Digital Reproduction of Small Gamut Objects: A Profiling Procedure based on Custom Color Targets

Giorgio Trumpy; Institute of Applied Physics "N. Carrara" (IFAC-CNR); Firenze, ITALY

Abstract

In this paper the optimization of color accuracy of digital reproductions is approached. Standard color targets currently available on the market, are constituted of colors spread uniformly in the color space, therefore, these targets are usable in any situation, i.e. for any chromatic content of the images to be profiled. The usage of standard color targets becomes an issue when the object that has to be reproduced is characterized by a small gamut of colors [1,2]. In this case the ICC profile that can be obtained with a standard color target may miss to match with sufficient accuracy the dominating color due to two different causes. First, with reference to the colors of the standard target, the software used to create an ICC profile attempts to optimize all colors, including those which are not present in the object. Secondly, the color of the object can be colorimetrically distant from the patches of the target and therefore the interpolation process required results in a low level of precision. Hence the profiling process would work better if the color of the patches of the target were chosen with reference to the palette of the object that has to be reproduced. Here this problem is approached empirically by developing a new profiling procedure. A custom-made color target has been created in order to optimize the color accuracy of the digital reproduction of a small gamut object. Selection of colors has been carried out from a color catalogue, choosing a set with colorimetric values uniformly distributed in the volume of the color space took up by the gamut of the object. Then, the creation of the ICC profile has been carried out referring to the new target. The main results obtained though a comparison between the developed custom profiling procedure and the standard profiling procedure confirmed a higher precision of the new procedure.

Introduction

Digital reproductions of "2-dimensional" cultural objects (e.g. paper documents, such as prints or photographs, fabrics, such as carpets or tapestries, paintings on canvas or board, frescoes, etc.) represent orthometric images (i.e. without any perspective deformations) that satisfy the requirement of uniformity of illumination of the surface during the acquisition.

In order to create a faithful digital reproduction of a work of art, the matching between the appearance of the reproduction and the appearance of the real object has to be achieved. Because of the adapting mechanisms of vision and spatial characteristics of the scene observed, the equality of CIELAB values does not always ensure this matching. However, an image with a minimized ΔE should be considered as a good starting point for the application of processing algorithms that reproduce color appearance phenomena [1].

Ordinary profiling method

The creation of color-accurate digital images requires the use of targets with standard colors for which the colorimetric coordinates are known. The target represents the reference for color optimization.

Creating an ICC profile of a device is a modeling operation that defines the better transformation that approximates the correlation between the RGB space of the device (device-dependent) and a color space (device-independent) [3]. This modeling operation can not ignore the conditions in which the acquisition takes place and therefore the color optimization is valid as long as those conditions remain unchanged.

The definition of the transformation is based on a set of experimental data (nodes); in the case of an acquisition device this nodes consist in the correspondences between the n colorimetric values of the target and the related RGB values saved by the device in the image:

$$[(X_i, Y_i, Z_i), (R_i, G_i, B_i)] \qquad i = 1, 2, ..., n \tag{1}$$

In order to predict the colorimetric values for the other RGB points we have to find the transformation f that approximates the behavior of the device [4]:

$$(X, Y, Z) = f\,[(R, G, B)] \tag{2}$$

Described transformation could pass exactly by the nodes; in that case it will give the best matching with the experimental data. Otherwise, we can take into consideration other types of constraints (e.g. constraints related to continuity issues) and search the transformation that minimizes the distances from the nodes, fulfilling the constraints at the same time.

The operations performed by the profiling software released today apply the second type of transformation and consequently do not get exactly the experimental points identified by the target. In order to show empirically the validity of this statement we perform the experimentation exposed in the following text.

First experiment: testing the ordinary profiling method

Using a Canon EOS 5D camera, equipped with the objective EF50mm f/1.4 USM, two images were acquired: one framed the standard ColorChecker target and the other framed, with the same environmental setting and parameters, a custom-made color target: both images have been acquired under diffuse sunlight.

The custom-made target has been realized with a selection of 18 colors taken from the PANTONE FORMULA GUIDE coated book and with the 6 patches of the ColorChecker grayscale, arranged as in the standard ColorChecker. The Pantone colors have been chosen in order to maximize their colorimetric distance from the colors of the standard ColorChecker.

A scheme that describes the custom target is reported in Figure 1.

Figure 1. *Scheme of the custom target*

Using the software ProfileMaker 5 two ICC profiles have been created: the first used the ColorChecker as reference, the second referred to the custom color target. The two ICC profiles have been both assigned to each of the two images of the targets. Color accuracy was then measured for the four images obtained; the distances ΔE_{00} [5] between the colorimetric values obtained on the optimized digital images and those tabulated has been calculated; the average distance of all patches of the target was then taken as indicator of color accuracy.

