How a 6-band LED and RGB Camera based Multispectral Imaging System Performed in COSCH Round-Robin Test

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ABSTRACT

Spectral object documentation working group in the COSCH (Colour and Space in Cultural Heritage), a European COST (COperation in Science and Technology) Action, conducted a round-robin test (RRT) with an objective of developing a comprehensive set of guidelines for spectral imaging based on devices and practices used by more than 20 European research laboratories. This paper presents results from a 6-band LED and RGB camera based multispectral imaging system (RGB-LEDMSI), which was one of the systems participated in the RRT. The RGB-LEDMSI system acquires a 6-band multispectral image in two exposures with three different LEDs lit at a time in quick succession. Spectral reflectance image is estimated from the 6-band image using a spectral estimation method. Performance of the system has been compared with a pushbroom hyperspectral imaging system. Results have shown that the system performed comparably with the hyperspectral system, but with a significantly higher spatial resolution and acquisition speed, confirming feasibility of the system and its potential to be used in cultural heritage applications.

KEYWORDS: multispectral, LED, COSCH, round-robin test

INTRODUCTION

COSCH (Colour and Space in Cultural Heritage) project was a four-year (2012-2016) European COST (COperation in Science and Technology) Action (http://cosch.info/) aimed at simplifying and defining good practices in high quality measurement and documentation of cultural heritage (CH) artifact; and fostering open standards for their state-of-the art documentation. COSCH Working Group 1 (WG1), one of the five working groups, responsible for spectral object documentation aimed to identify and explore important characteristics of different spectral imaging systems and understand how they influence data accuracy and information reliability with respect to the various types of studied artworks [1]. Spectral imaging has been used for accurate digital documentation of artworks. However, many different types of devices and techniques have been developed for spectral imaging in general and in cultural heritage applications [2]. The working group WG1 conducted a round-robin test (RRT) with an objective of developing a comprehensive set of guidelines for spectral imaging based on devices and practices used by more than 20 European research laboratories that took part in the RRT [3].

Spectral imaging has demonstrated to be beneficial for a wide range of applications including cultural heritage. However, because of the slow acquisition process, high cost and complexity of the existing systems its use has been limited. I have proposed several fast and inexpensive multispectral imaging systems (MSIs) and technologies in my PhD research towards fast multispectral imaging systems [4], such as a single-shot stereo camera based system (StereoMSI) [5], filter array based systems (FAMSI) [6], and LED and RGB camera based systems (RGB-LEDMSI) [7].

I had a privilege to be involved in the COSCH project as a WG1 member, and attended several meetings and training schools. I participated in the COSCH RRT to validate feasibility and effectiveness of our proposed systems in cultural heritage applications. The focus of this paper is on one of the systems participated in the RRT, a 6-band RGB-LEDMSI system. This system is based on the design and methodology proposed in [7]. The system can acquire a high resolution multispectral image at a very high speed, in just two exposures. The result from the system has been compared with a pushbroom hyperspectral imaging system used as a reference.

After this introduction, experimental setup is described in the next Section. Results are then presented and discussed in Section 3, and the paper is finally concluded in Section 4.

EXPERIMENTAL

A prototype 6-band RGB-LEDMSI system was built with a Nikon D600 RGB camera, and six LEDs from a JUST Normlicht's LED ColorControl light booth. A 6-band image is acquired in two exposures under two different LED combinations; each combination consisting of three different LEDs whose peak wavelengths lie in the three different regions (red, green, and blue) of the camera sensitivities. Optimal LED combinations 1-3-5 and 2-4-6 for the two exposures were selected using the LED selection method proposed in [7].

The RRT used the five selected 2D-object samples: a X-Rite ColorChecker Classic, a X-Rite White Balance, a nearly Lambertian SphereOptics Zenith Polymer Wavelength Calibration Standard, a Russian Icon printed on tin plate, and a Painted Color Panel reconstructed with medieval Tuscan technique [3]. Images of these sample objects are given in ***Figure 1***.

