Evaluation of six and eleven-channel high definition multispectral camera for fine art painting application

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ABSTRACT

Two versions of a commercial high definition camera having 6 and 11 filters are studied to compare the capabilities of multispectral imaging according to the following acquisition parameters: number of channels, nature of filters, source of lighting and method of spectral reconstruction; using a common technological architecture and algorithms. Results allow the contribution of additional selections in the accuracy of color restitution to be estimated and an hierarchy of reconstruction methods to be established. A set of charts is used to evaluate the performance of the studied systems.

1. INTRODUCTION

When multispectral image capture is applied to fine art paintings, high-quality, accurate color reproduction, new technical analysis[1] capability and predictive restoration become possible. In order to propose new solutions for art works and document scanning, three high-resolution scanning systems[2] having a dedicated synchronized lighting system were developed by LUMIERE TECHNOLOGY. They enable grayscale, RGB, 6 and 13 channel multispectral imaging. Since, the characteristics (i.e., sensor spectral response, optical filters transmittance, reconstruction methods and lighting system spectral distribution) of an ideal image acquisition system are dependent on the nature and specificity of materials used in fine art paintings, the acquisition system's performances need to be evaluated according to several artistic periods. In this paper we evaluate LUMIERE TECHNOLOGY's 6 channel and 13 channel image acquisition systems using three color charts. The evaluation was performed: by simulation using a virtual camera model then experimentally. The first section of the paper describes the acquisition systems, the second section presents the method used to perform the system's evaluation and the third section presents the evaluation results. Special focus is dedicated to painting materials.

2. SYSTEM CHARACTERISTICS

We have at our disposal two high definition digitization systems having the same CCD sensor array of 12,000 pixels and its electronic control circuit. The first is a 6 channel multispectral imaging system using a wheel holding 6 Schott colored glasses. Each filter is actually a sandwich of several filters selected at the Munsell Color Science Laboratory[3]. The second, 11 channel acquisition system uses Melles Griot interference filters and covers the visible spectral range with a 40 nm bandwidth (two additional IR filters were not used in these experiments). The filters distributions show very different approaches (see Figure 1). The common system characteristics and the calibration method were previously developed by the ENST Paris team within the framework of the European CRISATEL project and reported in the literature[4].

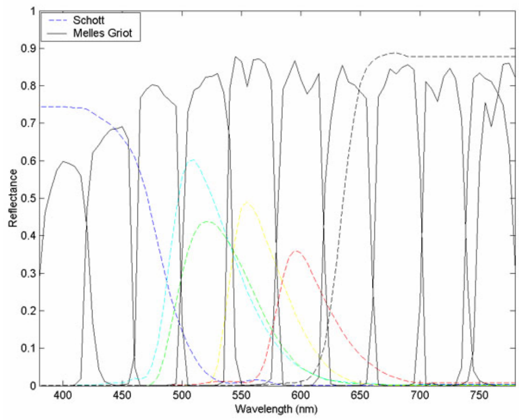

Figure 1: Set of filters used in this experimentation.

A virtual camera model is determined by the physical transfer function of all the elements. We measured all data corresponding to different elements of the system except the data of the lens compliant with the ISO6728-1983 standard. One obtains the camera's response c_k to the stimulation of an object of reflectance $r(\lambda)$ for every filter $\phi_k(\lambda)$ described by the following formula:

$$c_k = \int_{\lambda_{min}}^{\lambda_{max}} l(\lambda)\ i(\lambda)\ h(\lambda)\ r(\lambda)\ o(\lambda)\ \phi_k(\lambda)\ \alpha(\lambda)\ d\lambda + n_k \quad (1)$$

Where the spectral distribution of illumination is $l(\lambda)$, the cut-infrared filter's transmittance is $i(\lambda)$ (used only for 3 and 6 filter acquisition), the lighting system heat-cut filter's transmittance is $h(\lambda)$, the optical system's transmittance is $o(\lambda)$, the sensor's sensibility is $\alpha(\lambda)$ and the electronic noise n_k (with k equal to 6 or 11). The acquisition system can use one of two reconstruction methods: indirect (learning) and interpolation. The first, indirect method applies an important database of known stimulations and their corresponding responses to build an inverse operator that allows the reflectance of the digitized object from the camera's response to be obtained. We used pseudo-inverse as a mathematical transformation in this evaluation. The second, interpolation method consists of sampling the reflectance from the transmittance of the 11 filters of the CRISATEL camera. We used cubic spline to compute the missing values between the normalized values exhibited by the system. The 6 Channel acquisition system was selected for an exclusive use with an indirect method in contrast to the 11 channel acquisition system where both methods can be applied.

3. EVALUATION METHOD:

To perform comparison and evaluation of the acquisition systems performances, we modified parameters that may improve color accuracy of digitized documents. The first parameter is the chromatic selection: a 6 filter wheel and 13 filters mounted in a mechanical half-cylinder system. The second parameter is the method used to reconstruct spectral or colorimetric data. The last parameter is the lighting distribution using a tungsten light and a HQI metal discharge lamp. Note that the common system characteristics and the calibration method are not modified in this evaluation.

