CRISATEL multispectral imaging system

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ABSTRACT

CRISATEL is a European project started in September 2001 in the field of conservation and restoration of canvas paintings. It has involved museum laboratories, research institutes and private enterprise. One of its main achievements is a multispectral imaging system allowing the capture and the processing of paintings at ultra-high resolution (12 000 x 30 000, 13 bands: 10 in the visible, 3 in the infrared). We describe here the acquisition system, the camera calibration, the reconstruction of the spectral reflectance of the pigment layer imaged on each pixel and applications such as simulation of illuminant changes.

1. INTRODUCTION

A high resolution and multispectral imaging system has been developed as part of the CRISATEL European Union project. This system is dedicated to the digital archiving of canvas paintings[1]. In this field one of the main interests is to obtain an image representation independent of any specific illuminant and able to provide high fidelity displays or reproductions of the paintings in various controlled environments. This can be achieved by reconstructing the spectral reflectance curves at every sampled point of the digitised surface, since a representation based on object reflectance is independent of the illuminant used during the acquisition stage. This spectral reconstruction problem has been widely studied in the multispectral colour community; see for instance the works of Burns and Berns[2] or König and Praefcke[3]. Some previous applications to fine art paintings and to pigment spectral reconstruction can be found in the works of Maître et al.[4], Haneishi et al.[5] or Farrell et al.[6].

In the following we briefly describe the CRISATEL acquisition system, the calibration procedure, then spectral reflectance reconstruction performed on a calibrated multispectral image, and finally applications of multispectral images as simulation of illuminant changes.

2. ACQUISITION SYSTEM DESCRIPTION

The hardware of the CRISATEL acquisition system[7] is composed of a high-resolution digital CCD camera equipped with 13 narrow band interference filters and of a dedicated dynamic electronically controlled lighting system shown in Figure 1.

The digital camera is based on a charge-coupled device (CCD) composed of a 12000 pixel linear array. This array is vertically mounted and mechanically displaced along a horizontal axis by a precise step motor. The system is able to scan up to 20000 vertical lines. This means that images up to 12000 by 20000 square pixels can be generated. The current camera is equipped with a built-in half-barrel mechanism that automatically positions a set of 13 interference filters, ten filters covering the visible spectrum and the other three covering the near infrared. There is an extra position without filter in the half-barrel allowing panchromatic acquisitions. The spectral transmittance curves of the filters in the visible range have 40 nm bandwidth and are equally spaced from 380 to 780 nm with 40 nm steps. In the infrared range the filter transmittances have 100 nm bandwidth and are centred at 800, 900 and 1000 nm. We have controled that practically no spectral non-homogeneity in a channel image is introduced by the variation of the angle of incidence in the image formation. An image of the internal components of the camera is shown in Figure 2.

For readout operations the CCD linear array uses two channels which process the pixels on even and odd positions respectively. In each CCD channel the raw signal passes through an analogue amplifier. Each amplifier has two control parameters, an offset and a gain. The analogue signal delivered by the amplifier for each pixel is then quantized into 12 bits by an analogue to digital converter (ADC).

For a given scene and a given set-up of the lighting system, there remain two physical parameters, which allow us to control the amplitude of the signal: the aperture of the optical lens and the exposure time. Both factors can modify the number of incident photons trapped in each individual CCD cell. The aperture of our dedicated optical lens is kept fixed during an acquisition with all filters and therefore does not need to be controlled electronically. The exposure time can be automatically setup and changed from 1.3 ms to 200 ms by steps of 0.1 ms.

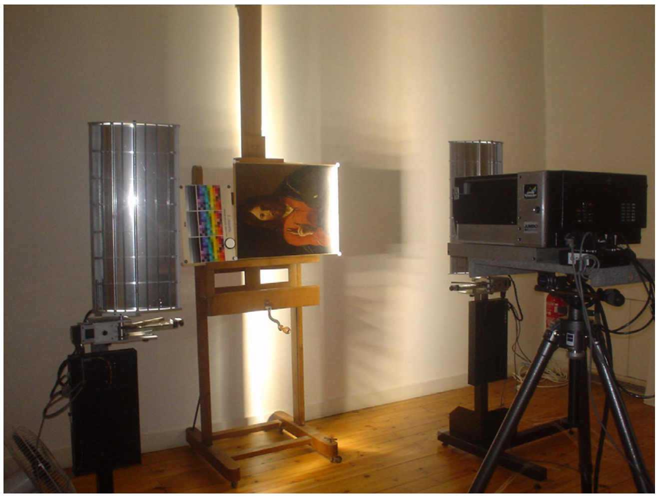

Figure 1: Classical set-up of the CRISATEL camera in front of a painting and of the two synchronized elliptical projectors on both side of the painting.

