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Spectral Reconstruction of Blacks and Whites by Using the Statistical Colorants

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ABSTRACT

In this paper, the spectral dimensions of two sets of samples including 457 black and 84 white fabrics are compared. White fabrics are treated with variety of fluorescent whitening agents and the blacks are fabrics that dyed with different combinations of suitable dyes and pigments. In this way, the reflectance spectra of blacks as well as the total radiance factors of whites are compressed in one to five compressed spaces using the principal component analyzing technique. The reduced data are then reconstructed and the averages of the percentile relative root mean square errors between the actual and the recovered spectra of each dataset are calculated to show the spectral dimensionality of both groups through the analyzing of spectral errors. Besides, the colorimetric errors between the actual and the compressed-reconstructed spectra are represented by the mean values of ΔE_{00} color difference values under D65 illuminant and 1964 standard observer. Results show that the total radiance factors of white samples are smoother than the reflectance spectra of blacks and could be adequately described in a 2-dimensional space, while blacks need to be characterized in higher dimensions i.e., 4, to approximately provide same cumulative energy content as well as spectral and colorimetric errors. Prog. Color Colorants Coat. 8 (2015), 135-144 © Institute for Color Science and Technology.

1. Introduction

Blacks and whites are identified by their low chroma values and their distributions around opposite poles of lightness coordinate in different color order systems [1,2]. While the ideal black and white resemble two singular points over the opposite poles and bring a one-dimensional spectral behavior, the real samples demonstrate different tints and deviate from ideal colorimetric and spectrophotometric behaviors

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[3,4]. Benefits of different shades and tints for such neutral colorants play a very important role in various industries such as textile, cosmetic, paper, leather, printing and plastic [5].

Because of the high commercial importance of blacks and whites, several researchers worked on different colorimetric aspects of such achromatic colorants, either spectrally [3, 4, 6] or colorimetrically [2, 5, 7-12]. From the colorimetric point of view, various researches focused on the colorimetric properties of achromatics in different color order systems and represent an assessment index to evaluate blackness and whiteness based on the results achieved from visual assessment experiments [2, 5, 7-12]. In this way, different parameters like hue preference of observers, the variation in decision of participants, the effect of colorimetric attributes of objects and the other effective parameters were considered [5, 7-9, 11, 12]. While the CIE (1982) whiteness index has been accepted to evaluate white specimens, some researches focused on the efficiency of CIE(1982) whiteness formula and tried to represent more effective whiteness indices [10-12]. Contrary to whites, there is no accepted blackness index and researchers still try to represent a formula to assess the object's blackness based on the perceived blackness of observers [7, 8, 13, 14].

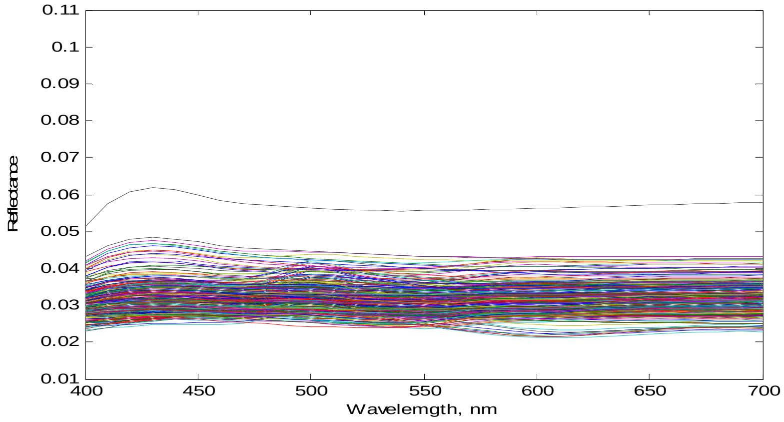
From the spectral point of view, it seems that the ideal achromatics exhibit one-dimensional behavior and could be assessed based on their corresponding lightness [3]. However in real world, achromatics deviate from the lightness axis and represent various tint attributes [3-5]. So, contrary to the first imagination, a one-dimensional gray space could not describe the spectral behaviors of achromatics. In fact, depending on the spectral variations of such samples at least a 2-dimensional subspace is needed to describe achromatics, reasonably. As expected, based on the inherent characteristic of these samples, the first dimension explains the neutral property of achromatic and the second one describes their tint attributes. Recently, the actual dimensions of spectral reflectances of blacks and whites have been individually discussed [4, 6] but in spite of inherent similarity, they have not been compared yet. This paper tries to extract the actual spectral dimension of huge sets of blacks and whites and compares them accordingly.

