Art-Works Colour Calibration by Using the VASARI Scanner

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Abstract

In this paper a method to assess the exact colour reproduction accuracy of a multispectral scanner capable to acquire digital images directly from paintings is first described. Then is presented an algorithm which compares two different digital true-colour reproduction of the same painting giving the chromatic distance between the two images. Such distance may be considered as a colour certification parameter of one of the two images when the other is takes as references (i. e. it approximates the original painting).

Introduction

One of the most important goals of the high-quality digital image reproduction is the achievement of a high chromatic fidelity to the original painting. In applications such as art archival, it is clearly imperative to obtain accurate colour measurements of the original image. In the reproduction of a colour image, the original image is initially recorded using a device that measures the reflected or transmitted energy of the image in a number of different wavelength bands. In practice, the colour values of the original image under a particular viewing illuminant are estimated from the data obtained from the recording device. This estimated data is then used by a reproduction device to match the original image under that viewing illuminant.

One approach to improve the colour accuracy of a colour measuring device is to use an increased number of colour filters.[1,2,3,4] In particular, a method for computing the optimal transmittances of such colour filters is demonstrated.[3,4] As the number of colour filters is increased, additional information about the reflectance spectra in the original image is obtained. This additional information is used to provide the colour match with the original image under a particular viewing illuminant.

In the framework of the EU project ESPRIT-MUSA, in the area of multimedia systems and telematics networks for dissemination of Art-Works, a new digital image acquisition system, the VASARI scanner, was developed and manufactured at the National Gallery, in London. As main result of this project, a new version of the VASARI scanner has been installed at the Uffizi Gallery Labs in Florence, on February 1995. This device, capable to acquire digital images directly from Art-Work.

The VASARI Scanner

Among the goals of a multimedia system that allows high-quality image reproductions is the achievement of a high chromatic fidelity to the original Art-Works (e. g., paintings). The colours of the digital reproduction should be related to those of the original painting, in order both to give a measure of colour fidelity, and to provide tools to enhance the chromatic quality of the poor reproduction. Some parameters that attempt to measure chromatic differences, as perceived by the human visual system, are reporter.[5,6]

The VASARI scanner is an extremely sophisticated imaging system which allows high-resolution and high-quality digital colour images to be acquired directly from paintings. Differently from commercial scanning systems working in 3 spectral bands, broadly corresponding to R-G-B, the VASARI scanner employs 7 spectral filters to span the visible wavelengths, from whose responses CIE XYZ tristimulus values are derived by a weighted interpolation.

Colour accuracy is ensured by a preliminary calibration procedure of the instrument in the XYZ domain based upon a least-squares (LS) fit to colour patches from a special colour-checker chart;[3] an accuracy measure of the calibration procedure is given by using the parameters described.[5,6]

The colour-checker chart introduced[3] is composed by 24 colours uniformly spread over the visible spectrum, of which full responses in the visible wavelength have been measured through a spectrophotometric laboratory instrument. Such colour patches are scanned and the XYZ responses compared to those recorded. Standard light conditions are ensured throughout by a uniform white illuminant of which the VASARI scanner is equipped.

Experiments of colour calibration with the VASARI scanner have been done also with the AgfaReference IT8.7/2 chart. It is a chart for calibration of scanner designed by IT8 Ansi subcommission and its constituted of 264 color patches and 24 levels of grey. Figure 1 describes the flow diagram of colour calibration in the VASARI scanner using Agfa IT8.7/2.

Figure 1. Flow diagram of the main steps of colour calibration in the VASARI scanner with Agfa IT8.7/2

It has been used as a vector space approach for colour correction. A colour stimulus recording is performed by measuring the intensity of filtered light. If $\mathbf{n}_i$ represents the transmittance of filter i, the recording process of a colour stimulus $\mathbf{c}$ can be modeled as

$$\mathbf{c} = \mathbf{N}^T \mathbf{L}_r \, \mathbf{f} + \mathbf{u} \quad (1)$$

where $\mathbf{N}^T = [\mathbf{n}_1 \; \mathbf{n}_2 \ldots \mathbf{n}_7]$ is the transmittance of the filters $\mathbf{L_r}$ is the recording illuminant, **c** is the 7-stimulus value recorded for spectral reflectance **f** (of the illuminated pixel) under illuminant $\mathbf{L}_r$, and **u** is the additive noise.

