lighting conditions. High specular reflection on the target yielded large amount of estimation errors. In addition, the spectral feature of the filters was shown to be important. Data from at least four filters are necessary to get a satisfactory reconstruction. On the other hand, it was observed that in addition to specular reflection, the distribution of light highly affects image stitching. Image stitching is important especially when acquiring images of large objects. It was shown that multispectral images could be used for the analytical imaging of artworks.

1 INTRODUCTION

Multispectral imaging finds wide array of applications in the field of medicine, remote sensing, satellite imaging and others (Elaksher, 2008; Lane, et al., 2008; Biehl, et al., 2002). This involves taking images at different wavelengths to capture spectral features that cannot be detected by the naked human eye. The spectral characteristics can be regarded as signatures, which can help in analyzing the object being imaged. In a way, multispectral imaging is different from "conventional" imaging techniques.

Conventional imaging is carried out in the visible region of the electromagnetic spectrum. This region covers wavelengths from 400-700nm, which corresponds to frequencies from 428-750 THz. This is called visible region because the human eyes are only sensitive within this range (Lee, 2005). Normally, this involves images with tristimulus values corresponding to red, green and blue colors (RGB). In applications such as display and visualization, this imaging technique is more than sufficient. The information that can be extracted from an image is only as good as the amount of data it contains. For a typical image with tristimulus values, its information is limited to color. However, if images are to be used for analytical imaging, conventional imaging might not be enough because of the limited amount of data.

Analytical imaging refers to techniques, which provides useful information about an object being imaged beyond its "conventional" visual content. In conventional imaging, normally, "what you see is what you get". This is based on the paradigm using three variables to characterize an image (MacAdam, 1993). With analytical imaging, it is desired that images provide more information, which may include material characteristics, surface and topographic information and spectroscopic data. It is based on the assumption that similar to other electromagnetic spectrum (e.g x-ray, microwave, etc.); material interaction within the visible light-near infrared (VL-NI) range can be quantified. However, this interaction is quite complex. In order

Toque J., Sakatoku Y., Anders J., Murayama Y. and Ide-Ektessabi A. (2009).
MULTISPECTRAL IMAGING - The Influence of Lighting Condition on Spectral Reflectance Reconstruction and Image Stitching of Traditional Japanese Paintings .
In *Proceedings of the First International Conference on Computer Imaging Theory and Applications*, pages 13-20
DOI: 10.5220/0001788000130020

perform sufficient analysis at VL-NI range; the amount of data an image contains should be increased. This may be accomplished using multispectral imaging (Conde, et al., 2004).

In this study, multispectral images were captured from 380-850 nm using image filters with different spectral transmittances. The images obtained contain information from the visible up to the near infrared range. The study focused on how the lighting conditions affect the reconstruction of spectral reflectance of Japanese paintings. Paintings were chosen as target because it normally requires non-destructive and non-invasive analysis. This is especially true if it is a cultural heritage (Balas, et al., 2003). Since paintings vary in sizes, it may sometimes not be possible to acquire the image of the whole painting at once if high-resolution images are desired. This will require image stitching. In this case, the influence of lighting is also of particular interest.

This study defines lighting condition as the cumulative effect of the various illumination factors affecting the perceived image. This includes intensity, type of light and angle of incidence. In reality, the factors affecting the lighting condition are not limited to the three mentioned. Since we are interested in the perceived image as detected by the image-capturing device, the factors can also include the distance of the light source to the target, surface property of the target and many more others. As the number of factors increase, the complexity of the interaction also increase. In this study, the factors are limited to the main light source characteristics based on preliminary investigations.

2 EXPERIMENT

Multispectral images were captured using a monochromatic CCD camera with spectral sensitivity from 350-1000 nm, which peaks at around 520 nm. The distance of the camera to the target was approximately 480 mm. The images were acquired using four types of filters (i.e. band pass filter, special purpose filter, sharp cut filter and infrared filter). A total of seven filters were used (BPB-50, BPB-55, BPB-60, SP-9, SC-64, SC-70 and IR-76). These filters have different peak sensitivities, which enable the images to contain more information from specific wavelength range. In some cases, an IR-cut filter was used, specifically BPB and SP filters, because they have unwanted sensitivities at the near infrared region. The sharp cut and IR filters were used for obtaining information at longer wavelengths. The schematic representation of the multispectral imaging system is shown in Figure 1.