2. Experimental

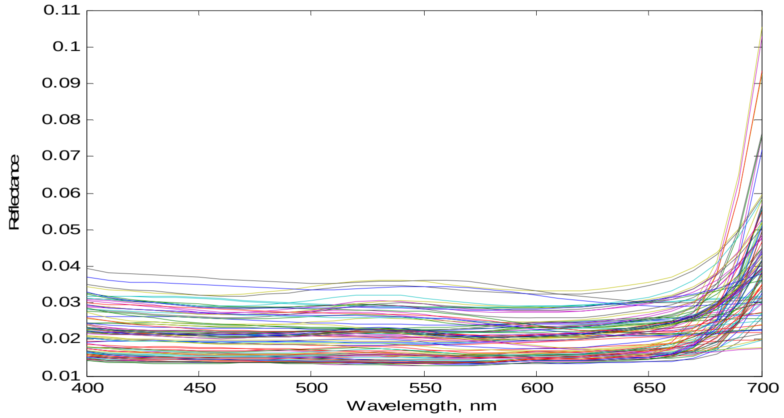
In order to compare the spectral dimensions of blacks and whites, two sets of samples including 457 black and 84 white fabrics were prepared. Different pigments and dyes, i.e., red, green, blue and yellow as well as different blacks were applied to prepare 457 black fabrics with various tints by printing and dyeing of woven cotton fabrics[4]. Color-Eye 7000A spectrophotometer from GretagMacbeth Company was used to measure the reflectance spectra of black samples. Samples were diffusely illuminated by a light resembling standard Illuminant D65 while the specular component of reflectance was included. The measurement was carried out from 400 nm to 700 nm at 10 nm intervals. Figure 1 shows the reflectance spectra of 457 black fabrics prepared by printing and dyeing methods over the visible wavelengths.

In addition, the total radiance factors (TRF) of 84 fluorescent whitening agents (FWAs) treated cotton fabrics were achieved from previous work [6]. Figure 2 explores the spectral behavior of 84 white fabrics. The principal component analyzing technique (PCA) [15-19] was employed to compress and recover the reflectance spectra of samples of each group in reduced spaces.

In this way, the first five characteristic vectors were extracted from the spectral domains of blacks and whites. Due to the bipolar spectral behavior of extracted eigenvectors they could not be considered as the real colorants which physically exist. Thus, they are defined as statistical colorants [4, 20]. The least square method was employed to achieve the concentrations of the extracted statistical colorants. By this way, the spectrophotometric matches were established between the actual and the reconstructed reflectances of blacks and whites.



(a)



(b)

Figure 1: The reflectance spectra of black fabrics prepared by a) printing and b) dyeing methods.

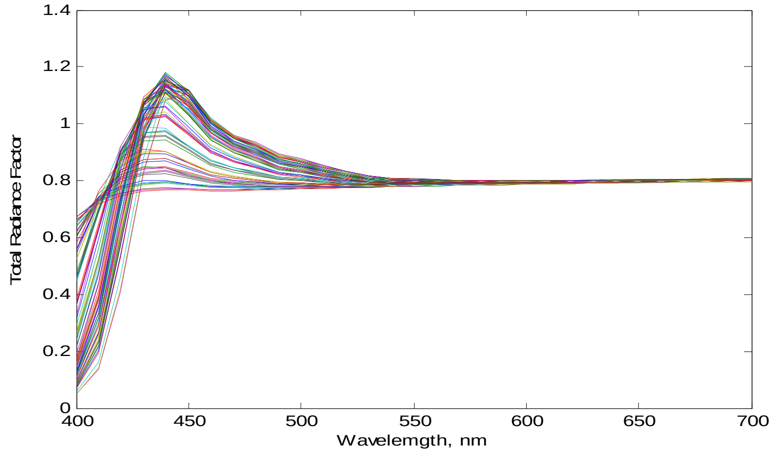


Figure 2: The total radiance factors of 84 white fabrics.