The results of this first experiment are shown in the following table:

Profiling reference	Color sample	Average distance ΔE_{00}
ColorChecker	ColorChecker	2,32
	custom color target	4,26
custom color target	ColorChecker	4,47
	custom color target	2,98

The values in the table show what was said before: the colorimetric distortion is smaller if color accuracy is read on the same colors that were used as reference for the creation of the profile. In fact, if the ColorChecker target is used as reference, in order to obtain the colorimetric values of the custom color target, the profiling procedure uses interpolation operations, while the values of ColorChecker, which are the same values on which profilation is based, do not imply uncertainty. In fact color accuracy results poorer (higher distances ΔE_{00}) for the custom color target. Accordingly, the contrary is confirmed.

Moreover, it has to be noticed that, even when we read color accuracy on the same colors that were used as reference for creating the profile, the error obtained is not negligible, as would be expected due to the fact that the values of the reference targets are known. This means that profiling does not identify a transformation *device space* ↔ *color space* that passes exactly by the nodes, but minimizes the distances from them.

For this reasons, the process of creating color profiles, as it is nowadays widespread, has some inherent weaknesses. The exposition below emphasizes two reasons for the ineffectiveness of profiling.

The uncertainty due to interpolation

From the theoretical point of view it will be always possible to obtain an exact optimization for the colors that corresponds to the patches of the target, since the colorimetric values of the target are the same tabulated values on which profiling is based (nodes)[i]. On the other hand, the colorimetric values of other colors will be derived, through interpolation processes, from the values of the colorimetrically neighboring patches.

As confirmed in the above experimental, the interpolation process entails a certain degree of uncertainty that increases together with the distance of the unknown point from the nodes used for interpolation. In order to achieve greater accuracy, it is convenient to reduce colorimetric distance between the reference constituted by the patches of the target and the colors that constitute the chromatic content of the images to be profiled.

Let's consider, for example, the digital reproduction of a sepia photograph: since the chromatic variability of the object is rather limited, it may happen that the colorimetric values of the photograph fall into a restricted area of the color space which is not covered by any color of the target. In cases like this the uncertainty due to interpolation can be considerable for all the pixels of the picture.

Problems due to the generalized palette of standard targets

The standard target used for profiling the digital capture devices are constituted by colors homogeneously distributed in the color space.

It has been already showed that the creation of ICC profiles doesn't obtain exactly the correspondences defined by the color target, but it rather represents a minimization of the distances from these corrispondances.

The implemented minimization is generally a global one: the minimized quantity is in fact an average of the colorimetric distances of all the patches of the target. This should guarantee that the system provides satisfactory results for any chromatic content.

Although, this satisfaction has the "flip side": when we compare the distribution of colors of the objects to be digitized with the distribution of colors in the palette of the target some problems emerge.

Namely, the chromatic content of an object to be digitized will not cover the entire color space, but only specific areas. Using a standard target, it may happen that, in the effort to contain the error also for colors that are not present in the object to be converted, the system makes a significant error in the area of the color space referring to the object [6].

Let us return to the example of the sepia picture: in order to contain the error for blue, which is not present in the photo, the system sacrifices the area of sepia. It is clear that this process will compromise accuracy of reproduction.

An adaptive method for profiling

In the previous text two causes of low efficacy of profiling were reported. The first is related to interpolation: colors of the object distant from the colors of the target show greater errors than those closer to them. The second is related to the minimization procedure, which chooses to optimize the overall error referring to a palette that covers the largest part of the color space. This penalizes those images whose colors are distributed in a small area of color space.

This work aims to solve these problems by developing a procedure of profiling (*adaptive procedure*) that uses specially created target (*target custom*), constituted of colors chosen considering the chromatic content of the objects to be digitized [6]. In this study, the colors have been selected from the PANTONE FORMULA GUIDE coated book.

In addition to the custom target, the novel profiling procedure need to have a software that creates ICC color profiles referring to the new target. We chose to use the software LittleCMS Profiler (abbreviated LProf), a software that creates ICC profiles for cameras and scanners using as reference the target IT8.7/2. It was decided to use this software as it is open source and as is possible to change the reference inputting external colorimetric data using the CGATS format. Moreover, in creating profiles LProf follows only the mathematical criterion of minimizing the colorimetric distance.

The most critical part of the proposed profiling procedure is the choice of the color of the Pantone book to be included in the custom target [7]. The colors of the custom target must be chosen so that their distances from the colors of the objects to be digitized are minimized. By viewing this in a color space, this means that the set of selected colors will be distributed in the volume identified by the chromatic content of the object to be digitized.

By following this procedure, the problems discussed above will be no longer valid: the interpolation operations will entail less uncertainty and, at the same time, the profile will not be based on a generalized palette.

