Measuring and Analyzing the Colour of the Iris with a Multi-Spectral Imaging System

Meritxell Vilaseca, Rita Mercadal, Jaume Pujol, Montserrat Arjona, Marta de Lasarte; Centre for Sensors, Instruments and Systems Development (CD6), Department of Optics and Optometry, Technical University of Catalonia (UPC); Terrassa, Barcelona - SPAIN

Rafael Huertas, Manuel Melgosa; Department of Optics, University of Granada (UGR) Granada - SPAIN

Francisco H. Imai; Samsung Information Systems America (SISA); San José, California - USA

Abstract

In this work we evaluate the spectral reflectance and colour associated to the human iris. Some prosthesis used in the clinical practice and cosmetic coloured contact lenses are also analyzed. Specifically 100 real irises corresponding to 50 patients, 68 fake eye balls and 17 coloured contact lenses have been studied. The spectral reflectance profiles in the visible range of these samples have been measured by means of a multi-spectral system developed for this purpose. The system consists of a 12-bit digital CCD camera and an RGB tunable filter, which allows the acquisition of a magnified image of the patient's eye and the reconstruction of the associated spectra by means of the Moore-Penrose pseudo-inverse method. The true spectral reflectances of the samples are also measured using a conventional tele-spectracolorimeter. The measured and reconstructed spectra are compared using the CIEDE2000 colour difference formula as well as the Root Mean Square Error (RMSE). The results obtained show that the system allows the reconstruction of the curves associated to human irises, fake eye balls, and coloured contact lenses with a high accuracy, mainly when the system is trained using the human irises database.

Introduction

The study of the colour of the human iris is not a deeply explored field so far. The coloration of this structure depends on hereditary factors, such as the amount of melanocyte cells and melanine granules inside them, as well as their distribution[1]. The first measurements performed in this area were delimited to simple subjective observations of the eye.[2,3] Recently, some more studies focused on the iris colour measurement using standard colour instrumentation, specifically spectroradiometers and colorimeters, have appeared[4]. However, due to the own coloration and texture variability of the iris, the measure of its colour becomes a difficult issue because of the limited spatial resolution commonly present in those kinds of conventional devices. Often large areas of the iris are integrated and therefore only an averaged spectral reflectance profile, or equivalently a mean colour, can be extracted from the recollected data. Therefore, the use of systems with higher spatial resolution to characterize this structure is very advisable, and in consequence, the multi-spectral systems, which commonly consist of a digital camera with many pixels, are very appropriate to achieve this purpose.

In previous work[5] we developed a multi-spectral system in order to measure the spectral reflectance in the visible range and the colour associated to the human iris[6]. We optimized the performance of the system trying different configurations of acquisition channels or filters, checked its feasibility and evaluated its efficiency by means of the spectral accuracy in the reconstructions achieved. The results obtained showed that a common three channel colour camera (RGB) was enough in order to reconstruct the analyzed reflectances with a good accuracy. The colour measurements associated to the analyzed irises with this system showed colour differences smaller than 3 CIELAB units for most of the samples: a colour-difference size which claims for the use of advanced colour-difference formulas like CIEDE2000.

The next step was to build a greater database of spectral reflectances associated to the human iris using the system developed, jointly with other colour research groups, and it constitutes the main goal of the present work. The use of the developed multi-spectral system allows the measurement of the reflectance and the corresponding colour just taking an RGB picture of the iris analyzed. Specifically, in this study we present the reconstructed spectra of 200 new samples corresponding to 100 human irises, and the results are analyzed in terms of colour differences CIEDE2000[7] and the Root Mean Square Error (*RMSE*)[8]. This more extended and representative database will allow us to better study the spectral reflectance and colour of the human iris, and can be useful in some applications such as in medicine and the cosmetics industry.