3. Results and discussion

Figure 1a shows that the printed black fabrics exhibit a nearly smooth spectral behaviors while, as Figure 1b demonstrates, distinctive tails are apparent for the dyed black series. On the other hand, based on Figure 2 the main variations of the total radiance factors of white fabrics relate to the short wavelengths of visible spectrum. Clearly, any deviation from smooth behavior of spectral data over the visible wavelengths affects the tint attribute of achromatics.

Table 1 shows the percentage of cumulative energy (CE%) [21] accumulated into reduced number of dimensions, i.e. 1 to 5 as well as the spectrophotometric and colorimetric errors of reconstructions. In this table, the averages of the percentile relative root mean square errors (rRMSE%) between the actual and the synthesized spectra of each dataset in different reduced spaces show the spectral errors. Besides, the colorimetric errors are represented by the mean values of ΔE_{00} color difference calculated under D65 illuminant and CIE1964 standard observer. According to Table 1, applying of the same number of eigenvectors results in greater values of CE% and the smaller values of corresponding rRMSE% for the whites in comparison to blacks. This indicates the lower spectral dimensionality of whites in comparison to black dataset.

It is worth to note that applying just one basis vector leads to the smaller mean value of color difference for blacks. This originates from the main spectral differences between the original and the reconstructed blacks in the two ends of visible spectrum. Oppositely, such spectral differences for whites are scattered around the 450 nm the bandwidth which the fluorescent whitening agents exhibit their maximum emissions. Obviously, such region is more sensitive for the human vision system than the two ends of visible spectrum.

Besides, as expected, describing of blacks and whites in higher dimensional spaces leads to less spectral and colorimetric errors. According to Table I, applying of 2 characteristic vectors results in recovering of 99.5% of total radiance factors of whites with acceptable spectral and colorimetric errors while 4 statistical colorants are needed to obtain the same results for blacks. It means that white samples could be described in more compressed spaces, e.g. 2, adequately while, to provide approximately the same spectral and colorimetric results, a higher dimensional spaces, e.g. 4, is needed to characterize black samples. Considering the results presented in Table 1, it is expected that the first 2 characteristic vectors extracted from the total radiance factors of whites behave like real colorants, spectrally. In other words, it is expected that the third, fourth and fifth statistical colorants extracted from the spectral domains of whites show less important data and/or the noisy spectral behavior over the visible wavelengths while for black fabrics, it is expected that the fifth extracted characteristic vector deviate from a smooth spectral behavior and could be the noise of measurements. To prove this claim, the first five eigenvectors extracted from the spectral domains of blacks and whites have been shown in Figures 3 and 4, respectively. In these figures, the lines signed by stars show the mean vector of spectral reflectances of blacks and whites.

Table 1: The percentage of cumulative energy as well as the spectral and colorimetric errors between the reconstructed and actual spectra of blacks and whites datasets in different reduced spaces.

# of eigenvectors	Blacks			Whites		
	CE%	rRMSE%	Mean DE00	CE%	rRMSE%	Mean DE00
1	86.50	5.13	1.36	88.16	3.81	1.70
2	97.15	3.18	1.34	99.57	1.39	0.24
3	98.70	2.10	0.76	99.81	1.09	0.17
4	99.51	1.29	0.30	99.92	0.35	0.17
5	99.75	0.95	0.21	99.98	0.14	0.10

As Figure 3 shows, the first and the second eigenvectors extracted from the reflectance spectra of black dataset show a contrary spectral behavior on the long wavelengths which results in duplicating the neutral behavior of the mean reflectance vector. According to Figure 3, it seems that the third and the fourth principal components are responsible to compensate the tint effect of blacks. On the other hand, Figure 4 shows that both the first and the second characteristic vectors extracted from the spectral domains of whites duplicate the spectral behavior of the mean total radiance factor.

Figures 3 and 4 and Table 1 show that whites could be reconstructed in a 2-dimensional space while blacks need to be described in a 4-dimensional space. In order to schematically compare the spectral behaviors of blacks and whites in compressed subspaces, the reconstruction results for three randomly selected samples, i.e., a white fabric, a printed black fabric, a dyed black fabric and a white fabric,, with 1 to 5 characteristic vectors are shown in Figures 5 to 7.

