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# Studying Art Paintings through a Multispectral Imaging System Composed of Light-Emitting Diodes Covering the Spectral Range from 370 to 1600 nm

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## ABSTRACT

Multispectral systems are implemented in many ways and are intended for different purposes. Some of them have been used for the study of art work but they have been mostly based on filters. In this work we assess the feasibility of a multispectral system based on Light-Emitting Diodes (LED) for the study of art work paintings. This system is comprised of two cameras and two sets of LEDs with different peak wavelengths of emission. Images from the 23 channels of the system give access to pixel-wise information of color and spectrum in the range of 370nm to 1600nm. The spectrum for each pixel is calculated via two methods: the pseudo-inverse estimation method using a training set of samples and the interpolation method using splines. The performance of the system in terms of color and spectral reconstruction is evaluated using three different metrics. The results obtained in spectral estimation shows a good performance of the system. In addition, some of the possibilities that the system offers are shown with images and spectra estimation of pixels for real wall paintings.

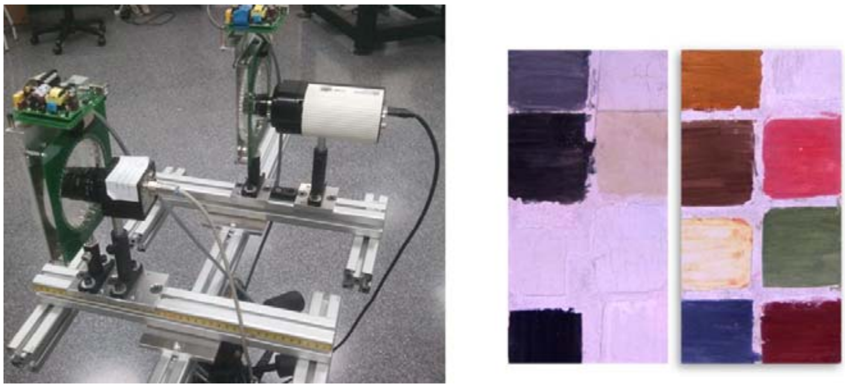
## 1. INTRODUCTION

Multispectral imaging is a field with application to a wide range of problems because it offers spectral information with high spatial resolution; these features are useful in the pharmaceutical industry, biology, arts and many others scenarios, Sheth et al. (2009); Vilaseca et al. (2008). In the art conservation area, some approaches of multispectral systems have been implemented in order to get access to a better color measurement and reproduction, to spectral information or the possibility of digital archiving of art work, Fischer and Kakuolli (2006). The recent development and accessibility to LED technology has become an attractive alternative to be used in multispectral systems, Brydegaard et al. (2009); Martinez et al. (2011), including those used in art work studies. LED elements have narrow-spectral emission and are available in several wavelengths over the different spectral ranges of ultraviolet (UV), visible (VIS) and near-infrared (NIR). Therefore, they allow lighting the sample with a large number of specific wavelengths or customized combinations of them in a fast way and in synchrony with the imaging sensors used. Following this idea, this work shows the evaluation of the performance of an LED based system and its use in the study of art work paintings in a museum. The system is evaluated in terms of color and spectral reproduction through three metrics and two methods of spectral estimation. These metrics show a good performance of the system and the high proximity of the results for the two methods of reconstruction supports the system accuracy, and therefore its suitability to study real wall paintings.

## 2. METHODS AND MATERIALS



The multispectral system has two modules. The first module comprises a monochrome CCD camera with 12 bit depth and 1392x1040 pixels, and a set of 16 groups of LEDs for illumination, each group with a specific peak wavelength of emission. The spectral response of this camera and the emissions of the LEDs in this module cover the spectral range from 370 to 950 nm. Likewise, the second module has an InGaAs camera with 14 bit depth and 320x256 pixels, and a set of 7 different groups of LEDs. This module covers the range of wavelengths of 900 to 1600 nm. Figure 1a shows the experimental setup with its two modules.



*a) b)*

*Figure 1. a) Experimental setup. b) Part of the palette of colors used as training set of samples.*

Images of wall paintings were captured using this system. The paintings are located in Saint Michel's cell at the Royal Monastery of Pedralbes (Barcelona) and are attributed to the painter Ferrer Bassa. They are an exceptional masterpiece of the Catalan Gothic painting scene dating from 14th century. Here, two methods for the spectral estimation from the digital values given by the system have been used: the pseudo-inverse estimation method (PSE) and the interpolation method based on splines (Interp), both of them widely described elsewhere, Vilaseca et al. 2006, Abed et al. (2009). In order to estimate the reflectances of these images using the pseudo-inverse method, a training process of the system must be carried out. For this purpose, a set of colored patches was generated (Figure 1b). These patches were painted with colors commonly encountered in Bassa's palette and emulating the fresco technique used by him.

Finally, to compare and evaluate the results of spectral estimation three different metrics were employed. The root mean square error (RMSE) and the goodness-of fit Coefficient (GFC), Hernández-Andrés et al. (2001), that account for spectral accuracy and the color difference formula DE2000 (DE00) that accounts for color evaluation, Sharma et al. (2005).

