Statistical Characterization of Spectral Reflectances in Spectral Imaging of Human Portraiture

Qun Sun and Mark D. Fairchild
Munsell Color Science Laboratory
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
Rochester, New York

Abstract

Spectral reflectances of various parts of human faces from various ethnic races were collected from experiments on spectral imaging of human portraits. Principal components analysis (PCA) was applied to those spectral reflectances not only from different races, but also from different face parts. The first three principal components can explain about 99.8% of cumulative contribution of variance of spectral reflectances for each race and each face part, and all races as well. Color differences of spectral reconstruction either for different races or for different face parts based on different sets of principal components were estimated. The results indicate that, when using 3 basis functions and under D_{50} illumination, the basis functions based only on spectra of Pacific-Asian will provide best overall color reproduction. However, from spectral matching point of view, three basis functions based on all spectra will provide the best spectral reproduction with minimum overall mean value of indices of metamerism. More analyses and comparison were applied to spectral reflectances of human facial skin from different sources. Those results provide practical suggestions for imaging or spectral imaging system design, especially imaging systems for human portraiture.

Introduction

Facial color reproduction is an important aspect of color-imaging system design and analysis. Because of the problems involved in the image capture and reproduction of metameric objects, spectral matches between the original objects and their reproductions are attracting the attentions of many researchers.[1-3] The key idea is to replace the world of red, green, and blue with the world of wavelength. The color, or spectra of human subjects depends chiefly on the presence of pigment and blood. [4,5] Different races and localizations of human beings have different spectral characteristics though the pigments involved are the same. When designing a spectral imaging system for human portraiture, for better color and spectral reproduction, it is very important to determine the number of channels used and the basis functions selected for spectral reconstruction of the final spectral images. Therefore, from the imaging point of view, it seems very important to understand the statistical characteristics of spectral reflectances of different races and different parts of human beings. In this research, we will concentrate on the human face which is the target of spectral imaging of human portraits.

Much research has been done on color of human beings, especially human skin. Biological and anatomical research indicates that the skin is made up of three layers, epidermis, dermis and hypodermis. Dealing with the color, we simply divide the skin into an outer thin layer, epidermis, and an inner, relatively thick layer, dermis. For normal human skin, the absorption of the epidermis is dominated by a black pigment called melanin though there are five different pigments in the skin.[6] The spectral characteristics of different races or different individuals are due only to variation in the amount of melanin present.[7,8] People with dark brown or black skin have many melanin particles; people with medium to light brown skin have fewer; people with very light brown to white skin have only a very few. Buckley and Grum,[9] Kollias and Baqer[8] performed experiments to measure the spectral characteristics of human melanin by measuring spectra of normal skin and vitiligo-involved skin of volunteers-patients. Their research indicated that the spectral reflectance of melanin in the visible range is monotonically increasing. The inner layer, dermis, is rich with blood vessels which contain hemoglobin. Hemoglobin has marked absorption bands around 575nm, 540nm and 410nm.[10,11] Brumsting and Sheard[4,5] indicated that the marked absorption bands of hemoglobin occur only when it bonds with oxygen within vivo skin. Heavily pigmented skin will present less pronounced effect of the hemoglobin absorption bands because of the masking effect of the greater amount of melanin pigmentation. Skin optics[12] further showed that the epidermis is a strongly forward scattering layer and, for all wavelengths considered, scattering is much more important than absorption.

The skin is not the only part of the human body that differs in color from one individual to another. The eyes and hair have the same elements affecting their coloring. Biological details of eyes and hair affecting their coloring can be found in reference 6.