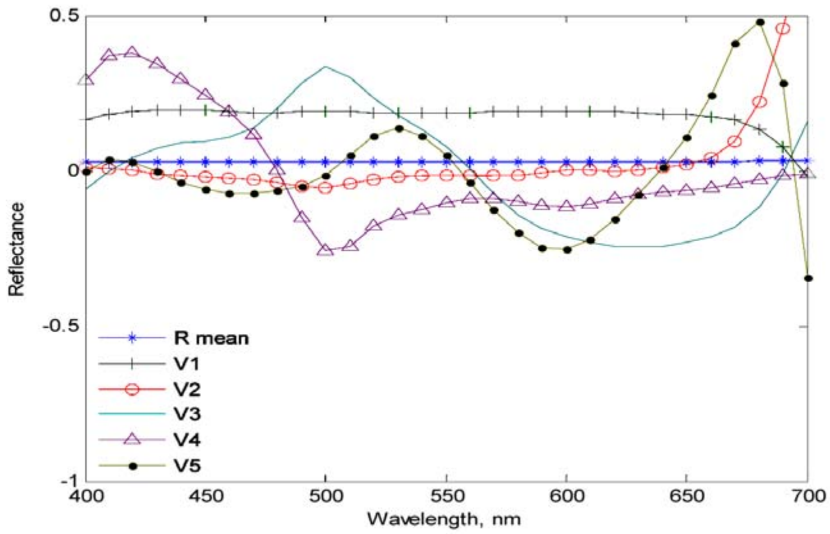


Figure 3: The first 5 characteristic vectors extracted from reflectance space of 457 black fabrics.

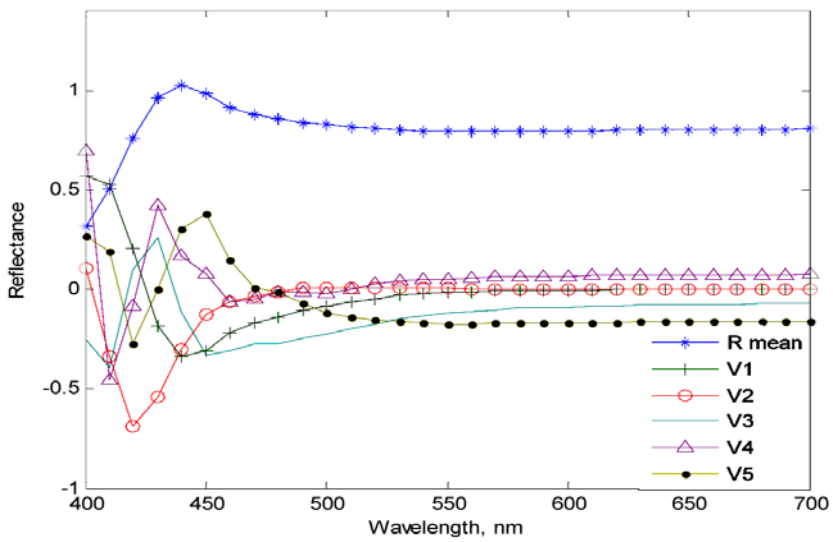
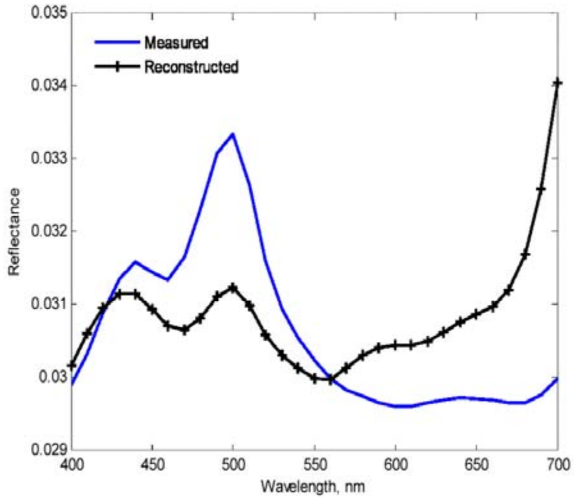