In the colour correction procedure the recorded data must be transformed to obtain the tristimulus values of the original image. Mathematically color correction can be described by

$$\mathbf{c}' = \boldsymbol{F}(\boldsymbol{c}) = \mathbf{A}^T \mathbf{L}_v \, \mathbf{f} \quad (2)$$

where $\boldsymbol{c}$ is the recorded data (see 1), $\mathbf{L}_v$ is the viewing illuminant, F is the ideal colour correction transformation, and the sampled CIE XYZ colour matching functions are contained in the columns of matrix **A**. Due to drastic reduction of information in the recording process it is impossible to find a linear transformation of the recorded data which match exactly the CIE XYZ colour matching functions. For this reason a colour correction of the recorded data may be obtained only by a linear minimum mean square error (LMSSE) approach. In this case the corrected colour $\mathbf{c}'$ is obtained by minimizing the error between the tristimulus value and its estimate value

$$\mathbf{e} = \| \mathbf{A}^T \mathbf{L}_v \, \mathbf{f} - F(\mathbf{c}) \|^2 \quad (3)$$

Considering a linear transformation $F(\mathbf{c}) = \mathbf{Wc}$, matrix **W** can be determined minimizing error e over a set of colours for which the true tristimulus values are known.

A subset of 20 patches of Agfa IT8.7/2 has been extracted to represent it meanly in hue, brightness and saturation. Matrix **W** has been determined using the remaining patches of Agfa chart. The color correction procedure has been tested over the subset of 20 patches.

In order to obtain a measurement of the residual perceptual error the distance ΔE (in CIE $L^*a^*b^*$ colour space)[5-6] between the actual and the corrected colours is considered as the measure of the colour correction procedure. When the number of filters of the acquisition device is high enough, the colour correction procedure is successful.[3] With the VASARI scanner, using six filters and the Agfa chart, an error of 2,9 over the subset of 20 patches has been found. This result is shown in Figure 2.

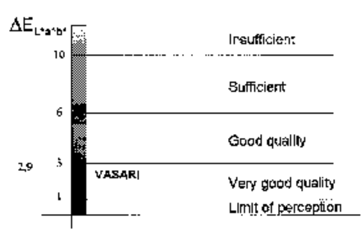

Figure 2. Representation in the $L^*a^*b^*$colour space of the result obtained with the scanner VASARI using AgfaIT8.7/2 chart.

Colour Correction of Low-end Devices

We shall suppose in the following to have two digital reproduction of the same painting characterized by a different spatial resolution and a different colour reproduction reliability as well. One of the two images (acquired from the VASARI Scanner) may be considered as the reference image. Such image is characterized by a triplet XYZ for each pixel which represents, with small approximation, the true colour of the original painting.[2] The other image is a three band image acquired from a commercial scanner by a photographic reproduction of the painting, characterized by a lower spatial resolution and a less accurate colour reproduction than the first one. The problem is that of associating the correspondent colours of the two images such as giving a colour calibration and a measurement of the color deviation of the second image based on the effective colours of the original painting (i. e. of the VASARI Scanner digital reproduction). The high-resolution and the low-resolution images, referred to as ***H*** and ***L*** respectively, cannot be roughly superimposed. In literature many registration methods, able to force two images to align with each other, are described.[8] These methods are able to achieve a certain degree of superimposition but are clearly approximated, i. e. a perfect superimposition is impossible. Thus, the colours association cannot be obtained by a rough association of each pixel of the first image with the correspondent pixel of the second image. A colour to colour matching is then implemented instead of a pixel to pixel matching. Note that the two images are characterized by a great number of colours (in general we deal with 24 bits images, i. e. the two images are sampled at 8 bit per pixel). Consequently, the number of colours should be reduced in order to associate a plausible number of homogeneous areas of the two images. The two images are so divided in a restricted number of areas chromaticity alike. To achieve this result it has been implemented a routine, named vgamut, which allows us to compress a 24 bits image in a n bits image (where $n < 24$) by using a modification of the Heckbeth's median cut algorithm.[9]

The original images ***H*** and ***L*** are divided in 2n areas of uniform colour. As an example, by choosing $n = 8$, the 8 bits images ***H****8* and ***L****8* are built where the pixels ***H****8*(i,j), and ***L****8*(k,l) are two 8 bits decimal number which addresses two LUT containing the 256 triplet of colours of the original images H and L respectively.