First, a colorimetric database of the book had to be created. The measurements were carried out with the spectrocolorimeter *Konica-Minolta CM-2600d*, equipped with an integrating sphere (8 mm opening diameter) and working in the d/8 configuration. This device obtain the colorimetric values from the reflectance spectrum of the point measured in the range 360 nm - 740 nm with 10 nm wavelength pitches.

Once generated the image file of the custom target and created CGATS file it had been possible to create a custom profile.

Second experiment: testing the adaptive profiling method (application to real cases)

The case study here reported concerns the digital acquisition of three photographic prints produced in the late nineteenth century, belonging to the *Berenson archive*[ii]. The photographic prints were acquired using the scanner *Microtek ScanMaker 1000 XL*. The images obtained were processed with traditional optimization procedures hence obtaining a rough distribution in the CIELAB space of the color content of the three photographic prints (Figure 2).

In order to create a custom-made color target specific for the color content of the prints, and in order for it to be easily usable with LProf, the following procedure has been carried out.

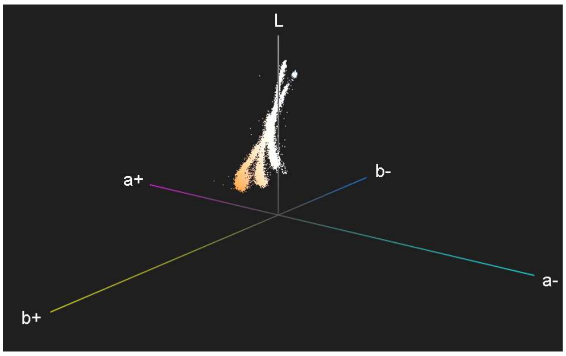

Figure 2. *Colorimetric values of the three photographic prints reported in the CIELAB space*

The first operation was to identify 228 colors to be substituted to the colors of the IT8 standard target; these colors have to be chosen so that their distances from the colors of the photographic prints are minimized.

Given the distribution in the CIELAB space, the smaller orthogonal parallelepiped that houses all the color-points of the three photographic prints has been identified. Afterwards the colorimetric database of the Pantone book has been queried in order to provide the set of Pantone color-points housed by the same parallelepiped: in this case study 323 Pantone have been found.

Finally a succession of exclusions has been operated till the number of Pantone selected has been brought down from 323 to 288. These exclusions were carried out aiming at making the colors of the custom target as equally spaced as possible, adopting an iterative procedure that identifies the couple of Pantone color-points characterized by the smaller colorimetric distance and than excluding one those two colors.

Figure 3. *The custom color target*

Afterward, using identical settings for acquisition, processing and saving of files, the IT8 target and the 228 Pantone selected for the custom target have been acquired.

The acquired images have been saved in TIFF format at 48 bit per pixel.

The image of the custom target (Fig. 2) was created with a graphics editing software, pasting on the patches of the standard IT8 image the RGB data obtained from the acquisition of Pantone colors. In order to avoid fluctuations due to the noise of the signal recorded, for each patch of the target the average value of a reasonable set of pixels has been calculated.

Two ICC profiles were created: one referring to the custom target (*adaptive profiling*) and another referring to the IT8 target (*ordinary profiling*). The two profiles were therefore assigned to the images of the photographic prints, hence obtaining two different optimizations of color.

Results

Efficacy of the adaptive method for profiling is demonstrated through a colorimetric comparison of a selection of points of the original pieces (the photographic prints). Using the spectrocolorimeter Konica Minolta CM-2600d, measurements on a set of points of original prints were carried out; each measure has involved a circular area with a diameter of 8 mm.

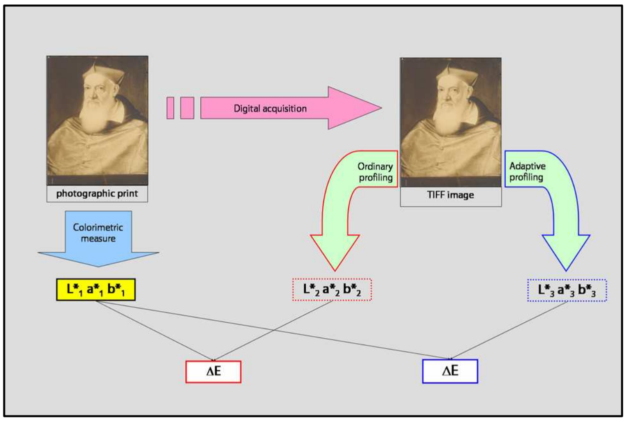

Figure 4. *Comparison of performance profiling ordinary and those of suitable profile*

For each point measured, on the image profiled with the ordinary method and on the image profiled with the adaptive method, the average colorimetric value of the pixels corresponding to the area measured by the instrument was calculated. The distances ΔE between the values read on the two images and those measured by the spectrocolorimeter were then calculated. Subsequently the results obtained are reported.