In summary, the color, or spectra, of human faces depends chiefly on the presence and variation of pigment and blood. Recently, researchers have done some spectral imaging experiments on human faces.[1-3] Their research showed that three basis functions are accurate enough to describe the spectral reflectances they collected and their experiments showed very successful results. However, the spectral reflectance database employed in those experiments was mostly concentrated on a single race and only on skin. The spectral measurement geometry is generally fixed to 45/0 or d/0. The statistical analysis of spectral reflectances for different human races and different parts of human face/head is not available. Considering the capability of spectral imaging systems for different races of human portraits it seems worth measuring spectral reflectances of different races and those spectral data should include skin, and 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 be 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. According to these considerations, a new spectral imaging system was designed for human portraiture that has the capability to capture spectral images of different races and describe spectral reflectances of skin, hair, eyes and lips very well.[13] The spectral data for this research includes five different races, Pacific-Asian Caucasian, Black, Subcontinental-Asian and Hispanic.[4] It can also be divided into four face locations/parts, skin, hair, eyes and lips. Due to this large range of races and parts on human faces, the accuracy of three basis functions used by other researchers needs to be re-evaluated. It is important to verify the accuracy of the number of basis functions used for all races and the accuracy of these basis functions applied to individual races and individual parts of human faces as well. The PCA method used in this research attempts to construct a small set of basis functions that summarize the original spectral data, thereby reducing the dimensionality of the original spectral data. The color accuracy of spectral reconstruction for all races, as well as individual races and individual parts, described by the extracted basis functions is provided and discussed. Moreover, some statistical characteristic comparison for the spectral reflectances of human facial skin, collected from a different source using contact-type measurement is included.

Experiment

The details of the experiment can be found in reference 13. Due to the limit of space, we will not repeat the experimental procedure here. Based on this experimental 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. The experiment was performed over a 7-month period. The subjects can be divided into five races, 11 subjects for Pacific-Asian, 8 for Caucasian, 7 for Black, 6 for Subcontinental-Asian and 2 for Hispanic. Each subject provided 16 spectral reflectances which, in general, will include 10 for facial skin, 3 for hair, 2 for eyes and 1 for lip. The locations of spectral measurement were randomly selected considering uniformity of sampling.

Results and Discussion

Based on the PCA results, the first three principal components for spectral reflectances of all races as well as individual races are shown in Fig. 1. It shows that the first three principal components of each race and all races have very similar shapes. This suggests the possibility that the first three principal components of any race may be used to describe the spectra of other races.

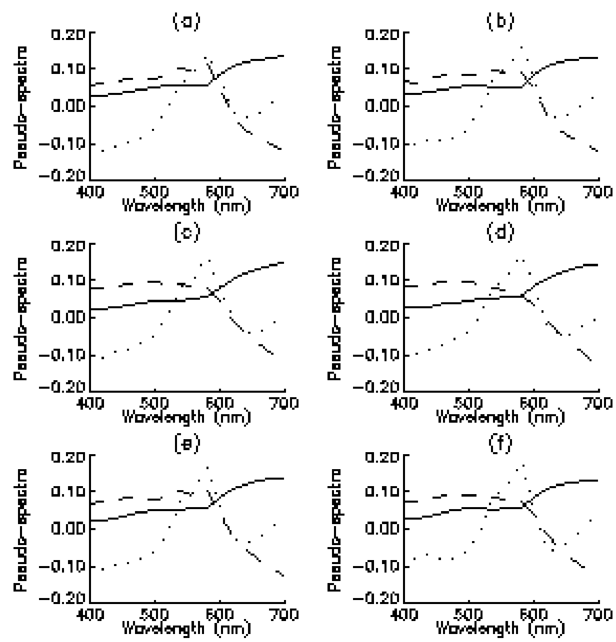

Figure 1. Graphs of the first three principal components of spectral reflectances for individual races and all races. Solid line is for 1st component, dot line for 2nd component and solid-dot line for 3rd component. (a) Pacific-Asian. (b) Caucasian. (c) Subcontinental-Asian. (d) Black. (e) Hispanic. (f) All races.

The cumulative contribution percentages of the first one to six principal components for spectral reflectances of all races as well as individual races are shown in Table 1. To save space in tables and graphs, the abbreviations PA for Pacific-Asian, C for Caucasian, SB for Subcontinental-Asian, B for Black, H for Hispanic and AR for all races will be used in the following sections. The results in Table 1 indicate that the first three principal components will cover over 99.8% of the variance for all spectral data of all races, and spectral data of individual races as well. This suggests that a spectral imaging system with proper selection of three basis functions will provide sufficiently accurate spectral reconstruction for all races as well as any individual race. Further observation indicates that, with three basis functions, the spectral reconstruction of Pacific-Asian, Caucasian and Hispanic races will have little bit more accurate results than that for Black and Subcontinental-Asian.