In this context, the multi-spectral system has been also used in order to analyze the reflectance and colour associated to a complete set of 68 fake eye balls used in the prosthetics practice We have compared the reflectance and colour for both groups, that is, the real irises and the simulated ones, analyzing their differences by means of the PCA analysis. Furthermore, this analysis has been completed training the system with different sets corresponding to the two groups of samples analyzed. Finally, the system has also been used to measure the reflectance and colour associated to 17 coloured contact lenses, used in the cosmetics industry. The results obtained for those lenses have also been compared with the former ones. All this information can be of great help in the prosthetics and cosmetics industry, and can establish which colourings and pigments used for the prosthesis and also for the contact lens manufacturing have a more similar coloration to the real irises and therefore, present a more natural and realistic appearance under various illuminants.

This paper is structured as follows: in the following section the multi-spectral experimental set-up used to capture the colour images of the samples is presented. In the method and materials section the reflectance of the samples analyzed is described (real irises, prosthesis, and contact lenses) and the methodology and metrics used to obtain the spectral reconstructions are listed. After that, the reconstruction results obtained for the different groups of analyzed samples considered in the study are presented in the results section. Finally, in the last section the most relevant conclusions regarding the reflectance reconstruction quality and the comparison between groups of samples are described.

Experimental set-up

The multi-spectral system used to obtain magnified images of the entire iris, prosthesis, and contact lenses, consists of a 12-bit depth cooled CCD monochrome camera (QImaging QICAM Fast1394 12 bit) with 1.4 MPixels (1392 × 1040), an objective zoom lens (Nikon AF Nikkor 28 – 105 mm), and an RGB tunable filter. Additionally, the system is also composed of an adjustable halogen lamp (Philips 15V 150W) attached to a stabilized DC power supply (Hewlett Packard 6642A) and a focusing lens, which allow to light the analyzed samples with a 45º angle of incidence, obtaining a rather uniform luminous field on the eye[5]. A flat field correction was also applied on the complete system, in order to both correct the camera response and the non-uniformity of the illumination[9]. Finally, a conventional tele-spectracolorimeter (Instruments Systems Spectro 320) located beside the camera and with a high spatial resolution was also used in order to measure the true spectral reflectance associated to very small areas on the samples analyzed. In order to obtain the reflectance values of the samples, a previous measurement of the radiance corresponding to a reference white plate placed at the same position as the eye was also necessary.

Method and materials

With the described system, we measured the mean digital output levels of the samples corresponding to two square areas of approximately 1×1 mm on the iris (Fig. 1), which presented a rather uniform coloration. At the same time, the corresponding averaged spectral reflectances in the visible range (380 – 780 nm) of those zones were also measured using the spectroradiometer.

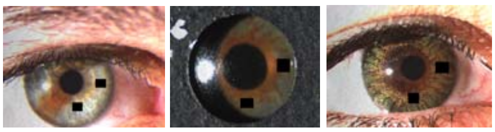

Figure 1. *Image of an iris, a prosthesis and a coloured contact lens, with the corresponding 2 analyzed areas.*

We analyzed 100 real human irises (50 subjects), 68 fake eye balls provided by a Spanish manufacturer (Ovidio S.L., Barcelona, Spain), and 17 coloured contact lenses (CIBA VISION Fresh Look) with very different colorations. The patient wearing the contact lenses in order to measure them was always the same and had a dark brown iris.

The true spectral reflectances corresponding to the three types of samples can be seen in Figure 2. A principal component analysis was performed over them. The cumulative proportion indexes (%), that is, the percentages explained by different number of eigenvectors for the different groups are listed in Table 1. The three principal vectors and the mean vector associated to each of them can also be seen in Figure 3.

As it can be seen, for the three groups of samples, the three first principal components explain more than the 99% of their variance. This is in agreement with former studies[5] in which it was found that three channels (RGB) were enough to obtain good reconstructions of the spectral reflectances associated to the human iris. The group of prosthesis is the one with the largest associated variance, meaning that there is a larger variability among spectra in this set than in the other two. The contact lenses are the group with the smallest variability, mainly because its smaller size in terms of number of samples. In Figure 3, it can be seen that the principal components associated to the groups of samples are similar, although they are not exactly the same.