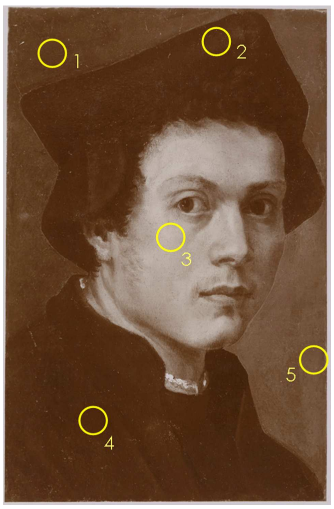

Figure 5. *Spectrocolorimetric measuring points on the photographic print n°103726*

Comparison between the ordinary and the adaptive method for profiling the digital image of print n°103726

Measure point	Spectrocolorimetric measurement			ΔE adaptive method	ΔE ordinary method
	L	a	b		
1	28,9	13,1	15,7	**3,5**	**8,7**
2	26,9	13,2	15,6	**4,2**	**7,0**
3	71,0	3,2	3,8	**5,9**	**3,5**
4	21,7	12,9	13,9	**3,1**	**8,5**
5	37,3	11,3	14,6	**4,1**	**8,7**

Figure 6. *Spectrocolorimetric measuring points on the photographic print n°103735*

Comparison between the ordinary and the adaptive method for profiling the digital image of print n°103735

Measure point	Spectrocolorimetric measurement			ΔE adaptive method	ΔE ordinary method
	L	a	b		
1	34,5	3,5	6,2	**2,4**	**8,1**
2	33,6	3,3	5,6	**2,1**	**7,9**
3	58,6	4,4	12,4	**6,4**	**6,9**
4	33,7	2,9	4,9	**3,4**	**8,6**
5	56,9	5,3	15,4	**5,9**	**6,8**

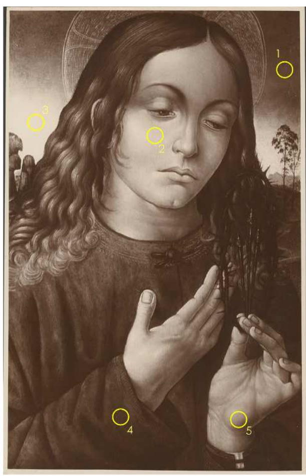

Figure 7. *Spectrocolorimetric measuring points on the photographic print n°103801*

Comparison between the ordinary and the adaptive method for profiling the digital image of photographic print n°103801

Measure point	Spectrocolorimetric measurement			ΔE adaptive method	ΔE ordinary method
	L	a	b		
1	33,8	8,3	10,7	**3,7**	**9,3**
2	78,6	4,3	9,4	**7,3**	**3,9**
3	84,8	3,2	9,3	**7,4**	**3,9**
4	29,1	7,1	9,1	**1,8**	**9,2**
5	59,5	6,6	10,0	**7,6**	**8,1**

Conclusions

This work has defined a novel methodology for the optimization of color in digital images implementable in digitization projects of artistic and documentary material preserved in archives, libraries, museums. It was developed a procedure for creating color profiles according to the standard ICC that, by using specific targets (*target custom*), constituted by colors appropriately selected from a color book, refers to the color content of the specific items to be digitized (*adaptive procedure*).

The usefulness of this approach was highlighted through the description and analysis of problems related to the procedure of profiling that uses standard targets (*ordinary procedure*). In particular, it was found that the digital reproduction of objects whose chromatic content is concentrated in a small area of the color space represents a case in which the ordinary profiling procedure may be scarcely effective.

The methodology has been applied to real cases; some old photographic prints were examined: a category of documents which represents a typical example of a restricted chromatic content.

Almost all the results obtained, expressed in terms of colorimetric distances from the spectrocolorimetric measurements performed on the original pieces, demonstrate that performances of profiling adopting the proposed method have improved with respect to the ordinary method that uses standard color targets.

Upcoming researches will be focused on the study of the correlation between the improvement of performances and lightness (L coordinate) of the original piece.

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[i] The above experimental demonstrates that this result is not obtained in reality

[ii] The Berenson archive is part of *The Harvard University - Center for Italian Renaissance Studies* located near Florence

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Author Biography

Giorgio Trumpy received his MSc degree in Science for Cultural Heritage from the University of Florence in 2009 with a thesis developed at the Institute of Applied Physics (IFAC-CNR).

From 2006 he works in the framework of projects of digitization of the Florentine museums heritage, collaborating with several public and private realities.

He’s a member of CREATE (Colour Research for European Advanced Technology Employment), a European group that promotes research through a series of conferences.