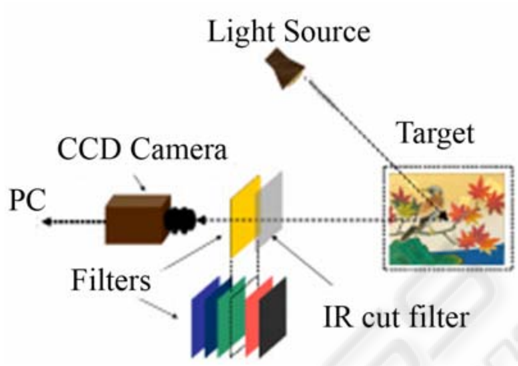

Figure 1: Schematic representation of the multispectral imaging set-up.

In order to investigate the effects onspectral reflectance reconstruction and image stitching of lighting conditions, images were acquired using four variations summarized in Table 1. Three parameters were selected, such as type of light source, light source angle and intensity. Based on preliminary investigations, these parameters were found to greatly affect the quality of the image and the corresponding information it contains.

Table 1: Lighting conditions used in acquiring the multispectral images. Note: E1 corresponds to experiment 1 and so on.

Parameters	E1	E2	E3	E4
Type	Halogen	Halogen	Halogen	Fluorescent
Angle (°)	30	30	60	N.A.
Intensity (%)	100	30	80	N.A.

2.1 Image Acquisition

In order to facilitate spectral reflectance reconstruction and image stitching, the target was imaged using the orientation shown in Figure 2. At first, the image of the upper half of the target was acquired. Then after that, the target was rotated 180° to capture the image of the other half.

A total of three targets were used; a white background, a learning sample and a Japanese painting. The white background is used to calibrate the uneven distribution of light when imaging the learning sample and Japanese painting. The learning sample, which was composed of conventionally used Japanese mineral pigments, was employed as a basis for estimating the spectral reflectance. A Japanese painting was chosen as the main target because of the technical challenges it presents (e.g. non-invasive, non-destructive, etc.). There exist other more advanced analytical technique for studying paintings, which are commonly x-ray-based (Marengo, 2006). However, x-ray-based technique is relatively non-destructive but not entirely non-invasive. Usually, a small piece of the sample is required. For paintings with high cultural value, taking even a minute sample is unacceptable.

Figure 2: Orientation of the target during image acquisition.

2.2 Spectral Reflectance Reconstruction and Image Calibration

The effect of the lighting condition during imaging was evaluated based on the accuracy of the spectral reflectance reconstruction and the quality of image stitching. Before reconstructing the spectral reflectances, the images were calibrated using a white background to compensate for the effect of the uneven distribution of light shone on the surface of the target. This helps facilitate better image stitching. The pixel values of the images were adjusted using Eq.1

$$T_i' = T_i\left(\frac{\overline{X}_{pv}}{B_i}\right) \tag{1}$$

where T_i corresponds to the i^{th} pixel value of the uncompensated target image, $\overline{X}_{pv}$ is the average pixel value of the white background, B_i is the i^{th} pixel value of the white background and T_i*' is the new* i^{th} pixel value of the white background-adjusted target.

After the images were adjusted using the white background, the spectral reflectance was estimated. In general, the spectral characteristic of an image is described by Eq.2 (Shimano, et al, 2007)

$$\mathbf{p} = \mathrm{C}\mathrm{L}\mathbf{r} + \mathbf{e} \tag{2}$$

where, **p** is the pixel value of the image captured at a certain band, C is the spectral sensitivity of the capturing device, L is the spectral power distribution of the light source, **r** is the spectral reflectance and **e** is an additive noise corresponding to the measurement errors of the spectral characteristics of the sensors, illumination and reflectances. All of the quantities in Eq.2 are functions of the wavelength. In this case, in order to estimate the spectral reflectance, the spectral characteristic of the camera and light source should be known. However, this information is often unavailable. Using pseudoinverse model, the spectral reflectance can be estimated without prior knowledge of the spectral characteristics of the camera and light source.