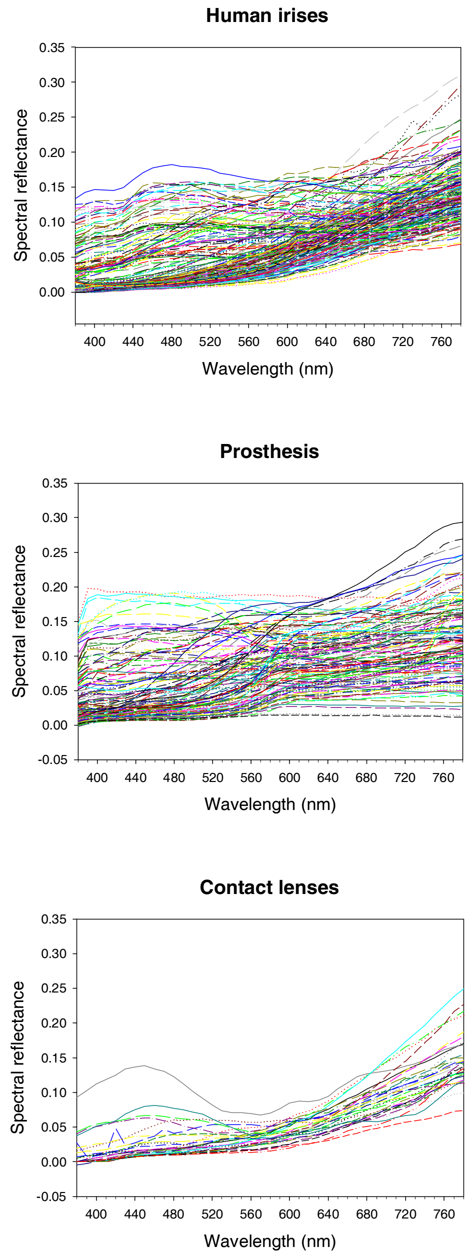

Figure 2. *Spectral reflectances of the analyzed human irises, prosthesis and coloured contact lenses.*

Table 1: Cumulative proportion index (%) for the three principal components corresponding to the human irises, prosthesis and coloured contact lenses.

PC	Irises	Prosthesis	C. lenses
1	95.22	94.51	97.38
2	98.70	97.34	99.13
3	99.72	99.08	99.61