(a) *ColorChecker*
(b) *White Balance*
(c) *SphereOptics Polymer*
(d) *Russian Icon*
(e) *Painted Color Panel*

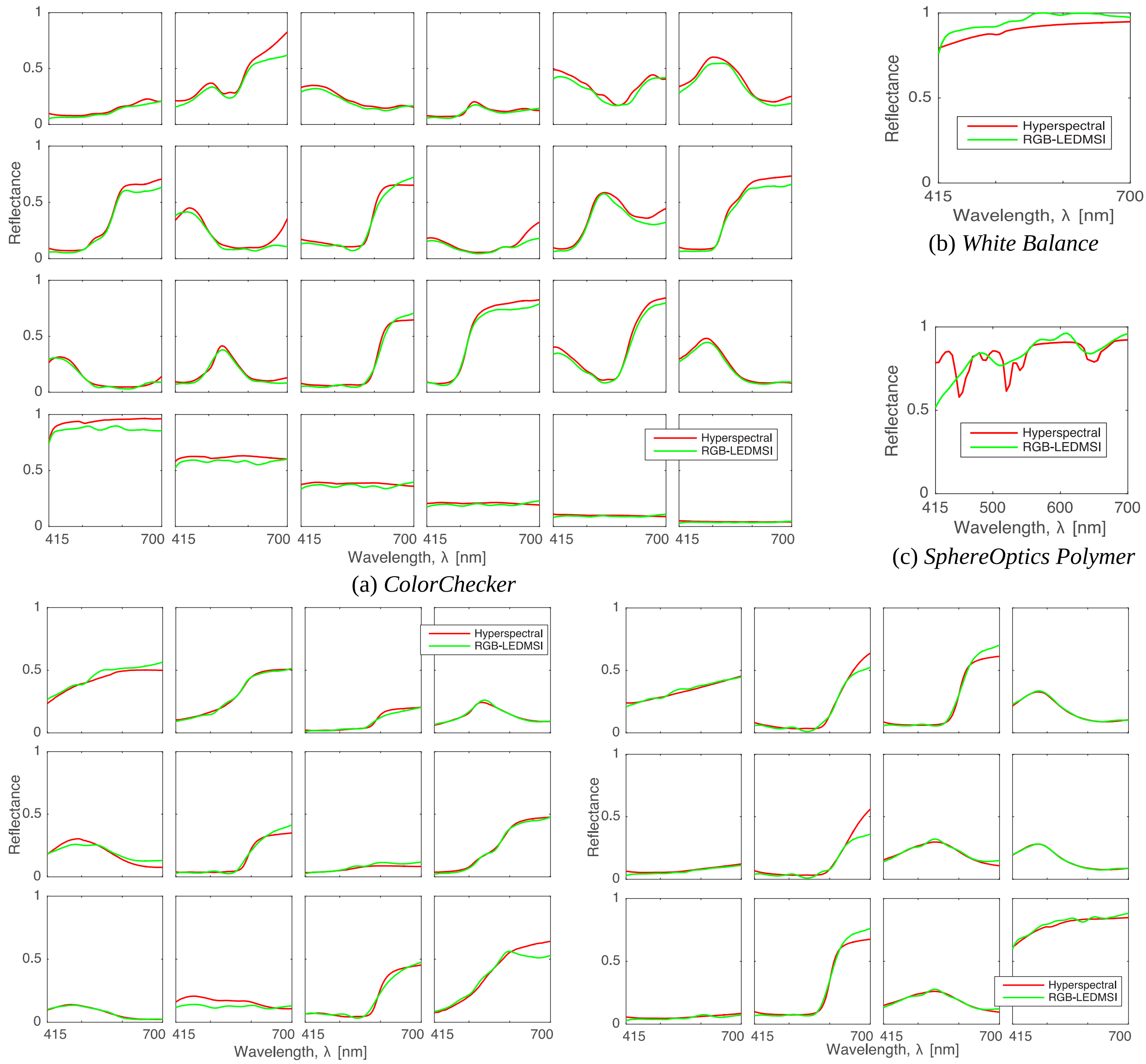
Figure 1. Sample objects used in the RRT. Selected areas in the Icon & Color Panel are marked & numbered.

Multispectral images of all the five sample objects along with a Macbeth ColorChecker DC (MCCDC) were acquired using the RGB-LEDMSI system. These images are then corrected for DC noise, non-linearity, and non-uniformity [4]. Bilinear interpolation is used to obtain a 3-band image from a raw camera sensor image [8]. The RGB-LEDMSI system is calibrated using the most significant sixty-two patches selected from among the two hundred and forty MCCDC patches using the selection method proposed by Hardeberg et al. [9]. Spectral reflectance images of the objects are then estimated from the six camera response values using the most widely used Wiener estimation method [10].