The pseudoinverse model is a modification of the Wiener estimation by regression analysis (Shimano, et al, 2007). In this model, a matrix W is derived by minimizing $\|R - WP\|$ from a known spectral reflectance of a learning sample, R, and the corresponding pixel values, P, captured at a certain band. The matrix W is given by Eq.3

$$W = RP^{+} \tag{3}$$

Where P^{+} represents the pseudoinverse matrix of P. By applying the derived matrix W to the pixel value of the target image, **p**, the spectral reflectance $\hat{\mathbf{r}}$ can be estimated using Eq.4

$$\hat{\mathbf{r}} = W\mathbf{p} \tag{4}$$

The size of the matrices used in Eq.3 and Eq.4 is a function of the number of learning sample k, number of multispectral bands M and number of spectral reflectances N measured at 10nm interval from 380-850 nm. In this study, k is 98, M is 7 and N is 48. The learning sample used in this study is a collection of 98 commonly used Japanese pigments and the spectral reflectance is measured using a spectrometer.

Reconstruction of the spectral reflectance was carried out using multispectral images because it can contain both spectroscopic and spatial information. With the conventional spectroscopes and spectrometers, the data acquired are only spectroscopic in nature. The information is confined to reflectance, transmittance and absorbance. However, by manipulating some image acquisition parameters (e.g. lighting angle, camera position, etc.) in multispectral imaging, it is possible to get spatial information about the object such as surface features, topography and other physical aspects of the material's surface.

Figure 3: Image of the Japanese painting used as target to evaluate the effect of lighting condition. The spectral reflectances are estimated from three regions on the painting.

In order to evaluate how the lighting condition affects the spectral reflectance estimation, three regions on the Japanese painting were selected namely Region 1, 2 and 3 as depicted by Figure 3.

3 RESULTS AND DISCUSSION

3.1 Image Stitching

Image stitching is important in acquiring images of large objects that cannot be captured entirely at once. This problem might seem trivial. In principle, as long as the object is in the line of sight of the capturing device, the size of the image that can be acquired is virtually unlimited. This can be accomplished by increasing the distance between the camera and the target object. However, as the distance increases, the resolution of the image decreases. This affects the quality of data the image contains. It is possible to solve this issue by performing some processing on the image but it is usually better to use the image with little alteration as possible in order to preserve the information it holds.

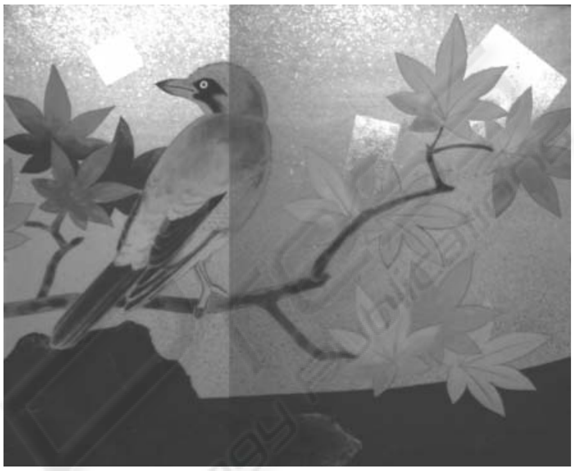

Figure 4: Stitched image of a Japanese painting using uncalibrated images.

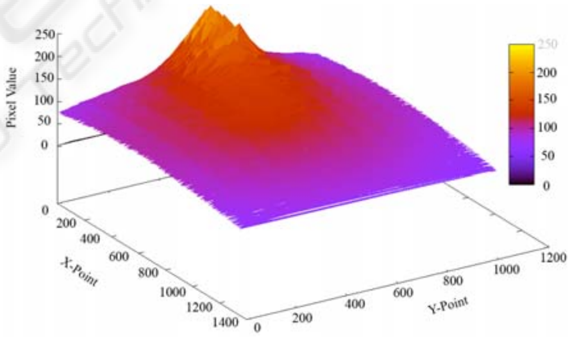

Figure 5: 3D representation of the distribution of light as reflected by the white background. The pixel values of the 1360x1024 image were used to create this 3D impression.

In this study, the influence of lighting condition on image stitching was investigated. Since the lighting was varied several times, it is to be expected to get images with different characteristics. Figure 4 shows an example of a stitched image acquired using IR 76 filter. The stitching line is very obvious which is a result of uneven light distribution. Figure 5 depicts a 3D representation. It can be seen that a portion of the target receives more intense light as compared to the other parts. As a result, some area appears to be brighter than the other. In addition to the obvious stitching line, some specular reflection can also be seen.