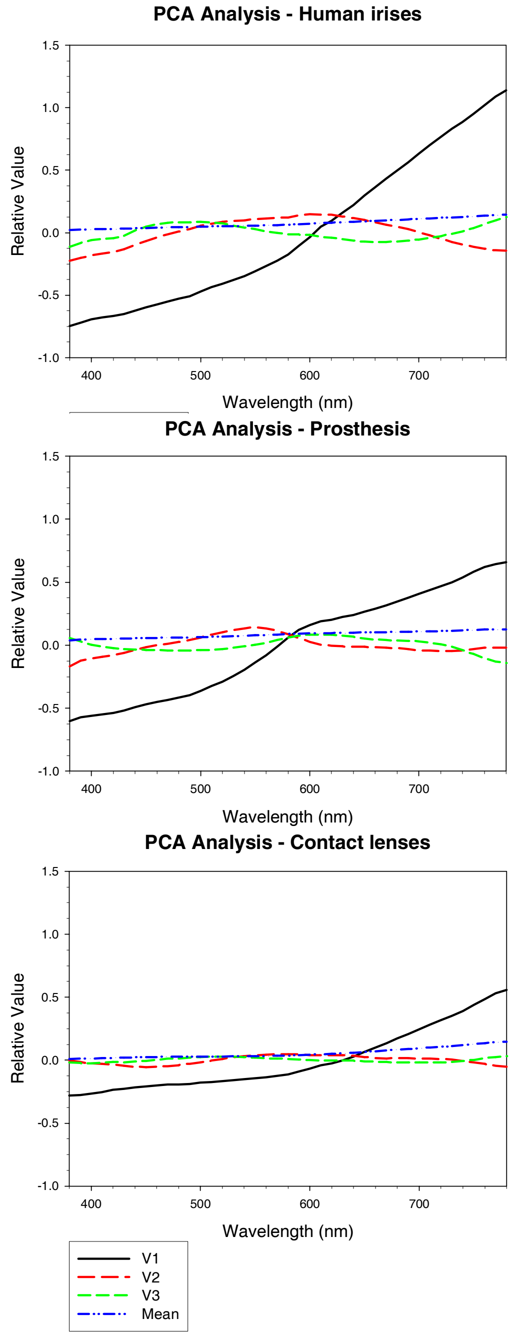

Figure 3. *Three principal vectors and mean vector corresponding to human irises, prosthesis and coloured contact lenses.*

The multi-spectral system developed used the Moore-Penrose pseudo-inverse estimation (PSE)[10] in order to reconstruct the spectral reflectances of the samples. This method requires a large and representative set of colour samples (training set) to train the system before performing the reconstructions of the studied samples (test set).

In this work, the reconstructions of the spectral reflectances of the three groups of samples were obtained with different combinations of test and training sets. First of all the same group of samples was used as test and training set, in order to analyze the feasibility of the system for reconstructing itself the spectral data. Secondly, different groups of samples were used as test and training sets, in order to study the capability of each group of samples for representing or describing the other two groups, in terms of spectral reflectance.

In order to compare the results obtained, that is, to compare the measured spectral reflectance and the reconstructed one, two metrics have been used: the last colour-difference formula proposed by the Commission of Illumination (CIE), CIEDE2000, and also the Root Mean Square Error (RMSE).

Results

As mentioned before, first of all the spectral reconstructions of the three kinds of samples were assessed, using the same groups as training and test sets. The corresponding results are shown in Table 2.

Table 2: CIEDE2000 and RMSE statistics comparing the measured and reconstructed spectral reflectances for the three groups of analyzed samples when the same group is used as training and test set.

	CIEDE2000	RMSE
Training set: Human irises Test set: Human irises		
Mean	3.16	0.0139
St. Dev.	1.41	0.0083
Min.	0.64	0.0030
Max.	6.97	0.0442
Training set: Prosthesis Test set: Prosthesis		
Mean	2.32	0.0130
St. Dev.	1.07	0.0073
Min.	0.54	0.0029
Max.	5.23	0.0402
Training set: Contact lenses Test set: Contact lenses		
Mean	3.30	0.0135
St. Dev.	1.22	0.0078
Min.	0.99	0.0033
Max.	5.14	0.0293

The three groups analyzed have mean colour differences (CIEDE2000) about 3 units or even smaller, meaning that the reconstructions in terms of colour differences are very accurate. The same conclusion is obtained when the RMSE parameter is studied. In this case, values in the range 0.013-0.014 are obtained, and they lead to good reconstructions of the visible reflectance. However, it can be seen that the best results are obtained for the prosthesis, for which the mean CIEDE2000 and RMSE are slightly smaller. This can be explained taking into account experimental errors associated to the measurements: the fake eye balls do not present any movement associated meanwhile for the other two types of samples, where the patient' eye is part of the scene, this is not true. This leads to a less precise measurement in the last cases.

From the results presented above, it can be affirmed that the system has the capability of providing accurate reconstructions of the visible spectral reflectances of the samples, when it is tested with the same group of samples with which it is trained.

Figure 4 shows some representative examples of spectral reflectance reconstruction for the human irises, the prosthesis and the contact lenses. Specifically, the best and the worst reconstructions for each group taking into account the CIEDE2000 formula can be seen.

