A New Procedure for Capturing Spectral Images of Human Portraiture

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ABSTRACT

This paper describes a new procedure of capturing spectral images of human portraiture. The designed imaging system was calibrated directly based on real human subjects and has the capability to provide accurate spectral images of human faces, including facial skin as well as the lips, eyes, and hair, from various ethnic races. The facial spectral reflectances obtained were analyzed by principal components analysis (PCA) method. Based on the results of PCA, spectral images using both three and six wide-band spectral sampling were estimated. The reconstructed spectral images for display based on an sRGB display model are evaluated. The results have proved that this new spectral imaging procedure is successful. The results also show that three basis functions are accurate enough to estimate the spectral reflectance of human faces. The derived spectral images can be applied to color-imaging system design and analysis.

Keywords: Spectral image, multi-spectral image, human face, human portraiture, spectral reflectance, PCA

1. INTRODUCTION

Facial color reproduction is an important aspect of color-imaging system design and analysis. Visible spectral images of human portraits are desired to test color imaging system design via computer simulation. Recent research of spectral imaging on human facial skin[1, 2] showed that three basis functions are sufficiently accurate to describe the spectral reflectances of human skin. Therefore, the spectral reflectance of each pixel of the captured image could be estimated from the values of three color channels and the spectral radiance of the illuminant used. These experiments showed very successful results. However, the spectral reflectance database employed in these experiments was concentrated on a single race and only on skin. The spectral measurement geometry is generally fixed to 45/0 or d/0. Considering the capability of spectral imaging systems for different races of human portraits it seems worth including spectral reflectances of different races and those spectral data should include skin, hair, eyes and lips as well. Since the human face is not a planar but a 3-dimensional object, the spectra of the subjects observed by the camera could vary with any geometry. In other words, to perform an accurate calibration of the spectral imaging system, the spectral database should be with large gamut including various geometric configurations. In addition, previous spectral portrait image researches performed the system calibration based on the painting samples which were the reproductions of the measured spectral reflectance of skin. Those paint samples were not available for us. Moreover, these approaches required very accurate reproductions of skin at a fairly early stage to avoid the errors passed through all the following procedures. According to these considerations, therefore, we proposed a new procedure and designed a new spectral imaging system for human portraiture that has the capability to capture spectral images of various races and describe spectral reflectances of skin, hair, eyes and lips very well. This imaging system would perform system calibration and capture spectral images based on the spectral data directly recorded from the real human subjects with certain lighting and camera conditions. The detail of the experiment procedure is provided. The measured spectral reflectances were analyzed by PCA. Based on the results of PCA, both three wide band and six wide band spectral images were estimated respectively. The results of the reconstructed spectral images for display based on sRGB model are shown and discussed.

3. EXPERIMENT

The imaging system and optical path for system calibration are shown in Fig. 1 as follows:

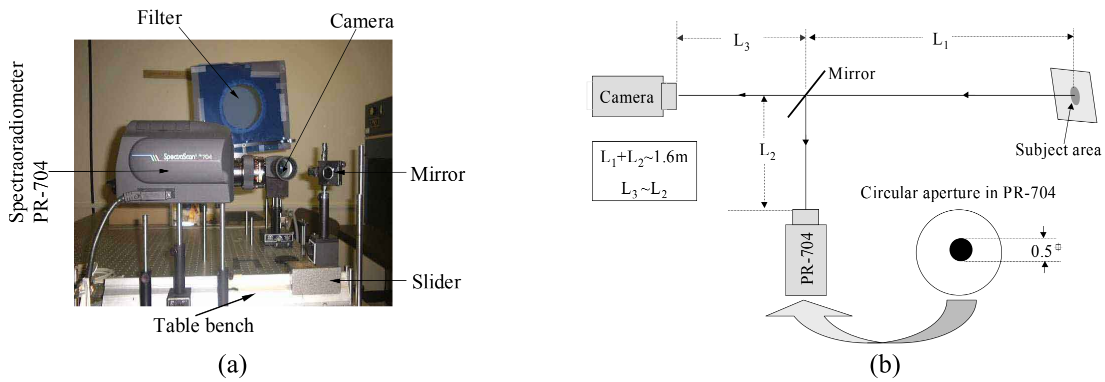

Figure 1. Imaging system (a) and optical path (b) for system calibration.