Table 1. Cumulative contribution percentage of principal components calculated from face spectra of individual races and all races.

# of PC	1	2	3	4	5	6
PA	99.56	99.76	99.95	99.98	99.99	99.99
C	97.75	99.65	99.91	99.96	99.98	99.99
SA	97.39	99.47	99.84	99.99	99.99	100.0
B	94.12	99.46	99.82	99.98	99.99	100.0
H	98.57	99.73	99.95	99.99	100.0	100.0
AR	97.87	99.57	99.89	99.97	99.99	99.99

Table 2. Cumulative contribution percentage of principal components calculated from face spectra of individual parts.

# of PC	1	2	3	4	5	6
Skin	97.90	99.40	99.83	99.95	99.98	99.99
Hair	98.76	99.88	99.95	99.99	100.0	100.0
Eyes	91.97	99.53	99.81	99.95	99.98	99.99
Lips	95.86	99.17	99.67	99.88	99.95	99.97

Table 3. Mean color difference in reproduction of individual races and all races using different sets of 3 principal components. The horizontal races are the spectral groups that yielded the principal components while the vertical races are the spectral groups the basis functions were applied to.

	PA	C	SA	B	H	AR
PA	**0.45**	0.95	0.73	1.05	0.60	0.98
C	0.66	**0.65**	1.06	1.20	0.65	0.83
SA	0.77	1.30	**0.54**	0.81	0.92	1.28
B	1.00	1.52	0.68	**0.84**	1.16	1.51
H	0.45	0.76	0.73	1.07	**0.46**	0.90
AR	0.67	1.05	0.76	1.00	0.78	**1.10**

The cumulative contribution percentages of the first three to six principal components for spectral reflectance of each facial part are given in Table 2. Not surprisingly, the first three principal components for most parts will provide over 99.8% variance of spectral reflectances with one exception of spectra of lips which is about 99.7%.

Next the mean color differences between spectral reflectances measured and reconstructed based on the first three basis functions are considered for the application of certain sets of basis functions to their own group and to spectra of other groups as well. The color difference equation applies $\Delta E^{*}ab$ with the CIE 2° observer and D_{50} illumination. The results shown in Table 3 are for different races. The basis functions based on spectra of all races will give smaller color difference for races of Pacific-Asian, Caucasian and Hispanic than that for races of Black and Subcontinental-Asian. This may be due to the facts that in heavy-pigment races, such as Black and Subcontinental-Asian, the spectral characteristics of hemoglobin are masked and show some slight specific property in spectra that need more basis functions to reproduce at the same level of accuracy as that for light-pigment races. It could also be due to the fact that more noise was involved in those data with lower signal. Considering individual race, not surprisingly, most races will have smallest color difference when the basis functions used for spectral reconstruction are based on their own spectra data. The basis functions based on light-pigment race will give smaller color difference when they are applied to light-pigment races. The same is true for the basis functions based on heavy-pigment races applied to heavy-pigment races. Mathematically, for basis functions based on all races, the variance of the data of five races are comparatively large because of including both low- and high-ordered statistics; for one race using one set of basis functions based on its own the variance of spectral data is comparatively small because of including only low ordered statistics. Hence, the best color reproduction or spectral matching will occur when spectra of each race employ its own set of basis functions. Most interesting is that the first three basis functions based on any individual races will provide smaller mean color difference for overall spectral reconstruction of all races. The first three basis functions of Pacific-Asian will provide the smallest color difference for overall spectra of all races; it will improve about 40%! Moreover, using this set of three principal components, the color difference of spectral reconstruction for other races will be decreased about 20 ~ 55% compared to that using the first three basis functions yielded from overall spectra. This suggests that to obtain better color reproduction of spectral imaging system, when using three basis functions under D_{50} illumination, the basis functions based on spectra of Pacific-Asian race will be the best choice, not the basis functions based on spectra of overall races. This may be partly due to the fact that the Pacific-Asian is medium-pigment race and its spectra have both characteristics shown in light- and heavy-pigment races. One thing should be emphasized here that, for the calibration purpose, the spectral data of all races is still required to get the maximum gamut. Further research indicates that, using six basis functions, the set of basis functions based on spectra of overall races will be the best choice. One should always keep in mind, however, that best colorimetric matching does not always guarantee to provide best spectral matching, and vice versa. Considering spectral reproduction itself, it may be better to estimate the root mean square (RMS) error between original spectra and reconstructed spectra. To more precisely demonstrate the color reproduction of spectral matching, the indices of metamerism employing Fairman's metameric correction using parameric decomposition[15] will be an alternative choice. Table 4.1 and 4.2 show the results of RMS and mean metameric indices using the same sets of basis functions as in table 3 respectively. The indices of metamerism were calculated using illuminants of D_{50} and A.