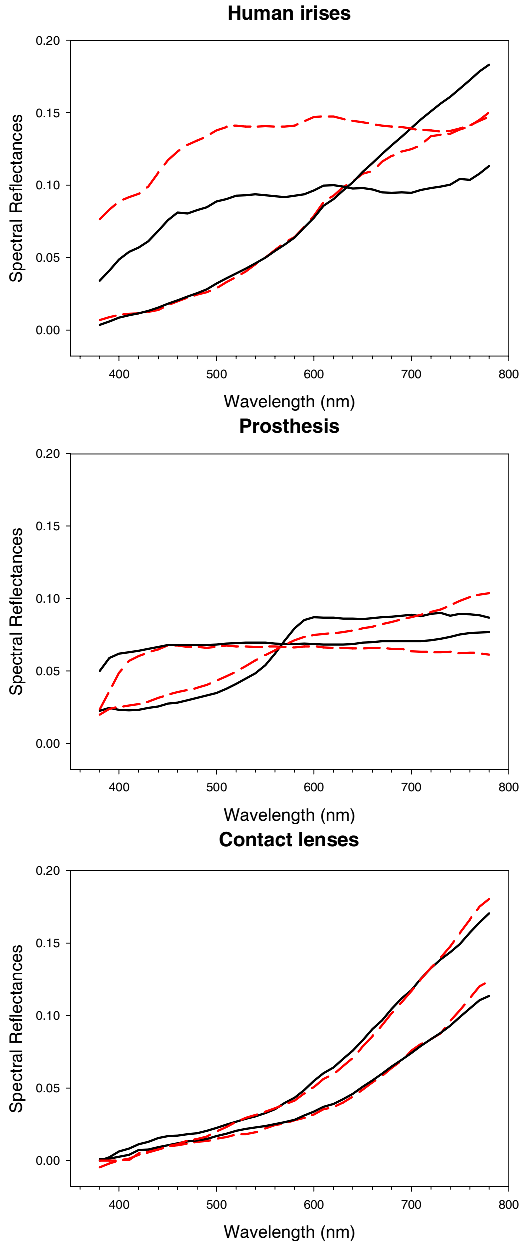

Figure 4. *Best and worst spectral reflectance reconstruction for the three groups of samples analyzed: human irises, prosthesis and coloured contact lenses.*

Once the feasibility of the system has been tried, the next step is answering whether the system can be trained with a different set of samples regarding the actual test set. That will inform us about the capability of each group of samples for describing the spectral reflectance profiles of the other two groups. The obtained results in this case are shown in Table 3.

It can be seen that when the system is trained using the human irises, the reconstructions for the prosthesis and the contact lenses are still rather accurate, meaning that the 100 irises are a quite good representation of all the colours associated to the different samples analyzed. In this case, the mean colour differences are still close to 3 CIEDE2000 units, and the RMSE is similar or smaller than 0.02, values for which the reconstructions can be still considered accurate. Better results are obtained for the contact lenses, probably due to the fact that the measurements of these samples are performed on a real iris, and therefore, the actual reflectance measured is mainly affected by the contact lens but also by the colour of the patient's iris underneath.

Table 3: CIEDE2000 and RMSE statistics comparing the measured and reconstructed spectral reflectances for the three groups of analyzed samples when a different group is used as training and test set.