Generally, when an object is subjected to a radiation, three common interaction occurs. The incident radiation may be reflected, absorbed and transmitted as illutrated by Figure 6. It can be a mixture of any of the three. Depending on the characteristics of the material and the energy of the radiation, this interaction can be more complex. However, radiation in the form of visible light, the three mentioned is likely to occur. In imaging, the reflected portion of the radiation is more significant. This is the quantity that the camera sensors used to form the images. As shown in the simplified model below, reflected light is further classified into specular and diffused reflection (Vargas, 2006). Specular reflection is the potion of the reflected light that is also known as a mirror reflection. This results to saturation in some parts of the target painting. Once the image is saturated, little information can be extracted from it and worse it obscure the stitching of the images.

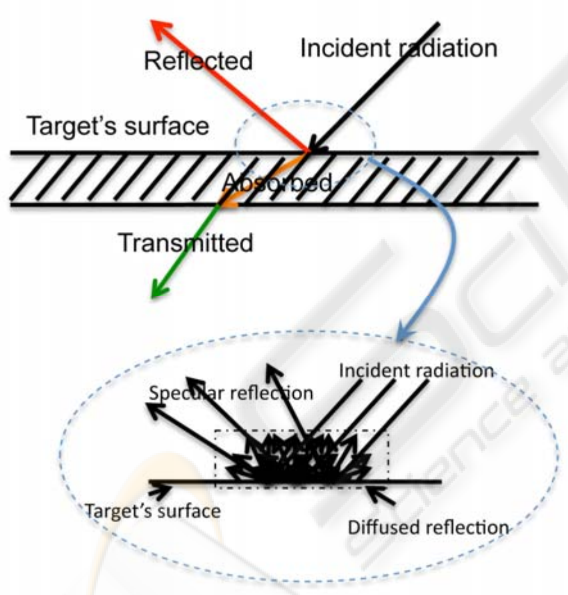

Figure 6: Simple interaction model when a material is subjected to radiation.

In order to solve the issues brought by the uneven light distribution, the images were calibrated using a white background. The details of the calibration process are described in the previous section. The images were acquired using various position in order to have a specular reflection-free image. Figure 7 shows an example of the final stitched image. After calibration and removal of regions with high specular reflections, the stitching line is barely visible. It is believed that the quality of the stitching can be further improved by using more sophisticated calibration techniques. In this study, only a simple technique was implemented. It was discovered that this method is only effective within a certain threshold. If the standard deviation of the average pixel values of the white standard is less than 20 pixels, then method employed here is sufficieint. If it goes beyond the 20 pixels threshold, stitching lines eventually become visible. Therefore there is a need to improve the white background calibration by using other techniques.

Figure 7: Stitched image of the Japanese painting calibrated using a white background.

3.2 Reconstruction of Spectral Reflectance

In this study, three regions on the painting were selected where the spectral reflectances were reconstructed. The three areas possess distinct charateristics which was the reason for its selection. For example, Region 1 is the area on the Japanese painting that experienced high specular reflection. This region has gold foil laid on the the surface. Using gold foils in painting is a common practice in Japanese art. Since the region has metallic constituent, it explains why it has high specualr reflection. This significantly affected the estimated spectral reflectance as shown in Figure 8. The figure shows five reflectances, four from the different lighting conditions and one for the spectral reflectance measured using a spectrometer. This acts as reference spectral reflectance. It can be observed that the reconstructed spectral reflectances of the multispectral images on Region 1 is quite poor. This might due to the reflectance characteristics of the gold foil in the region. Specular reflection was not observed in all experiments, when this was the case, Region 1 appeared to be dark. This results to very low spectral reflectance but still not close to the measured reflectance. Unfortunately, the lighting parameters used in the experiment were not optimum. However, the main aim of the study is to observe how the lighting condition affects the estimation. Based on the phenomena observed, it can be concluded that the issue on specular reflection needs to be addressed in order to have better reconstruction.

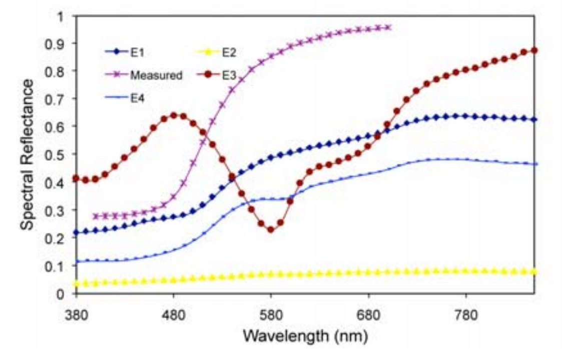

Figure 8: Reconstructed spectral reflectance from multispectral images on Region 1 of the Japanese painting.