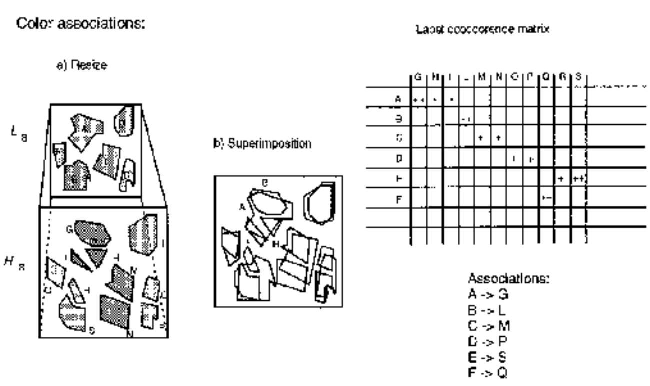

Figure 3. Association of the colours of the low resolution image (L) and high resolution image (H).

The procedure which is able to associate the colours of the two n bits images ***Hn*** and ***Ln*** is shown in Figure 3. The different colours are for simplicity represented as different shaped areas filled with different patterns. The low resolution image Ln is firstly resized and then superimposed to the high resolution image ***Hn***.

After the label cooccurence matrix, containing in the (i,j) position the number of pixels characterized by the i-th colour in one image and by the j-th colour in the other, is calculated. Finally the colour association is derived by considering the couples yielding the maximum over each row.

Now, a set of 2n RGB values of the low resolution image has been associated with the correspondent XYZ values of the VASARI Scanner image (considered with good approximation as the true XYZ values). Then, the colour correction procedure is described in section 2 is implemented by minimizing the error (3) over the associated colours. The residual mean square error $\Delta EL^*a^*b^*$ gives a measure of the quality of the colour correction procedure and will be considered in the following as the certification parameter CL of the low resolution image L. Figure 4 shows a flow diagram representing the colour correction procedure describe above.

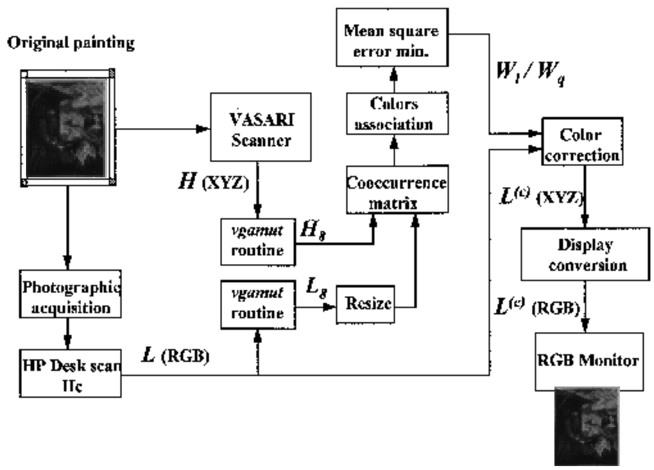

Figure 4. Block diagram of the colour correction procedure proposed in this paper.

Experiments performed at the Dipartimento di Ingegneria Elettronica (DIE) have shown that the proposed colour correction procedure is quite attractive. the low-end acquisition device used to test the colour correction procedure was a scanner HP Desk Scan IIc. First a photographic reproduction of a painting has been acquired by the low-end scanner then the painting has been acquired directly by the VASARI Scanner at the Uffizi Gallery. the average value of the parameter *CL*, evaluated in two different experiments (i. e. for two different paintings), was equal to 4 in the case of quadratic transformation and 6 in the case of linear transformation. The corrected images ***L***(*c*) were characterized in both the two experiments by a significant improvement in the chromatic fidelity to the original paintings when compared with the original ***L*** image. This improvement was more evident in the case of the quadratic transformation. However a perceivable difference between the corrected image and the original painting remained as a consequence of the value of the residual error *CL* (greater than 1 in all the cases). Note that the corrected ***L***(*c*) image is an XYZ image; thus, it is necessary to derive the XYZ->RGB transformation which matches the RGB monitor where the image must be displayed.

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