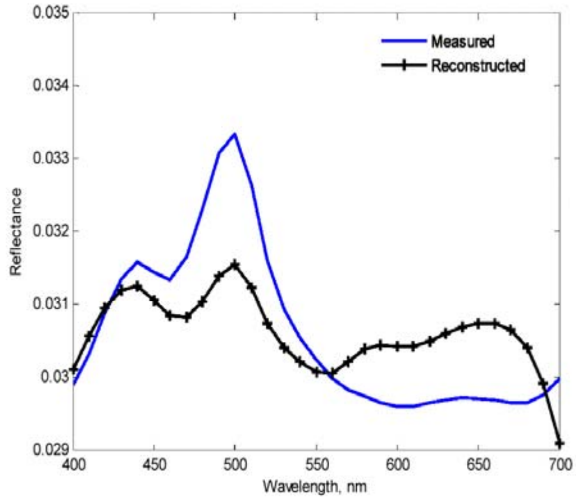
Figure 4: The first 5 characteristic vectors extracted from total radiance factors of 84 white fabrics.

Figure 5 (a to e) shows the measured and the reconstructed reflectance spectra of a black fabric prepared via printing method where the number of principal components employed to reconstruct the reflectance spectra increases from 1 to 5.

In these plots the solid line shows the measured reflectance and the line signed by (+) indicates to the reconstructed reflectance. According to Figure 5, as is expected, the differences between the measured and the reconstructed reflectance spectra decreases while the number of characteristic vectors increase. Besides, it is found that at least 3 to 4 statistical colorants are needed for satisfactory representation of printed black fabrics. Moreover, based on Figure 5e, it seems that by applying of the fifth statistical colorant, the reflectance spectra of black fabric could be fully recovered.



(a)



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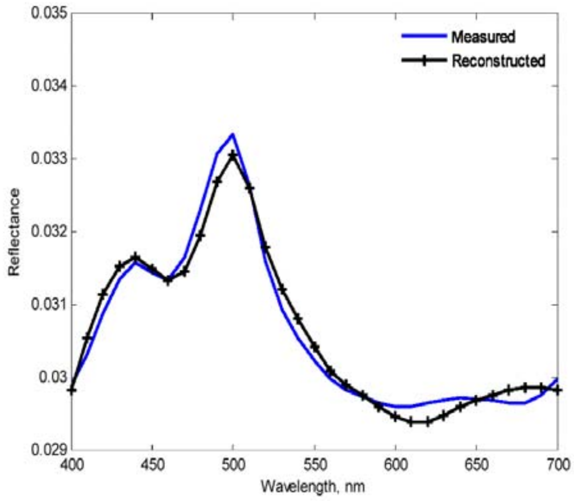
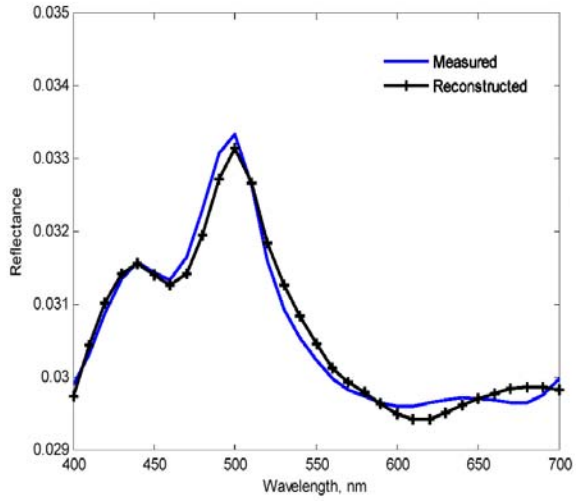
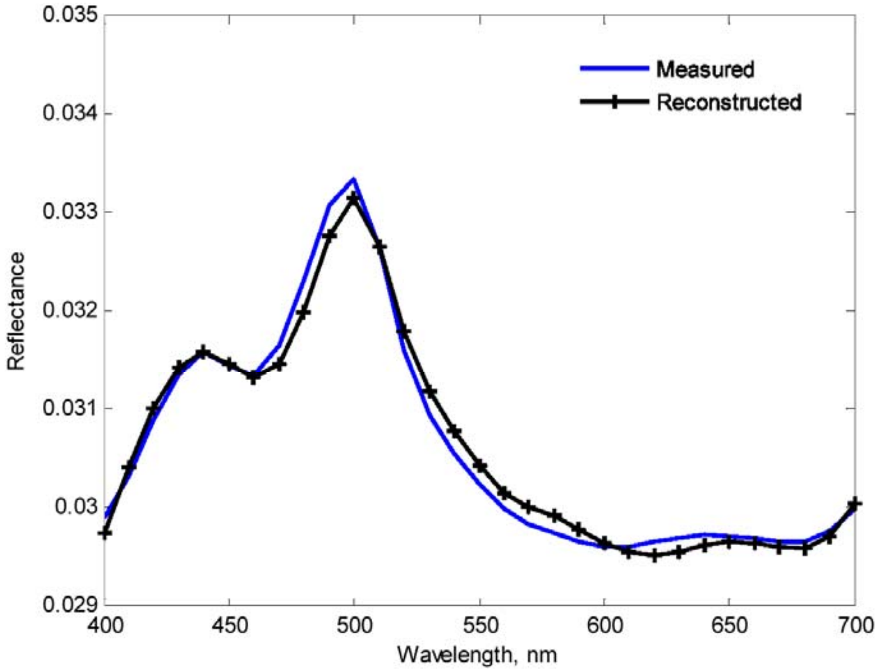