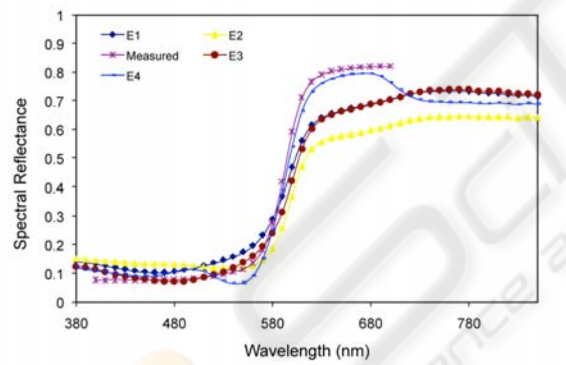

Figure 9: Reconstructed spectral reflectance from multispectral images on Region 2 of the Japanese painting.

On the other hand, Region 2 was selected because it did not show any specular reflection in all the experiments. It is painted with an orange mineral pigment resembling atumn leaves. Compared to Region 1, the reconstructed spectral reflectance is close to the measured reflectance up to wavelengths of 600 nm. Between 600-700 nm however, the estimation was relatively poor except for E4. The estimated spectral reflectance of E4 was close to the measured one up to 700 nm. At the near infrared region, no comparison can be made because the data from the spectrometer is only available from 400-700 nm.

Finally, Region 3 was selected because it yielded multispectral images with and without specular reflection across the different parameters. What is unique in this region is that it has both mineral and metallic pigment. The metal consitituents in this case are traces of silver particle instead of foil. Figure 10 shows the reconstructed spectral reflectance. The estimation is still not as accurate as it should be but it is better compared to Region 1. Again, the poor reconstruction may be attributed to specular reflection. In this case since the metallic constituents are in particle form, the effect on the multispectral images is not as severe when compared to the gold foil.

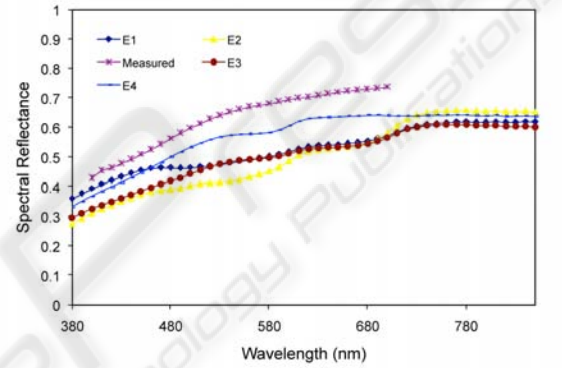

Figure 10: Reconstructed spectral reflectance from multispectral images on Region 1 of the Japanese painting.

The accuracy of the spectral reflectance reconstruction may also be explained by the characteristics of the filters used to capture multispectral images. In order to get a good estimation, the filters should be able to get significant amount of data. Figure 11 shows the spectral characteristics of the seven filters used along with the measured spectral reflectances of the selected regions. Among the selected regions, Region 2 has the most number of filters that are able to collect spectral information. A total of four filters were able to collect the necessary data especially between 420-580 nm. This can explain why the accuracy of the estimation is relatively better if compared to the other wavelengths.

On the other hand, the filters with short wavelengths and long wavelengths collected the data from Region 3. No filter was able to collect any useful information between 480-680 nm, which can explain why the reconstructed spectral reflectance within this range deviated from that of the measured. Finally as for Region 1, on top of the severe effect of specular reflection of the gold-laden surface, it can be observed that only two filters were able to collect information.

In addition, it is interesting to note how well the estimated spectral reflectances above 700 nm were convergent except for Region 1. Evidently, the influence of high specular reflection also affected the reconstructed reflectance at that wavelength. It is difficult to ascertain its accuracy because the measured data only goes up to 700 nm but it may be assumed that it might be good enough.

Why is important to reconstruct the spectral reflectance above the visible range? This is because previous studies have shown that some materials have unique spectral features at the near infrared range (Anderson, 1947). In addition, acquiring images beyond the visible range can help increase the amount of information available from the image.