Table 4. RMS values and metameric indices of spectral resproduction for individual races and all races using different sets of three principal components. The horizontal races are the spectral groups yielded the principal components while the vertical races are the spectral groups the basis functions were applied to. (1) RMS values, unit of 10^{-4}; (2) Metameric indices.

	PA	C	SA	B	H	AR
PA	**29**	41	69	75	32	34
C	56	**38**	108	107	50	43
SA	51	55	**30**	32	48	40
B	57	58	34	**32**	54	43
H	27	32	62	69	**24**	32
AR	47	47	70	72	44	**39**

(1)

	PA	C	SA	B	H	AR
PA	**0.15**	0.29	0.38	0.46	0.21	0.26
C	0.25	**0.18**	0.51	0.52	0.23	0.19
SA	0.37	0.49	**0.24**	0.32	0.37	0.34
B	0.46	0.56	0.30	**0.34**	0.46	0.39
H	0.14	0.28	0.30	0.39	**0.18**	0.23
AR	0.28	0.35	0.37	0.43	0.29	**0.28**

(2)

Table 4 indicates that, for best spectral matching of overall spectra, the set of basis functions based on spectra of overall races will be the best choice. Because of the reason mentioned above, the best spectral reproduction or spectral matching for spectra of each race will occur when it employs its own set of basis functions. Both tables also show that overall reconstructed spectra based on the basis functions yielded from light-pigmented races will provide better color as well as spectral reproduction. As similar to the situation in the results of Table 3, Table 4.2 shows that the basis functions based on spectra of Pacific-Asian will still give much better color and spectral reproduction when applying to overall spectra of all races though basis functions based on spectra of all races will be the best choice, precisely. Further research indicates that, using more than three basis functions based on spectra of all races will provide remarkably smaller errors in spectral and colorimetric matching compared to using other sets of basis function based on other individual races though their difference may be not detectable for human visual system. In practice, however, we should consider this advantage provided by spectral of all races. It should be emphasized here that caution should be used when using RMS error to analyze the spectral reproduction since RMS error only provides information of the absolute spectral difference between measured and estimated results. For example, in Table 4.1, RMS values for Caucasian and Black are the same when using basis functions based on all spectra. However, considering the much smaller absolute values of spectral reflectances of Black compared to that of Caucasian, one concludes that basis functions based on all spectra will provide better spectral reproduction for Caucasian than for Black, which can be proved from the results in Table 4.2 that mean index of metamerism for Black is double the value for Caucasian.

Table 5. Mean color difference and indices of metamerism in reproduction of individual face parts using different sets of 3 principal components. The horizontal races are the spectral groups yielded the principal components while the vertical races are the spectral groups the basis functions were applied to. (1) Mean color differences; (2) Indices of metamerism.