Hyperspectral images of the samples acquired with a VNIR pushbroom hyperspectral imaging operated in the 415-1000nm range are used as reference images to compare the performance of the RGB-LEDMSI system. Results are compared spectrally using GFC (Goodness-of-Fit Coefficient) and RMS (Root Mean Square) error metrics and colorimetrically using CIELAB ΔE^*_{ab} color difference metric.

RESULTS AND DISCUSSION

Vitorino et al. [11] highlighted that each color patch in the ColorChecker is not completely homogeneous. Rectangular areas within similar color regions in a sample image are manually selected, and average spectral reflectances of the surfaces are obtained. Twelve different areas in the Icon and the Color Panel images, 24 color patches of the ColorChecker and one central area in each of the White Balance and SphereOptics polymer samples are selected. ***Figure 1*** shows the areas selected and numbered in the Icon and the Color Panel images. ***Figure 2*** depicts the averaged spectral reflectances of the selected areas in the five objects obtained from the RGB-LEDMSI system along with the reference hyperspectral system. SURF feature based image registration algorithm [12] was used to obtain corresponding points in the images acquired with the two systems. Manual adjustments were made in case image registration didn't work well. Statistics of spectral and color estimation errors in case of all the five sample objects are given in ***Table 1***.



(a) *ColorChecker* (b) *White Balance* (c) *SphereOptics Polymer* (d) *Russian Icon* (e) *Painted Color Panel*

Figure 2. Averaged spectral reflectances of the selected areas (given column-wise) in the 5 samples.

Table 1. Statistics of spectral and colorimetric estimation errors.

Sample object	GFC		RMS		ΔE^*_{ab}	
	Mean	Std.	Mean	Std.	Mean	Std.
ColorChecker Classic	0.9960	0.0059	0.035	0.018	2.96	0.77
White Balance	0.9998	-	0.054	0.000	2.38	-
SphereOptics Polymer	0.9943	-	0.090	0.000	5.72	-
Russian Icon	0.9958	0.0044	0.023	0.015	4.18	2.19
Painted Color Panel	0.9965	0.0044	0.021	0.016	2.90	1.50
Average	0.9965	0.0049	0.044	0.010	3.63	1.49

From the spectral curves, we see that the estimated spectral reflectances of most of the surfaces from the RGB-LEDMSI system are quite close to the ones from the hyperspectral system. Both spectral & colorimetric estimation errors are reasonably good with the average GFC, RMS and ΔE^*_{ab} values of 0.996, 0.044 and 3.6 respectively; indicating a comparable performance of the two systems. The same but lightly and heavily painted color in the Color Panel produced similar reflectance curves, indicating systems' capability in identifying the pigments.

Performance of a LEDMSI system depends on several factors such as camera, number and type of LEDs, demosaicing algorithm, and noise [13]. A simple bilinear interpolation is used for demosaicing. Furthermore, no special device was used to handle specular reflections. Specular reflections were prominent particularly in the images of the Russian Icon. Areas prone to specular reflections have been ignored. Using a sophisticated demosaicing algorithm and by fine tuning the system with a more optimal number and type of LEDs and using cross-polarization filters to handle specular reflections [14], and also considering other influencing factors as well, we can anticipate further improvement in the results.

A high-end pushbroom hyperspectral system is used as a reference system because such a system is by far considered more sophisticated and can acquire more accurate spectral images. However, hyperspectral systems are quite expensive and they require time consuming and complicated acquisition process. In comparison, the proposed RGB-LEDMSI system is significantly faster, simpler and inexpensive. Moreover, such a system can acquire significantly higher spatial resolution images (6016x4016 to 1466x1032 in our example). Comparable results from a simple 6-band system confirms the effectiveness and feasibility of such a system. Such a system thus provides an alternative solution for spectral imaging useful in many application domains including cultural heritage.

CONCLUSION

This paper presented the results from a 6-band RGB-LEDMSI system in the COSCH RRT. Results show a comparable performance to a hyperspectral system both in terms of spectral and colorimetric estimations. The RGB-LEDMSI system can acquire high resolution multispectral images very fast. Therefore, such a system provides a fast, simple, and cost-effective solution for spectral imaging in cultural heritage applications on which COSCH project was dedicated to. A possible further work could be to compare performance of different fast spectral imaging solutions in the context of the COSCH RRT.

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