Computer graphics solutions for dealing with colors in archaeology

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Abstract

A main issue in the archaeological research is to deal with colors of soils and artefacts, especially pottery. Since, in many cases, color information are crucial for the interpretation of cultural products, to avoid risks of a too subjective autoptic recognition Munsell system is commonly used in archaeology.

This method widely used in other fields, like geology and anthropology, is based on the matching between the real color and its standardized version on Munsell Charts. But it has significant limitations, due to the influence of cultural background, color sensibility and education, that can mislead archaeologists in their daily work.

In this paper a semi-automatic method of color detection on selected regions of digital images of ancient pottery is presented. This tool, whose encouraging experimental results are widely discussed in the contribute, is aimed to prevent eventual subjective errors during color identification and to speed up the process of identification itself. In order to emphasize the relativity of Munsell system, a statistical analysis was carried out on a group of potsherds selected for this research, pointing out the range of different colors identified on a single specimen by different observers.

The starting point of the experiment was to take digital pictures of specimens together with the Gretag-Macbeth Color Checker Chart, whose chromatic values have been objectively established. The digital image is processed with color balancing techniques aimed to restore the original value of Macbeth patches, in order to eliminate distortions coming from acquisition process. After the color correction, several regions of interest are selected via 'point and click' for the identification of surface color, the algorithm converts RGB values in Munsell data. The reliability of our tool is also verified comparing this chromatic values with the color specification of pottery sherds performed with a spectrocolometer using the CIELAB space to evaluate the differences.

The results obtained and percentages of successful matching with Munsell color identification coming from the statistical analysis, seem to open new perspectives for the development of a full automatic system with a GUI interface aimed to facilitate significantly some aspects of the archaeologist's work.

Introduction

Every observer perceives color differently. A major obstacle encountered when comparing colors is the choice of descriptive words. Color also varies in its appearance due to changes in the light source and the distance of the light source. The color identification as any other cognitive process can also be seriously influenced by cultural and linguistic background as well as psychological state [1]. Furthermore, it must also be taken into account that colors can only be described unequivocally as long as all the interlocutors can actually see them. If, however, one scholar receives the information exclusively from the oral or written reports of one of the others, he must try to picture a particular color without having perceived it herself or himself. The mental image thus created will thereby only in the rarest cases correspond to the visual impression which the other person was stimulated to communicate.

Since color can only inadequately be described by verbal means, nowadays whenever one wants to make unequivocal systematically, constructed color chart are used.

At the beginning of the 20th century, Albert H. Munsell [2] brought clarity to color communication by establishing an orderly system for accurately identifying every color that exists. The Munsell color system is a way of precisely specifying colors and showing the relationship among colors. Every color has three qualities or attributes: hue, value and chroma. Munsell established numerical scales with visually uniform steps for each of these attributes.

In archaeology Munsell charts are widely used as the standard for color identification of soil profiles, organic materials, rock materials, colored glasses, metals, paintings, textiles and mainly pottery.

For which regards the interpretation of pottery the precise color identification of such parts like clay body, treated surfaces, core, and outer layers like slip and painting, it is fundamental for defining its stylistic and technical features.

As a coding framework, the charts both mediate perceptual access to the colored object being classified, and provide a color reference standard. This tool does not stand alone as a self-explicating artifact; instead its proper use is embedded within a set of systematic work practices, varying from community to community. As demonstrated in application in fields of archaeology, anthropology, these practices can contribute to misclassification of colors [1]. In fact, Munsell notations are not always unequivocal and the limits of their use are well known since decades [3].

Besides the above mentioned cultural, linguistic and psychological background, several other factors can misled the observer in the task of color identification of pottery. The most common are surface homogeneity of the material, state of color surface, color type, test condition, accuracy of assertion, color blindness, quality and type of the Munsell charts.

While Munsell system is ideally shaped for smoothed surfaces no displaying disturbing textures, the pottery surfaces are just in rarest cases homogenous both in relation in their color and their texture, often altered by cracks and superficial voids. Decorative techniques aimed to smooth, coat or glaze can also modify the real chromatic value of the surface. Some kind of patina and incrustation can cause misinterpretation of the color as well as artificial light sources, different than natural daylight must be avoided. Finally, an additional human error can be determined by the inaccuracy caused by tasks involving thousands of checks and by problems coming from quite common deficiencies in color perception [3]. In this perspective, the development of an automatic system for classification of colors in archaeology, and in particular in the field of pottery research, must be considered crucial for providing a solution to all the above mentioned problems.

In this paper, we propose an algorithm to extract an objective Munsell definition of colored selected regions of digital image. The method corrects the illumination defects in the picture in order to create the ideal illumination that permits one to extract the color information.