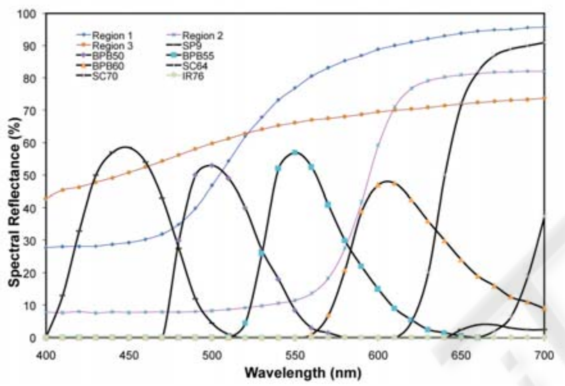

Figure 11: Spectral characteristics of the filters used in capturing the multispectral images along with the measured spectral reflectance of the three selected regions.

4 CONCLUSIONS

In this study, the influence of lighting condition on image stitching and spectral reflectance reconstruction was explored. Using multispectral images, spectral reflectance of a traditional Japanese painting was estimated by the pseudoinverse method. Results show that specular reflection, which is influenced by illumination, significantly affects the accuracy of the reconstruction. It was also observed that the spectral features of the filters used play an important role. According to the comparison of spectral reflectance curves, the estimation is more accurate between 420-580 nm especially for Region 2 because at least four filters were able to collect information within that range. On the other hand, it was shown that image stitching was greatly influenced by the light distribution on the target and its surface reflection characteristics. Stitching lines were highly visible when specular reflection is severe. It is also observed that the calibration technique was only effective within a 20-pixel standard deviation-threshold. Beyond this, more advanced calibration technique is necessary.

ACKNOWLEDGEMENTS

This work has been done as part of the project “An Integrated System for Secure and Dynamic Display of Cultural Heritage” sponsored by Japan Science and Technology Agency, Regional Resources Development Program. This collaborative project was organized by Kyoto University Graduate School of Engineering, S-tennine Kyoto (Ltd) and Kyushu National Museum. The Authors would like to express their thanks to Imazu Setsuo of Kyushu National Museum and other staff of the museum and, Oshima of S-tennine Kyoto and his group for supporting this work.

REFERENCES

Anderson, J.A., 1947. The diffuse reflectance of paints in the near-infrared. *Journal of the Optical Society of America.* 37(10), pp. 771-777.

Balas, C., Papadakis, V., Papadakis, N., Papadakis, A., Vazgiouraki, E., Themelis, G., 2003. A novel hyper-spectral imaging apparatus for the non-destructive analsyis of objects of artistic and histori values. *Journal of Cultural Heritage*, 4, pp 330s-337s.

Biehl, L., and Landgrebe, D., 2002. MultiSpec—a tool for multispectral–hyperspectral image data analysis *Computers & Geosciences*, 28(10), pp.1153-1159

Conde, J., Haneisihi, H., Yamaguchi, M., Ohyama, N., Baez, J., 2004. Spectral reflectance estimation of ancient Mexican codices, multispectral images approach. *Revisita Mexhicana De Fisica*, 50(5), pp. 484-489.

Elaksher, A., 2008, Fusion of hyperspectral images and lidar-based dems for coastal mapping. *Optics and Lasers in Engineering*, 46(7), pp. 493-498

Lane, G.R., Martin, C., Pirard, E., 2008. Techniques and applications for predictive metallurgy and ore characterization using optical image analysis. *Minerals Engineering*, 21(7), pp. 568-577.

Lee, H-C., 2005. *Introduction to color imaging science.* Cambridge, UK, Cambridge University Press.

MacAdam, D., 1993. *Selected Papers on Colorimetry-Fundamentals, volume 77 of Milestone Series.* Bellingham, Washington, SPIE Optical Engineering Press.

Marengo, E., Liparota, M.C., Robotti, E., Bobba, M., 2005. Multivariate calibration applied to te field of cultural heritage: analysis of pigments on the sureface of a painting. *Analytica Chimica Acta*, 553, pp. 111-122.

Shimano, N., Terai, K., Hironaga, M., Recovery of spectral reflectance of objects being imaged by multispectral cameras. *Journal of Optical Society of America A*, 24(10), 3211-3219.

Vargas, W., Amador, A., Niklasson, G., 2006. Diffuse reflectance of TiO_2 pigmented paints: spectral dependence of the average pathlength parameter and forward scattering ratio. *Optics Communication*, 261, pp. 71-78.