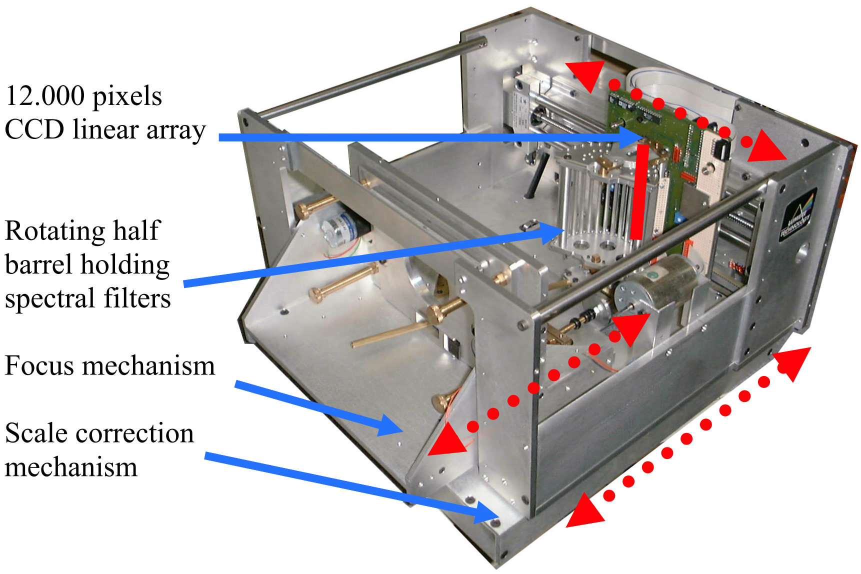

Figure 2: Internal camera structure and system components of the CRISATEL camera (©Lumiere Technology). Dotted arrows indicate motorized mechanisms.

A step motor precisely controls the focus of the lens. Due to the remaining chromatic aberration of the lens and to the different thicknesses of the filters, the focal length is not exactly the same for the 13 channels resulting in images of slightly different scale. The multispectral camera provides a displacement system of the full camera body that can partly compensate these differences in scale for every spectral channel (see Fig.2). Despite this compensation some misalignments of several pixels can still be observed between the images acquired with different filters. A digital post-processing step has been developed to align the full set of 13 images by using correlation techniques.

The lighting system is composed of two elliptical projectors equipped with either Halogen lamps or HQI bulbs. The optical axis of the camera is positioned perpendicularly to the painting surface. The projectors are positioned laterally at the left and right sides of the painting (see Fig. 1).

They each project a narrow vertical light beam and rotate synchronously with the CCD displacement, their projected beam remaining superposed on the surface of the painting while scanning it.

3. SYSTEM CALIBRATION

An evaluation of the CRISATEL multispectral camera has been performed [8]. The data collected during this evaluation allowed us to design and implement a calibration procedure, which needs to be done after any new set-up of the acquisition system. It consists in a series of experiments first to select the parameters to be used for the image acquisition, and second to collect experimental data, which will be used in a post processing stage to correct the obtained multispectral images.

When the positions of the camera and of the two projectors have been fixed prior to a new acquisition session, the lighting system is warmed up, the lens aperture is chosen and the camera is focused on a painting for each one of its 13 channels. The exact position of the lens controlled by a step motor is stored for each image channel. A homogeneous diffuse white board is then positioned in the plane where paintings will be scanned. The calibration procedure is then composed of the following steps. 1) Selection of the remaining camera parameters: the gain and offset of the two CCD amplifiers and the exposure time. They are chosen such that the images present a high dynamic range with a maximal signal to noise ratio. 2) Measurement of the non-homogeneity of the lighting spatial distribution on the painting plane. At the end of the procedure, corrections are applied in order to compensate for the lighting defects. 3) Measurement of the non-homogeneity in the physical response of every element of the CCD linear array to compensate for the inter-cell variability of the dark current contribution and of the photosensitivity.

4. SPECTRAL RECONSTRUCTION

Various techniques have been proposed for the reconstruction of the spectral reflectance curve of the object surface imaged in each pixel of a calibrated and corrected multispectral image. We have compared linear and non-linear methods, some of them having been proposed by several of the authors: methods based on the inversion of the physical measures of the acquisition system; interpolation methods; the SVD Pseudo-inverse[9], the Non-averaged Learning Pseudo-inverse[10], the Non negative Least Square[10] (NNLS) and the Mixture Density Networks[11] which are four methods based on the learning over a training set of spectral reflectance patches and their corresponding camera responses. We have used for that the CRISATEL colour chart composed of three similar sets of colour patches, which differ in that the first set has no varnish, the second set has a thin layer of matt varnish and the third set has a layer of brilliant varnish. Each set contains 117 colour patches: 81 colour patches and 36 grey patches. We have divided the chart into two sets, one used for training and the other for testing. A full analysis of these results is available [12].

Direct inversion methods require the measure of the CCD sensitivity and of the CRISATEL filter transmittances. Although these measures have been done carefully by using a monochromator and a calibrated radiometer for the CCD sensitivity and a spectrophotometer for the filter transmittances, we have noted that direct inversion methods perform badly compared to the other methods. Methods based on interpolation provide intermediate results. The best results are obtained with training methods. This is mainly due to the fact that our training and test sets all belong to the specific canvas-painting environment, which in our case favours training methods. The smaller errors are obtained with the Mixture Density Networks and the Non-averaged Learning Pseudo-inverse method.