Three different charts are selected to evaluate system performances, the GretagMacbeth colorchecker DC target, the CRISATEL project's acrylic Pébéo chart and the restorer François Pérégo's collection[5]. The variety and homogeneity of pigments differ from one chart to another. The colorchecker target has several mixtures staged on the axis of luminosity L* and some primary glossy pigments. It represents a homogeneous part of the global color space. Thus, we use it as a standard during learning process and to find the system limitations. The Pébéo chart has 15 pure pigments among the 117 glossy applications with the remaining 102 being mixtures of pigments realized from 38 pigments used during the 19th and 20th centuries. The Pérégo collection contains 250 pure pigments describing the evolution of the materials available to the painter from antiquity to the present time. Increasing complexity of these charts is based on number of pure pigments.

The system performances evaluation was performed in two steps: first by simulation using the virtual camera model; then experimentally using LUMIERE TECHNOLOGY acquisition systems. The results are developed in the following section.

4. RESULTS

4.1 SIMULATION:

The 6 channel acquisition uses Schott filters having a gaussian shapes. Performances are connected to the variety of pigments (see Table 3) in the reconstructed charts and number of channels. Studying the results of Pébéo and Pérégo charts, we observe an identical progression between their ΔE^*_{ab} value for indirect methods applied to 6 and 11 channel image acquisition system whereas this progress is less important with the interpolation method. The interpolation method offers performance stability. For example, the subset of the Pérégo collection (15th century pigments) shows a comparable result to the initial set. In this case of a smaller palette, indirect methods allow better significant performance improvement than interpolation method.

Table 3: All results of comparison between each multispectral system, chart code : 1 = Colorchecker, 2 = Pébéo, 3 = Pérégo and 4 = 15[th] century.

	6B indirect			11B indirect			11B interpo		
	ΔE^*_{ab}	RMS	GFC	ΔE^*_{ab}	RMS	GFC	ΔE^*_{ab}	RMS	GFC
1	0.40 [0.03-4.87]	0.011 [0.001-0.060]	99.85 [99.99-91.67]	0.27 [0.007-2.54]	0.005 [0-0.02]	99.97 [99.99-99.64]	1.08 [0-11.14]	0.016 [0-0.050]	99.93 [100-97.91]
2	0.71 [0.08-3.97]	0.020 [0.0006-0.070]	99.62 [99.99-94.18]	0.40 [0.02-2.42]	0.006 [0-0.025]	99.92 [99.99-98.72]	1.57 [0.05-5.94]	0.015 [0-0.050]	99.92 [99.99-98.64]
3	1.19 [0.06-12.94]	0.057 [0.025-0.258]	99.12 [99.99-86.07]	0.65 [0.01-6.20]	0.008 [0-0.040]	99.97 [99.99-99.28]	2.04 [0.02-13..87]	0.020 [0-0.080]	99.90 [99.99-98.40]
4	0.70 [0.08-2.59]	0.045 [0.003-0.20]	99.07 [99.99-92.52]	0.29 [0.02-0.73]	0.003 [0-0.080]	99.98 [99.99-99.82]	1.87 [0.06-5.77]	0.014 [0-0.038]	99.92 [99.99-99.29]

Table 4: Mean values of ΔE^*_{ab} for Pébéo chart and with HQI source reconstructed with colorchecker DC target (CCDC), this figure introduces a RGB results to compare with multispectral acquisition system .

Filter / Chart	Pébéo	Pébéo (CCDC)
3B Schott	1.92 (max: 11.79)	3.1(max: 16.8)
6B indirect	0.71(max: 3.97)	1.18(max: 11.10)
11B indirect	0.40(max: 2.42)	0.83(max: 6.83)
11B interpolation	1.58(max: 5.94)	1.58(max: 5.94)

General results highlight the advantage of the 11 channel acquisition system using the indirect method. On the other hand, the results imply an ideal base of learning by simulating the materials of the object to be digitized. However, the loss of performance is identical for the 3 channel or 6 channels acquisition and subordinate for the 11 channel acquisition (see Table 4). As these filters are very selective (pass-band), they give the less-tolerant calculated transfer function. In constrast, the shape and filters overlap of the 6 channel acquisition system allow the progressiveness of the camera signal. The comparison results show also limits and precautions when the colorchecker target cannot always correspond to a specific color domain.

The ten first ΔE^*_{ab} maximum values of colorchecker DC target are essentially the glossy primary color samples. Observed ΔE^*_{ab} maximum values of Pébéo chart and Pérégo collection concern synthetic pigments with base of cadmium, cobalt, phtalocyanine and monoazoic pigments. Using Multispectral acquisition systems and in a final goal of pigment identification from the estimated spectra, it is necessary that distortion does not affect their characteristic signature. We find these distortions in all kinds of acquisition for different reasons: limit and sampling errors and learning errors. With the interpolation method and the limit of sampling situated at 400 nm, it becomes difficult to distinguish some pigment particularities in near UV.