(c)



(d)

Figure 5: The actual and reconstructed reflectance spectra of a randomly selected black fabric prepared via printing method. The reconstruction has been done by applying of a)1, b)2, c)3, d)4 and e)5 statistical colorants.



(e)

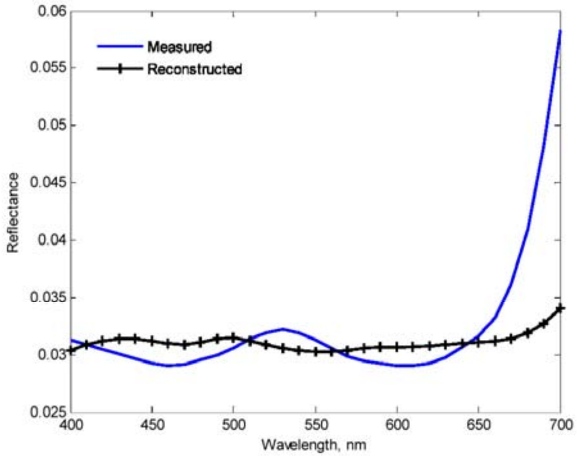
Figure 5: Continued.

Figure 6 (a to e) indicates the actual and the reconstructed reflectance spectra of a black fabric prepared via dyeing method where the number of characteristic vectors applied to reconstruct the reflectance spectra varies from 1 to 5.

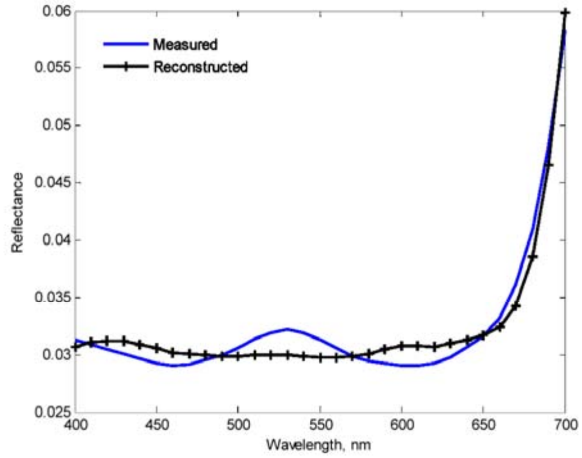
Again, the solid line shows the actual reflectance and the line signed by (+) indicates the reconstructed reflectance. As Figure 6 shows, increasing the number of statistical colorants leads to the decrease of the spectral differences between the measured and the reconstructed reflectances. On the other hand, comparing of Figures 6c and 6d confirms that there is not a significant difference between the recovered reflectance spectra of a dyed black fabric with 3 or 4 statistical colorants. Besides, Figure 6e shows that the reflectance spectra of a dyed black fabric could be approximately duplicated by applying 5 characteristic vectors.