The rest of the paper is organized as follows. In Section 2 the proposed technique is described; the next Section reports a series of experiments devoted to assess the effectiveness of the method based also on experimental data obtained from color specification by spectrophotometric method. Finally, some conclusions are given together with a few hints for the future work.

2 Proposed System

The proposed system is a semi-automatic algorithm aiming to find the best match between a user selected color in a picture of an archeological sherd with a color in the Munsell charts [2].

Focusing on a particular color in the sherd, the system must provide the color in the Munsell table that best matches it. There are several problems to overcome: first of all, the acquisition process is not usually obtained in good illumination conditions. Pictures are often acquired in artificially illuminated rooms, with uncontrolled light sources in order to reply the real in situ conditions. It means that the color correction of the camera is not always able to compensate correctly for the illuminant. This problem, known as "white balance", is a main issue to deal with [4]. Secondly, the sherd point that the user is asked to click should be representative of the sherd. Noises and dirty spots can make really difficult this process. Lastly, also the matching between the RGB color in the picture and their equivalent in Munsell table is not a minor problem, since it is necessary change in a different data space. We define a system and a pipeline to overcome all these problems. A database has also been set up to make the tests and it is available in [5] to let the reader use and/or extend it for further research.

The proposed pipeline (Figure 1) is composed by a color correction, a patch extraction, and a color matching modules. In the next sub-sections each block is analyzed in detail.

Figure 1. *Block scheme of the proposed algorithm pipeline.*

2.1 Color correction

In the color correction module, the image is compensated for the illuminant. This problem is known as "white balance" and there are lots of algorithms in literature to reduce the problem in a fully automatic way [4, 6, 7, 8]. Unfortunately, a zero failure algorithm does not exist, since the white balance is an ill-posed problem and all the methods available are based on assumptions. Whenever, when the assumptions are not verified, the algorithm fails [9]. Moreover there is another problem: the pictures are obtained from a camera and the white balance is already applied (like other algorithms, e.g., color matrix, gamma correction, etc.). It may produce problems in color reproduction. In order to control these problems, we started taking pictures with a color checker chart (Macbeth chart) acquired in the same image: first to obtain the best correction (to validate all the other steps of the algorithm); and second to create a ground truth to validate further methodologies.

In the Figure 2 some pictures of the dataset are shown. They were acquired in different illumination conditions. In Figure 3 the related histograms of the '*light skin*' patch (the second patch of the Macbeth chart) are shown. It is evident the effect of the illuminant on the color rendition: without any post-processing correction, the color matching is impossible.

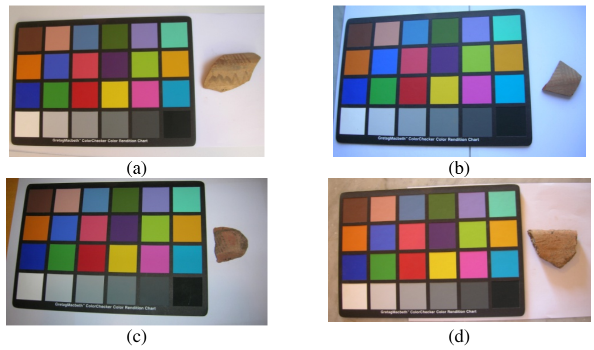

Figure 2. *Examples from the dataset with different illuminants; the effect of the different light conditions is evident.*

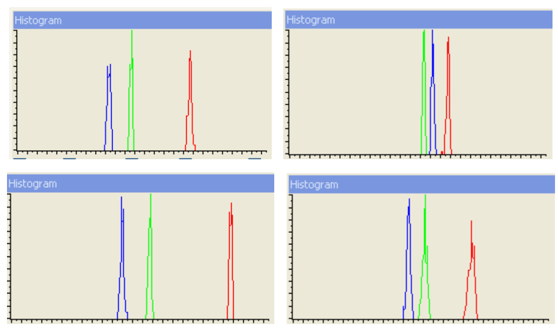

Figure 3. *Histogram of the Macbeth chart 'light skin' patch (ISCC/NBS name: light reddish brown; Munsell notation: 2.2YR 6.47/4.10 as reported in [13]) in the four images in Figure 2. The RGB mean values are, respectively (from top to bottom, from left to right): (177, 116, 93), (157,143,133), (217,135,110), (181,133,116).*

The algorithm proposed supposes that images are acquired with the Macbeth chart and the correction is performed compensating some patches of the chart.