For example, the Study of white pigment dating becomes difficult (lead white versus titanium white pigment). The sampling and learning errors are situated in the high edges of absorption/reflection. The spectras with edges or peak between two adjacent filters have their slope (lead iodide yellow) or peak location (verditer blue) modified.

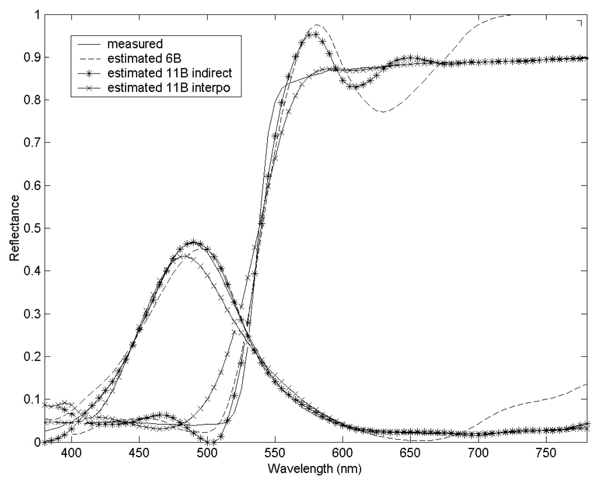

Figure 2: Example of pigment reflectance producing worse results in multispectral acquisition: Verditer blue and lead iodide yellow.

Additionally, fine characteristics such as the cobalt blue or ceruleum blue are not retranscribed with any technique due to sampling error and spline interpolation. With the indirect method, learning errors appear differently with the choice of learning charts. During our learning process, the distances of extrem pigment with average and smooth sample characteristics provoked a loss of tolerance in the transfer function of camera signal towards spectral value.

4.2 ACQUISITION RESULTS:

Some precautions must be underlined before the comparison between simulation and acquisition data. The spectral range in the acquisition result is 400 nm to 700 nm instead of a range of 380 nm to 780 nm for simulation result due to temporarily limitations of commercial software. The parameter of lighting distribution is not included because simulation and acquisition results do not show any significant difference between lighting sources. The hierarchy in the methods is preserved (see Table 5) and the learning error is correctly predicted by the model. The difference of performance between the Pébéo chart and the colorchecker target is not strictly similar to simulation. This is may be due to the difference of illumination/viewing geometry between the acquisition system and the spectrophotometer used. The filter shapes and their overlapping in the 6 channel camera allow learning errors to be limited. The 11 channel acquisition system using interpolation method achieves the limit of acceptable color difference.

Table 5: Mean values of ΔE^*_{ab} for Pébéo chart and colorchecker target with HQI source, chart code : 1 = Colorchecker, 2 = Pébéo, 3 = Pébéo reconstructed with colorchecker target.

	6B indirect Simulation	6B indirect acquisition	11B indirect Simulation	9B indirect Acquisition	11B interpo Simulation	9B interpo Acquisition
1	0.4 (max.: 4.87)	2.16 (max.: 11.13)	0.27 (max.: 2.54)	1.8 (max.: 12.68)	1.08 (max.: 11.14)	4.46 (max.: 19.25)
2	0.71 (max.: 3.97)	2.78 (max.: 6.56)	0.40 (max.: 2.42)	2.04 (max.: 10.87)	1.56 (max.: 5.94)	6.65 (max.: 13.44)
3	1.18 (max.: 7.61)	4.03 (max.: 14.8)	0.83(max.: 6.83)	6.23 (max.: 20.75)	1.56 (max.: 5.94)	6.65 (max.: 13.44)

5. CONCLUSION

We compared two different concepts; the 6 channel camera designed to achieve good results with a selected learning chart and the 11 channel camera designed as low resolution spectrophotometer independent of color charts. The 6 channel results demonstrate a better performance and robustness of the indirect method using gaussian filters. The interpolation method has an interesting stability when the provenance of a document is unknown or a significant chart does not exist. The additional infrared data of the complete 13 channel camera allow individual pigments to be identified but a new solution to sampling near UV must be applied. A compromise could be two separated layers of processing after painting digitization and its dedicated chart (classified by historic period). This would consist of a first spectral reconstruction with an interpolation method followed by a second step of adaptative indirect reconstruction that implies comparison of normalized camera signals corresponding to the two digitized documents. In a commercial context, the necessity of production and productivity of each system allows selection of the adapted technology. When in normal production the 6 channel acquisition system can digitize 10 paintings per day (100 per day in RGB mode) versus only 2-3 per day with the 13 channel acquisition. However, the 13 channel system generates significantly greater data useful for future purposes.

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