5. MULTISPECTRAL IMAGE MANAGEMENT AND APPLICATIONS

More than 100 canvas and wood paintings have been digitised in various museums during the CRISATEL project lifetime. According the system calibration preceding each acquisition session, the geometry and the radiometry of every channel raw images have been corrected by post-processing. The resulting corrected 12 bits multispectral images have been finally stored in the EROS database of the C2RMF.

To produce a colour image the spectral reflectance is first reconstructed at every pixel by using one of the existing spectral reconstruction methods. An illuminant being chosen we compute the XYZ tristimulus values of the corresponding painting surface element by using classic colorimetric formulae with integration along the visible spectrum. The estimated XYZ tristimulus values are then transformed in the colour space of the output device used for the visualisation or the reproduction (e.g. a calibrated monitor or colour printer) by using colour profiles. This makes simulation of illuminant changes a straightforward realistic application of multispectral imaging which can be of a great help, e.g. for a curator preparing a new exhibition.

All these post-processing tools have been implemented using VIPS[13]. VIPS is an Open Source image processing software developed at the National Gallery in London for the efficient manipulation of very large images as those acquired on paintings with the CRISATEL multispectral system. Dedicated image viewers have been developed for multispectral images allowing: a) interactive visualisation (panning, zooming, 12 bits range control), b) navigation between channel images, c) spectral curve reconstruction of any chosen pixel, d) colour visualisation under any given illuminant, plot of resulting 3D histogram, etc.

6. CONCLUSION

The CRISATEL multispectral system is now used by the C2RMF for the digital acquisition of paintings from different periods and styles on a large scale in several museums in France. The next main aims are to characterise the palette of the artists, to identify the pigments they used by comparing the reconstructed spectral reflectance curves with pure and mixed pigments chosen as references. The digital results have to be controlled by measuring on several areas of the painting surface the real physical curves with a spectrophotometer. Analysis by X Ray micro-fluorescence will be also additionally used to identify the chemical composition of the pigments.

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References

1. Lahanier C., Alquié G., Cotte P., Christofides C., de Deyne C., Pillay R., Saunders D., Schmitt F., "CRISATEL: high definition spectral digital imaging of paintings with simulation of varnish removal", ICOM-CC 13th Triennial Meeting, vol 1, pp. 295-300, Rio de Janeiro, Brazil, 2002.
2. Burns P. D. and Berns R. S., "Analysis Multispectral Image Capture", in Proceedings of Fourth Color Imaging Conference Color Science, Systems, and Applications, Scottsdale, Arizona, USA., pp. 19-22, 1996.
3. König F. and Praefcke W., "A multispectral scanner"., chapter in MacDonald and Luo, pp. 129-144. 1999.
4. Maître H., Schmitt F., Crettez J., Wu Y., and Hardeberg J.Y., "Spectrophotometric image analysis of fine art paintings", in Proceedings of Fourth Color Imaging Conference Color Science, Systems, and Applications, Scottsdale, Arizona, USA, pp. 50-53, 1996.
5. Haneishi H., Hasegawa T., Tsumura N., and Miyake Y., "Design of Color Filters for recording Art Works", in Proceedings of IS&T 50th Annual Conference, Cambridge, Massachusetts, USA, pp. 369-372, 1997.
6. Farrell J. E., Cupitt J., Saunders D. and Wandell B. A., "Estimating Spectral Reflectances of Digital Images of Art", in Proceedings of International Symposium on Multispectral Imaging and Color Reproduction for Digital Archives, Chiba, Japan, pp. 58-64, 1999.
7. Cotte P., Dupouy M., "CRISATEL High Resolution Multispectral System", in Proceedings of PICS'03 Digital Photography Conference, Rochester, USA, pp. 161-165, 2003.
8. Ribés A., Brettel H., Schmitt F., Liang H., Cupitt J., Saunders D., "Color and Spectral Imaging with the Crisatel Acquisition System", in Proceedings of PICS'03 Digital Photography Conference, Rochester, USA, pp. 215-219, 2003.

9. Burns P. D., “Analysis of image noise in multitraitement color acquisition”, Ph.D. thesis, Center for Imaging Science, Rochester Institute of Technology, USA, 1997.
10. Imai F. H., Taplin L. A. and E. A. Day, “Comparison of the accuracy of various transformations from multi-band image to spectral reflectance”, Technical Report of the Rochester Institute of Technology. Rochester, USA, 2002.
11. Ribés A., and Schmitt F., “A Fully Automatic method for the Reconstruction of Spectral Reflectance Curves by using Mixture Density Networks”, Pattern Recognition Letters, **24** (11), pp. 1691-1701, 2003.
12. Ribés A., “Analyse multispectrale et reconstruction de la réflectance spectrale de tableaux de maître”, Ph.D. dissertation, Ecole Nationale Supérieure des Télécommunications, Paris, France, Dec. 2003.
13. Cupitt J. and Martinez K., “VIPS: an image processing system for large images”, in Proceedings of SPIE conference on Imaging Science and Technology, San Jose, Vol. 1663, 1996.