	Skin	Hair	Eyes	Lips	AR
Skin	**0.64**	0.97	1.04	4.57	0.75
Hair	6.16	**0.13**	0.98	16.38	2.57
Eyes	1.20	0.40	**0.37**	2.03	0.62
Lips	1.45	0.70	1.13	**0.69**	1.13
AR	1.81	0.72	0.95	6.28	**1.10**

(1)

	Skin	Hair	Eyes	Lips	AR
Skin	**0.17**	0.82	0.23	0.90	0.18
Hair	1.95	**0.05**	0.29	4.47	0.71
Eyes	0.31	0.67	**0.12**	0.62	0.16
Lips	0.19	0.88	0.41	**0.13**	0.22
AR	0.53	0.66	0.24	1.50	**0.28**

(2)

The results shown in Table 5 are for different facial parts. It indicates that the set of first three basis functions based on all spectra will give at least double mean color difference for hair spectral reconstruction compared that for other parts. This may be due to the fact that spectral reflectances of hair are so dark that spectral reconstruction using three basis functions based on all spectra will yield some negative values in some wavelengths, hence larger color difference. The results also indicate that the basis functions from skin can not be used to describe the spectra of hair. On the other hand, somewhat surprisingly, basis function based on spectra of hair can be used to describe other parts very well. This shows that the major color difference occurs in the spectral reproduction of hair. However, since much of human portrait will deal with skin, it is worth using the set of basis functions yielded from overall spectra with the cost of relatively large color difference of spectral reproduction for hair. Our further research indicates that this problem can be solved using more basis functions based on overall spectra. Considering three basis functions based on spectra of lips, it shows that due to their specific spectral characteristics, they can not be used to describe spectra of other parts. The corresponding indices of metamerism are shown in Table 5.2. Table 5.2 proves that the set of first three basis functions based on all spectra will provide very good color and spectral reproduction for skin, eyes and lips with the cost of relatively high color and spectral error for hair. On the other hand, somewhat interesting, basis functions based on spectra of eyes will provide the smallest mean metameric index of overall spectra. However, it is not a best choice for spectral reproduction of skin. As mentioned, it is worth using the set of basis functions yielded from overall spectra, which will improve about 30% color and spectral reproduction of spectra of skin compared to that using basis functions based on eyes.

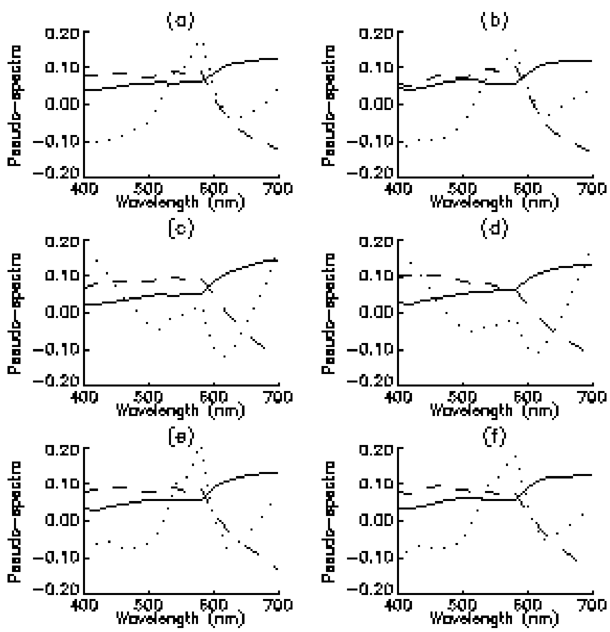

Figure 2. Graphs of the first three basis functions for spectral reflectances of facial skin of individual races and all races. Solid line is for the 1st component, dashed line for the 2nd component and dotted line for the 3rd component. (a) Pacific-Asian skin; (b) Caucasian skin; (c) Subcontinental-Asian skin; (d) Black skin; (e) Hispanic skin; (f) Skin of all races.

Since facial skin is the most important part in color and spectral reproduction of human portraits its spectral characterization is considered in more detail. The first three basis functions are shown in Fig. 2. It shows that, for skin spectra, three light-pigment races have very similar first three basis functions while the same is true for two heavy-pigment races. However, it is obvious that the third basis functions of light and heavy pigmented races are different. This may be due to the fact that skin of heavy pigmented races has masking effect on spectral characterization of hemoglobin. Comparing basis functions based on spectra of all skin in Fig. 2(f) and basis functions based on all spectra of all races in Fig. 1(f), it shows that the two sets of first three basis functions are very similar. This may be the reason why basis functions based on all spectra of all races can provide quite accurate color and spectral reproduction for spectra of skin, and vice versa.