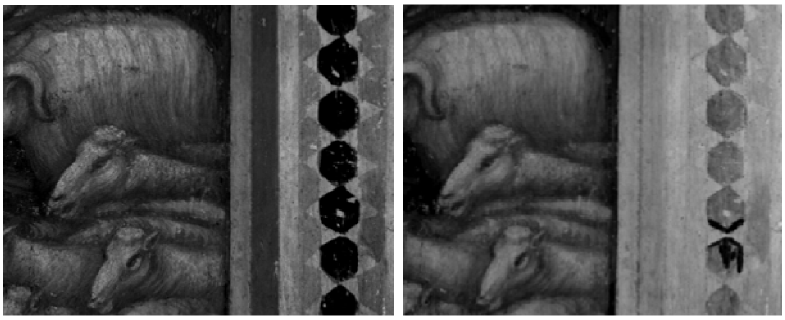
## 3. RESULTS AND DISCUSSION

Results in Table 1 are obtained when measurements over the training set are carried out. They show a general good performance of the system, but with some differences depending on module and estimation method. The pseudo-inverse method yields better results for both modules than the interpolation method, although both methods have poorer performance in the second module where the minor quantity of channels, that is to say, number of LEDs, makes the values of the RMSE increase. Even so, these values are near to 2% that is still a low value. The GFC results also confirmed the same, where 0.999 values represent good spectral matches. In terms of color differences the pseudo-inverse method has again a better performance, but it is worth noticing that no training process is necessary for the interpolation method, fact that depending on the situation may compensate its higher, but still good, mean value in DE00 and RMSE.

*Table 1. Results of evaluation metrics in spectral estimation for the training set of samples.*

| *Mean Values* | *Module 1* | | | *Module 2* | |
|---|---|---|---|---|---|
| | DE00 | RMSE x100 | GFC | RMSE x100 | GFC |
| PSE | 0.988 | 1.094 | 0.999 | 1.970 | 0.999 |
| Interp | 2.193 | 1.830 | 0.999 | 2.351 | 0.998 |

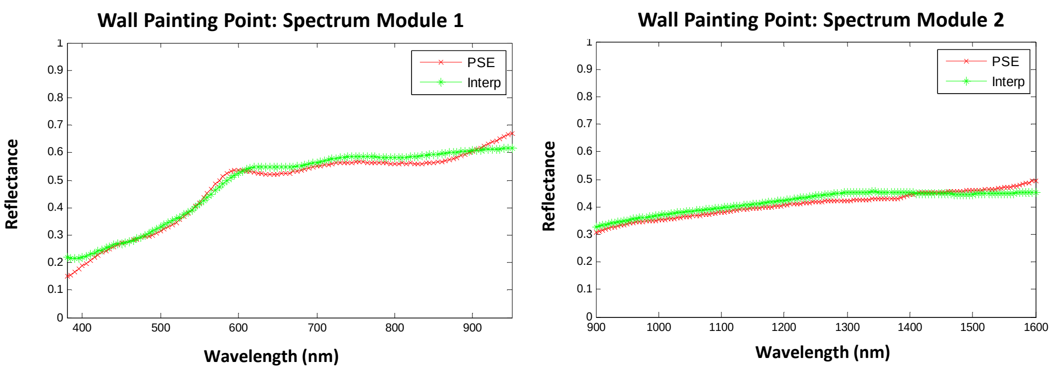
Figures 2a and 2b show monochromatic images of Bassa's wall paintings at the spectral channels of 630nm and 1200nm. These two images are examples of images in the visible range and the infrared range, respectively. Just observing the images some differences can be noticed, this is a key point for people in the restoration field, as it allows assessing the art works over different portions of the spectrum.



a) b)

*Figure 2. Images of Ferrer Bassa's wall painting. a) Image at 630nm b) Image at 1200nm.*

Figure 3 shows the result of spectral estimation using pseudo-inverse and interpolation methods, for two pixels in the images in Figure 2. The metrics between these spectra give values of RMSE(%) = 2.266 and GFC = 0.999 in the first module and RMSE(%) = 2.285 and GFC = 0.999 for the second module, meaning that these spectra have a good matching. We claim that the resemblance between these estimated spectra are a proof of their proximity to the real spectra of those pixels. This is because the interpolation method should at least follow roughly the shape of the real spectrum and it gives a clue about whether the pseudo-inverse method is also yielding a correct result.




a) b)

*Figure 3. Spectral estimation of two points over the wall painting in Figure 2. Comparison between the pseudo-inverse and interpolation methods, a) for module 1, and b) for module 2.*

## 4. CONCLUSIONS

The implementation of a multispectral system based on LEDs for art work studies has been shown. The performance of the system in spectral reconstruction for a training set of samples has been evaluated through three different metrics. These three metrics show that the pseudo-inverse estimation method has slightly better accuracy than the interpolation method in the two different modules that comprises the system. Even with this difference in the results, the two methods have considerably good performance (DE00 near 2, RMSE near 2%, GFC of 0.999). The images of spectral channels of real art work and the comparison of reconstruction of pixel spectra in this real sample underlines the possibilities that this system can offer to people involved in the field of art study and conservation.

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