The portrait studio digital camera used for this research is SONY DKC-ST5 Digital Photo Camera that has a three-chip high-resolution CCD with total 1,400,000 pixels. Its output image is 24-bit, 8-bit for each channel, size of 2048×2560 with TIFF format. The lighting system consisted of two lighting heads (Scanlite Digital 1000, Elinchrom) with Halogen Photo Optic lamps (FEL/1000w, 120V). A Photo Research Inc. SpectraScan 704 (PR-704) spectroradiometer was used in the spectral measurement. The wavelength range used in this experiment is in visible region, 400 ~ 700nm with 2nm interval. A 202 half C.T blue filter, Professional Lighting Filters, Bogen Photo Corp., was chosen to give additional filtered RGB for six-band spectral imaging. The measurement system was calibrated by a high quality white reference, a barium sulfate coated paper with spectrally flat and uniform property. As shown in Fig. 1(b), optical radiation being measured passed through the circular aperture inside PR-704 and then reached the detector for the spectral measurement. A mirror was attached to a slide mounted carrier that could move along the table bench. This system was calibrated so that the pixel positions in the image of a subject that contributed to the spectral measurement in PR-704 were known. The distance between the object to PR-704, L_1+L_2 in Fig. 1(b), was selected in such a way that the uncertainty of calibrated pixel area was less than 2.5% on the assumption that the object surface would move back and forth around the calibrated position within 2cm. The distance we selected was about 1.6m. We could select a longer distance for accuracy purposes. However, the area covered by the aperture of PR-704 would be too large and the spectra measured would be spatially averaged too much. It was estimated that, with ~3% error of subject surface that corresponding to subject moving back and forth about ±3 cm, the color difference was less than 0.08. This proved that the designed imaging-measurement system, theoretically, was quite accurate. During the experiment the subjects were sitting on a chair with their heads against a holder. They were asked to adjust their chair up and down, left and right, until the position of interest fell into the grid box which was shown on the monitor. We first took a picture of the subject, then moved the mirror to its calibrated position and made spectral measurement of the same subject at the same position. The spectral reflectances of various face surfaces of subjects and their corresponding camera responses, digital counts, therefore, could be obtained. Based on this system setting, the spectral measurement would match the different geometries as detected by the camera.

A total 34 of subjects from age 18 to 40, 11 female and 23 male participated in the experiment. The experiment was performed from June to January. The subjects can be categorized into five races, 11 subjects for Pacific-Asian, 8 for Caucasian, 7 for Black, 6 for Subcontinental-Asian and 2 for Hispanic.[3] Each subject provided 16 spectral reflectances which, in general, would contain 10 for facial skin, 3 for hair, 2 for eye and 1 for lips. The locations of spectral measurement were randomly selected considering uniformity of sampling. Therefore, a total 540 of spectral reflectances and their corresponding camera digits were obtained for imaging system calibration and modeling.

4. RESULTS AND DISCUSSION

Applying PCA to 540 spectral reflectances obtained, the basis functions and their coverage percentages were calculated. The cumulative coverage percentages (CCP) for the first six basis functions are shown in table 1. The results in Table 1 indicate that the first three basis functions will cover ~ 99.9% variance for all spectral data of all races. Our further research indicated that the same is almost true for spectral reflectances of individual races and different parts of faces.[4] This suggests that spectral imaging system with three wide bands may provide sufficiently accurate spectral reconstruction for all races. The first three basis functions are shown in Fig. 2. Our further research also showed that different sets of first three basis functions based on spectra of individual races have very similar shapes.[4]

Table 1. Cumulative coverage percentages of first 1~6 basis functions based on all spectra.

No. of PC	1	2	3	4	5	6
%	97.89	99.57	99.89	99.97	99.99	99.99

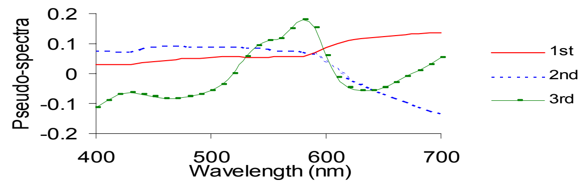

Figure 2. First three basis functions of all spectra.