The cumulative contribution percentages of the first one to six basis functions of skin spectra for individual races are shown in Table 6. It shows that three basis functions will cover over 99.7% of variance of skin spectra for each race.

Table 6. Cumulative contribution percentage of principal components calculated from spectra of skin spectra of individual races.

# of PC	1	2	3	4	5	6
PA	95.65	99.04	99.69	99.89	99.95	99.96
C	94.21	99.01	99.71	99.84	99.94	99.97
SA	97.36	99.34	99.78	99.98	99.99	99.99
B	97.77	99.60	99.92	99.98	99.99	99.99
H	96.40	99.45	99.82	99.97	99.98	99.99

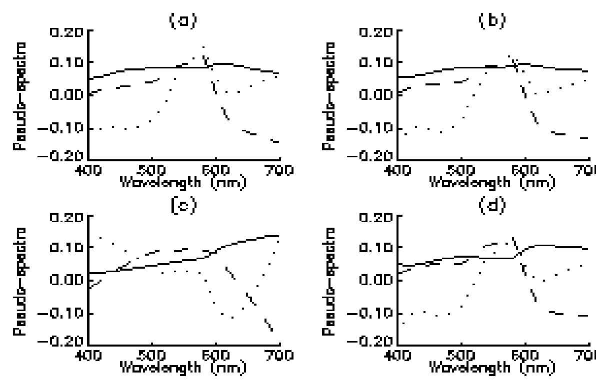

Figure 3. First three basis functions of skin spectra of individual races and all races in Oulu data. Solid line is for the 1st component, dashed line for the 2nd component and dotted line for the 3rd component. (a) Oulu Pacific-Asian; (b) Oulu Caucasian; (c) Oulu Black; (d) Oulu All.

The spectral reflectances shown above were measured using remote-type method. It is worth doing some comparison with spectra measured by contact-type method from other researchers. Based on current available spectral data, skin spectra only are concentrated on. The skin spectra measured by contact-type method here are provided by Dr. Pietikäinen from Oulu University, Finland [16] and referred to as Oulu data. Oulu data contains 357 spectra measured from facial skin of 119 subjects with Minolta CM-2002 spectrophotometer. Each subject provided 3 spectral measurements from left and right cheek and forehead. Details of Oulu data are given in reference 16. The Oulu data is characterized into three races, Pacific-Asian, Caucasian and Black. There were 10 Pacific-Asian subjects, 101 White and 8 Black. The first three basis functions of Oulu data of each race are given in Fig. 3.

Comparing Fig. 2 and Fig. 3, it shows that basis functions of light pigmented skin have very similar shapes while basis functions of heavy pigmented skin, Black skin, have very similar shapes of their own. The cumulative contribution percentages of the first one to six principal components of skin spectra for individual races in Oulu data are shown in Table 7. It shows that the cumulative percentage using three basis functions for light pigmented races, Pacific-Asian and Caucasian, in Oulu data are relatively small compared to that of the spectral data in Table 6. Japanese skin spectra reported by Imai[1] has comparable cumulative percentage using three basis functions with that of Pacific-Asian skin in our spectral data.

Table 7. Cumulative contribution percentage of principal components calculated from facial skin spectra of Oulu data from various races.

# of PC	1	2	3	4	5	6
PA	93.42	97.52	99.27	99.71	99.91	99.97
C	82.41	95.24	98.53	99.37	99.74	00.87
B	98.30	99.71	99.87	99.97	100.0	100.0
AR	94.20	98.45	99.60	99.81	99.92	99.96

Further research shows that basis functions based on all races will provide best color reproduction for overall skin spectra. Also, like the results in Table 3, basis functions based on light-pigment skin can not provide good color reproduction for heavy pigmented skin, and vice versa. Some other results will be provided on the presentation.