Figure 7 (a to c) shows both the actual and the reconstructed total radiance factors of a fluorescent whitening agent treated fabric where the number of characteristic vectors applied to reconstruct the reflectance spectra increases from 1 to 3. Similar to Figures 5 and 6, the solid line shows the actual total radiance factor and the line signed by (+) indicates the reconstructed spectra. According to Figure 7a, applying just one characteristic vector results in a suitable recovery of the total radiance factor of randomly selected white fabric. Besides, based on Figure 7b, the total radiance factor of whites could be duplicated by employing 2 statistical colorants. With regard to Figures 7b and 7c, it is found that whites could be described in a 2-dimensional subspace, satisfactorily.

Comparing Figures 5, 6 with Figure 7 proves this fact that the total radiance factors of 84 white fabrics investigated in this research are scattered around 2 characteristic vectors suitably while for blacks a 3 to 4-dimensional subspace is needed to describe them, satisfactorily.



(a)



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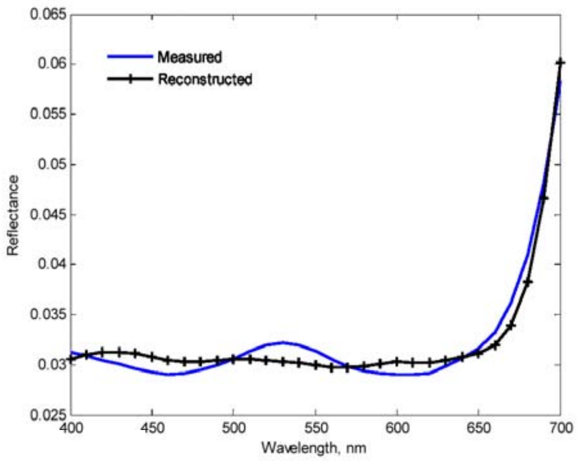

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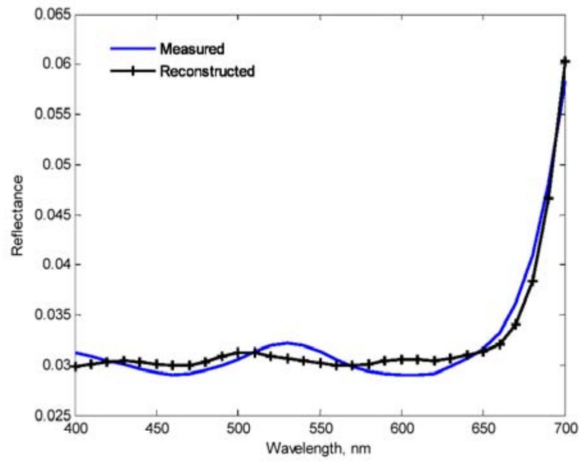
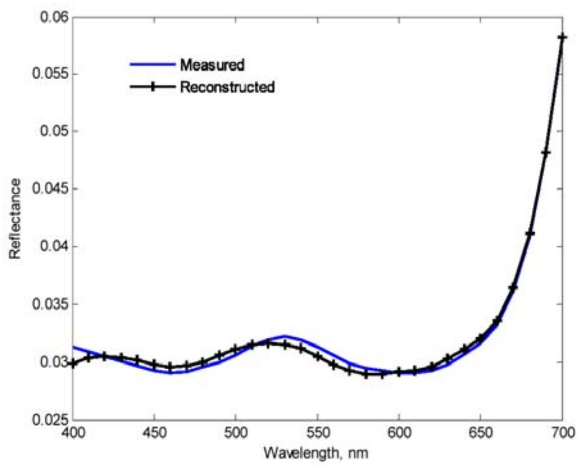


(d)



(e)

Figure 6: The actual and reconstructed reflectance spectra of a randomly selected black fabric prepared via dyeing method. The reconstruction has been done by applying of a)1, b)2, c)3, d)4 and e)5 statistical colorants.