	CIEDE2000	RMSE
Training set: Human irises Test set: Prosthesis		
Mean	3.71	0.0198
St. Dev.	1.56	0.0147
Min.	0.74	0.0040
Max.	7.65	0.0730
Training set: Human irises Test set: Contact lenses		
Mean	3.10	0.0166
St. Dev.	1.39	0.0088
Min.	1.01	0.0030
Max.	7.03	0.0405
Training set: Prosthesis Test set: Human irises		
Mean	4.84	0.0211
St. Dev.	1.60	0.0108
Min.	0.71	0.0059
Max.	9.72	0.0729
Training set: Prosthesis Test set: Contact lenses		
Mean	5.18	0.0233
St. Dev.	1.34	0.0091
Min.	2.33	0.0124
Max.	8.69	0.0500
Training set: Contact lenses Test set: Human irises		
Mean	4.86	0.0214
St. Dev.	2.27	0.0116
Min.	0.60	0.0025
Max.	10.81	0.0588
Training set: Contact lenses Test set: Prosthesis		
Mean	7.51	0.0321
St. Dev.	3.00	0.0152
Min.	1.66	0.0069
Max.	14.59	0.0734

On the other hand, when the system is trained using the prosthesis and the reflectances belonging to the other two groups of samples are reconstructed, the results are slightly worse. The mean CIEDE2000 in these cases are around 5 and the RMSE are higher than 0.02. This implies that the reflectances associated to the 68 fake eye balls do not represent the other samples with as good precision as the real irises do. This could be because of the colourings and pigments present in this kind of samples as well as the texture, features which can differ from the real colours of the iris. The same explanation could be applied to the contact lenses, because as it has been stated before, the colour measured on them is also affected by the real iris under them.

Finally, if the coloured contact lenses are used as the training set in order to reconstruct the human irises and the prosthesis, the results obtained are in general very poor. In these cases the mean CIEDE2000 colour-differences are 4.86 and 7.51 respectively, but in both cases the standard deviation associated is very high, meaning that there is a high dispersion among the results. This can also be seen with the corresponding ranges, that is, the minimum and maximum colour difference and RMSE. This can be due to the limited number of contact lenses analyzed, as well as their reflectance profiles, which can not be representative of the real reflectances present in human eyes and also the fake eye balls.

Conclusion

In this work we study the spectral reflectance curves and the colour associated to the human iris as well as used in the clinical practice and cosmetic coloured contact lenses. The spectral reflectance curves in the visible spectrum of the three groups of samples are analyzed with a conventional spectroradiometer and also a multi-spectral system with three channels, obtained with a tunable RGB filter. The reconstructed spectral profiles are compared with the measured ones by means of two different parameters: the CIEDE2000 colour-difference formula and the Root Mean Square Error (RMSE).

For the three types of samples, and when the system incorporates the same group of samples as training and test sets, it can be seen that the reconstruction results are very accurate. In this case the mean colour differences are around 3 CIEDE2000 units, or even lower in the case of the prosthesis because a minor experimental error is present. The mean RMSE is close to 0.013-0.014. These results provide quite good reconstructions, and in general, the reconstructed and measured profiles are similar.

Finally, the system is evaluated when different groups of samples are used as training and test sets. In this case, the best reconstructions are obtained when the system is trained with the human irises. Using this training set, both the prosthesis and the contact lenses can also be reconstructed, and the mean CIEDE2000 is still close to 3 units, meanwhile the RMSE is slightly lower than 0.02. When the system is trained by means of the fake eye balls, the results for the other two groups are not as good. In this case the mean CIEDE2000 is about 5 and the RMSE is higher than 0.02. Therefore, it can be concluded that the prosthesis do not represent the other samples with as good precision as the real irises do. This can probably be explained because of the colourings and pigments present in this kind of samples, which differ from the other. The reconstructions of irises and prosthesis obtained using the contact lenses as training set are even worse, probably due to the limited number of contact lenses measured here, and their specific colorations on just one dark brown iris.

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Author Biography

Meritxell Vilaseca completed her BSc Degree in Physics at the Autonomous University of Barcelona in 2000 and received a Ph.D. in Optical Engineering from the Technical University of Catalonia in 2005. She completed her Degree in Optics and Optometry at the Technical University of Catalonia in 1996. She is currently working as a researcher in Optical Engineering at the Technical University of Catalonia. Her work focuses on colour imaging (device calibration and characterization, colour management, spectral imaging) and industrial colorimetry.

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