Conclusion

This research analyzes the statistical characteristics of spectral reflectance of human portraiture using PCA methods. The results show that the first three basis functions will provide sufficiently accurate color reproduction of spectral reconstruction for spectra of all races and individual races and individual facial parts as well. Considering color reproduction of spectral reconstruction using three basis functions in each race, the set of basis functions based on spectra of Pacific-Asian will provide best overall results. However, from spectral matching point of view, three basis functions based on all spectra will provide the best spectral reproduction. Skin spectra from different sources with different races show consistent statistical properties. Those results will provide us practical suggestion for imaging or spectral imaging system design for human portraiture. It may also have potential application to optimize spectral sensitivities of digital camera and set of inks of printer to provide best color reproduction of human face images.

Acknowledgements

The authors express their thanks to Eastman Kodak Company for their financial support for this research. The authors also express their appreciation to those who participated in this research.

Reference

1. F. H. Imai, N. Tsumura, H. Haneishi and Y. Miyake, Principal Component Analysis of Skin Color and Its Application to Colorimetric Color Reproduction on CRT Display and Hardcopy, *J. of Imaging Sci. and Tech.,* **40**, 5, pg. 422-430 (1996).
2. N. Tsumura, H. Haneishi, Y. Miyake, Independent-component Analysis of Skin Color Image, *Opt. Soci. of Amer.*, **16**, 9, pg. 2169-2176 (1999).
3. N. Tsumura, M. Kawabuchi, H. Haneishi, Y. Miyake, Mapping Pigmentation in Human Skin by Multi-Visible-Spectral Imaging by Inverse Optical Scattering Technique, *8th Color Imaging Conference,* pg. 81-84, Scottsdale, Arizona, USA, Nov., (2000).
4. L. A. Brunsting, C. Sheard, The Color of the Skin as Analyzed by Spectr0photometric Method. II. The Role of Pigmentation, *The J. of Clinical Investigation*, **7**, pg. 575-592 (1929).
5. L. A. Brunsting, C. Sheard, The Color of the Skin as Analyzed by Spectrophotometric Method. III. The Role of Superficial Blood, *The J. of Clinical Investigation*, **7**, pg. 593-613 (1929).
6. R. C. Cohen, *The Color of Man*, Rondom House, Inc., New York, (1968).
7. E. A. Edwards, S. Q. Duntley, The Pigments and Color of Living Human Skin, *The Amer. J. of Anatomy*, **65**, 1, pg. 1-33 (1939).
8. N. Kollias, A. Baqer, Spectroscopic Characteristics of Human Melanin in Vivo, *The J. of Investigative Dermatology*, **85**, 1, pg. 38-42 (1985).
9. W. R. Buck, F. Grum, Reflection Spectrophotometry, *Archives of Dermatology*, **83**, pg. 111-123 (1961).
10. G. B. Buck, H. C. Froelich, Color Characteristics of Human Complexions, *Illuminating Engineering*, **43**, 1, pg. 27-49 (1948).
11. E. Angelopoulou, The Reflectance Spectrum of Human Skin, http://www.cis.upenn.edu/~elli/tech-report.skin.pdf, (1999).
12. M. J. C. Van Gemert, S. L. Jacques, H. J. C. M. Sterenborg, W. M. Star, Skin Optics, *IEEE Transactions on Biomedical Engineering*, **36**, 12, pg. 1146-1154 (1989).
13. Q. Sun, M. D. Fairchild, "A New Procedure for Capturing Spectral Images of Human Portraiture," Proceedings, AIC Color 01, Rochester, USA, in press (2001).
14. http://www.whitehouse.gov/omb/fedreg/race-ethnicity.html, *Standards for the Classification of Federal Data on Race and*

Ethnicity, Office of Management and Budget, The White House, USA, August (1995).

15. H. S. Fairman, Metameric, "Correction Using Parameric Decomposition," *Color Res. Appl*., **12**, pg. 261-265 (1987).
16. The University of Oulu Physics-Based Face Database, http://www.ee.oulu.fi/~msoriano/pbfd.html, (2000).

Biography

Qun Sun received his B.S. degree in Radio-Physics from the East China Normal University at Shanghai (China) in 1985 and MS in Physics from Florida International University (USA) in 1997. He is currently a Ph.D. candidate in Imaging Science, Munsell Color Science Laboratory, Rochester Institute of Technology (USA). His current research focuses on the spectral imaging of human portraiture and imaging quality of spectral imaging system.