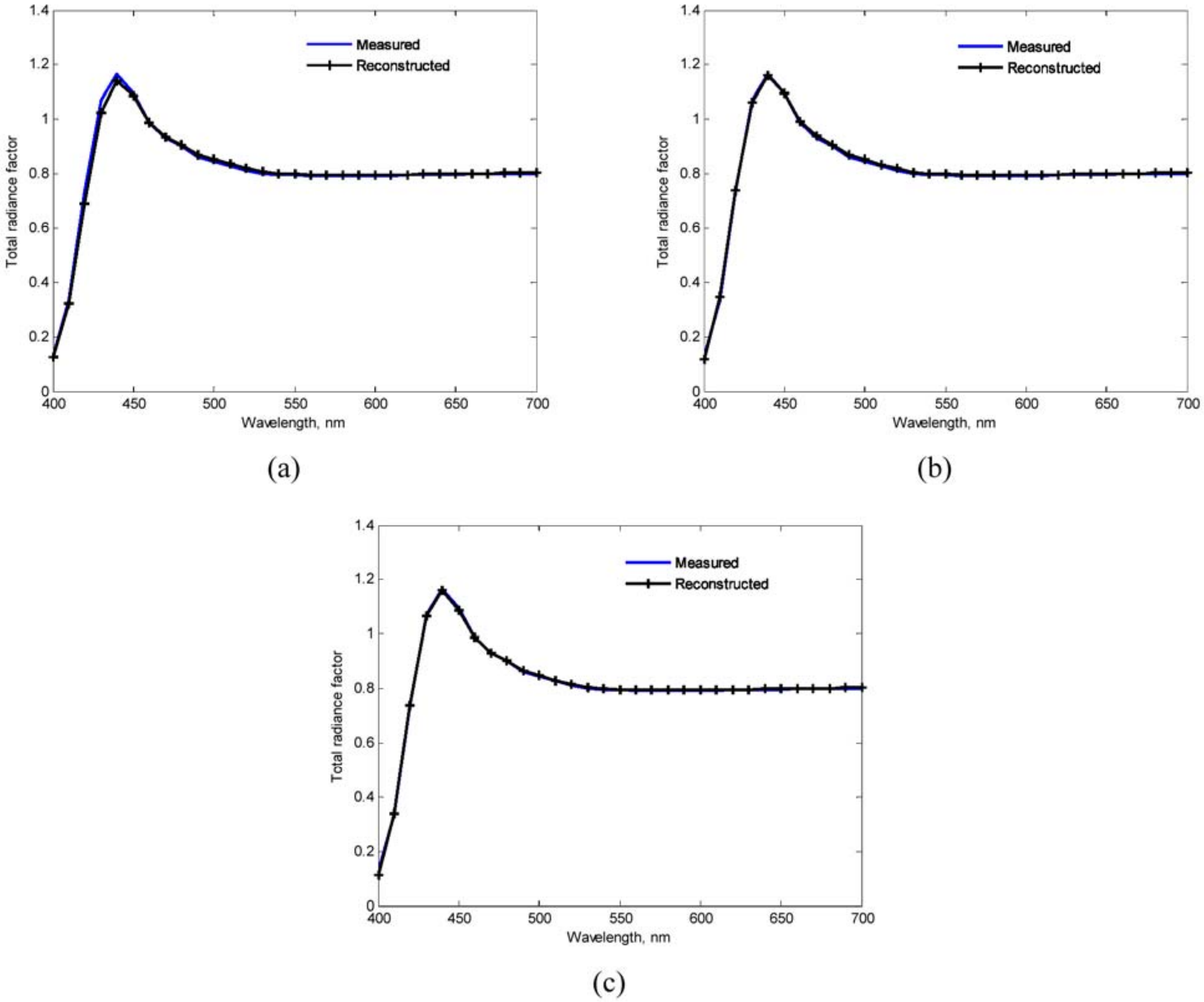


Figure 7: The actual and reconstructed total radiance factors of a randomly selected white fabric. The reconstruction has been done by applying of a)1, b)2 and c)3 statistical colorants.

4. Conclusions

In spite of our expectation, the real white and black samples, contrary to ideal one, have some deviations from the lightness axis which makes them to appear with different tints. From the spectral point of view, at least a 2-dimensional space is needed to describe the lightness and the tint effect of real achromatic fabrics. Because of the inherent similarity of blacks and whites, it is expected that these samples could be spectrally and colorimetrically represented in low dimensional spaces. In order to validate this proposal, the spectral behaviors of two sets of near to neutral samples including of 457 black and 84 white fabrics were compared. The principal component analysis technique was applied to compress and reconstruct the reflectance spectra of desired datasets in reduced spaces. Results showed that a 2-dimensional spectral space is enough for spectral characterization of white samples, sufficiently. On the other hand, for providing approximately same value of accumulated energy and the spectral and colorimetric errors, more statistical colorants i.e. 4, were needed to describe the black dataset.

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