The mean color differences, metameric indices and spectral root mean square (RMS) errors of the spectral reconstruction for spectra from individual races and different parts of faces based on three basis functions are given in Table 2. The color difference equation applies CIELAB with 2° observer and D50 illuminant. The metameric indices were calculated using illuminations of D50 and A with Fairman's metameric correction using parameric decomposition.[5]

Table 2. Mean color difference, metameric indices and RMS errors of the spectral reconstruction for spectra from individual races and different facial parts. (a) For individual races where PA, C, SA, B, H and AR are abbreviations for Pacific-Asian, Caucasian, Suncontinental-Asian, Black, Hispanic and All Races respectively; (b) for different facial parts

	PA	C	SA	B	H	AR
ΔEab	0.98	0.83	1.28	1.51	0.90	1.10
Index	0.26	0.18	0.34	0.39	0.23	0.28
RMS	0.0034	0.0043	0.0040	0.0043	0.0032	0.0039

(a)

	Skin	Hair	Eye	Lip
ΔEab	0.74	2.57	0.62	1.13
Index	0.18	0.71	0.16	0.22
RMS	0.0042	0.0026	0.0034	0.0049

(b)

The results in Table 2 indicate that three basis functions will provide quite accurate color and spectral reproduction for overall spectra, especially skin and eyes, though there are relatively large errors for spectra of Black subjects and spectra of hair. Our further research indicated that those relatively large errors for spectra of Black subjects are mainly contributed by spectra of hair since spectral reflectances of hair require high order statistics, more basis functions (based on all spectra), to represent them. The biological analysis on this topic is beyond the scope of this research. Since skin spectra are the most important part in spectral imaging of human portraits, the results in Table 2(b) are quite acceptable.

The results of modeling from digital counts to spectral reflectances using 3 and 6 bands are shown in Table 3 where 3P7T and 3P17T represent the use of 3 basis functions with 7 terms (including covariance terms) and 17 terms (with higher order terms) of digital counts involved in calibration regression respectively and similar definition for 6P7T using 6 basis functions. The details of camera system calibration and spectral imaging modeling can be found in references.[1, 6]

Table 3. Results of system modeling from linearized digits to eigenvalus using 3 and 6 bands respectively.

Method	ΔEab	Index	RMS
3P7T	2.68	0.73	0.012
3P17T	2.32	0.66	0.011
6P7T	1.76	0.48	0.010

The results in Table 3 indicate that three basis functions will provide acceptable color and spectral reproduction after the calibration. More terms involved in regression of transform matrices or more basis functions used will provide more accurate color and spectral reproduction. On the other hand, however, more terms and more basis functions used, more image noise will be involved.[7] Therefore, in practice, we need to make a compromise. Once transform matrices were determined, the spectral reflectances could be estimated, pixel by pixel, from the original images, hence, obtained the spectral images. For display, the spectral reflectance of each pixel in those spectral images estimated was converted to CRT digits for display using sRGB model and CRT characterization model. For demonstration, some spectral image samples for display are given in Fig. 3. Spectral images for display given in Fig 3 show that, spectral images of 3P7T are little blurred and have small color shift. Spectral images of 6P7T have more image noise. This is partly due to the fact that the camera we used has more noise, especially in blue channel image. Spectral images of 3P17T will be the best with more accurate color and spectral reproduction compared to spectral images of 3P7T, and less image noise compared to spectral images of 6P7T. Image quality research in spectral imaging is currently been carrying on.

(a) (b)

Figure 3.Samples of original images and estimated spectral images for display. (a) Caucasian subject. Images from top to bottom are R, G and B channel images respectively. Images from left to right are original image without filter, original image with filter, 3P7T image, 3P17T image and 6P7T image. (b) Black subject. The same image arrangement as (a).

5. CONCLUSION

A new procedure for capturing spectral image of human portraiture has been proposed. The facial spectral reflectances obtained were analyzed by PCA method. The PCA results indicate that three basis functions will provide quite accurate color and spectral reproduction for facial spectral reflectances from various races and different parts. Three band and six band spectral images of human portraits have been successfully obtained. High order transform matrices will provide more accurate, three-band, spectral images with acceptable image noise. However, for six-band spectral images, transform matrix with low order of 7 terms will give most acceptable results. Due to the limit of image quality of the camera used, the 6-band spectral image did not meet the quality we originally expected. To obtain more accurate, multi-spectral image, a camera with high quality in terms of noise is required. The obtained spectral image can be applied to color-imaging system design and analysis.

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