It is supposed to compensate for the illuminant according to the von Kries–Ives adaptation [10], i.e., the correction can be obtained by multiplying every color component with an amplification coefficient that could be obtained starting from one patch or by using more patches. If we use p patches, a set of redundant equations are obtained, and an optimization techniques, e.g. Least Squares Method, can be used to obtain the gains. The error function E to be minimized, for a number p of selected patches, is:

$$E = \sum_{i=1}^{p} e_i^2 \quad (1)$$

where e_i is the error contribution of each patch:

$$e_i = \left|(g_r \cdot R_{in}) - R_t\right| + \left|(g_g \cdot G_{in}) - G_t\right| + \left|(g_b \cdot B_{in}) - B_t\right| \quad (2)$$

And g_r, g_g and g_b are, respectively, the gains values, R_{in}, G_{in} and B_{in}, the color in input, while R_t, G_t and B_t, the average values of the patch.

This formula provided good results in terms of visual quality. Other types of error measurements can be used, e.g., in a more perceptually uniform color space.

In our system we started using the six gray patches in the bottom of the chart. Of course, in order to reduce the noise, the patch color is obtained as mean of a patch crop. The entire process is shown in Figures 4 and 5.

Figure 4. *Color correction module using one neutral patch.*

Figure 5. *Color correction module using six neutral patches.*

In the '*Patch extraction*', user has to select the patches and the system retrieves the mean value of the patch. In the '*wb coeffs*' block the system computes the gains according to the formulas shown above.

2.2 Patch extraction

After the color correction, the user has also to choose the color to be matched in the Munsell table. A 'point and click' is the best user friendly way to do it. In order to reduce difficulties due to noises or scratches in the archeological finds, when the user points over a colored surface, a homogeneous patch is shown. The color of the patch is obtained, for the generic pointed pixel at position *(p, q)*, as median of a square window of size *n*:

$$C = median(C_{ij} \mid i = p-n,..., p+n \text{ and } j = q-n,..., q+n) \quad (3)$$

Where C=R, G, or B; n=10 in the actual implementation. The use of the median instead of the mean value allows reducing the influences of impulsive noises and scratches in the patch extraction. Figure 6 shows a snapshot of the software.

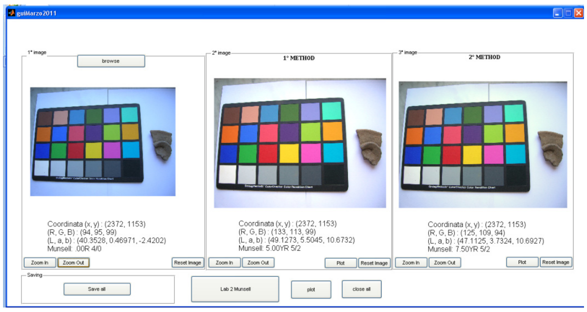

Figure 6. *A snapshot of our software.*

2.3 Color matching

The color matching block aims to obtain the color in the Munsell table most similar to the patch chosen by the user. Each color is represented by three components: hue (H), value (V) and chroma (C). The •E^*_{ab} in the CIELAB color space (*L*a*b* coordinates*) has been chosen to quantify the chromatic differences because this representation is *perceptually uniform*, i.e. a change of the same amount in a color value produces a change of about the same visual importance [11]. All the patches in the Munsell table were represented in the CIELAB color space. The block based scheme of the color matching phase is shown in Figure 7.

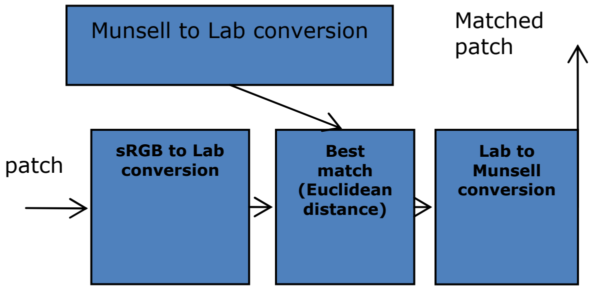

Figure 7. *Color matching block based scheme.*

The best matching is performed using the minimum Euclidean distance between the patch and all the Munsell colors. The matched color is hence converted in the Munsell space and is provided to the user.

3 Experimental Results

3.1 Test of the method

First of all, we have tested that the proposed method works correctly considering the archaeologist suggestions. To test this, we have acquired the image of the Munsell charts with the Macbeth color checker (Figure 8). In this way, the algorithm of color correction works well if the single patch has the correct color as shown in the Munsell table, in 90% of the experiments.

In order to test our proposed method, in Table I some results using the image of archaeological sherds [5] are presented. The second column shows the subjective color suggested by the archaeologist. The third column reports the more representative color in the sherd computed in the input image without any corrections. In the fourth and fifth columns the results of our techniques are shown. In particular the color correction results obtained using one neutral patch are reported in the table as "Method I", and the technique that uses six neutral patches is called "Method II".

Even if they are different from the human suggestion, they are very close to this. Hence, this means that the system works in the right direction.

We have observed that experimental results are close to the archaeologist suggestions with a success rate of 85% when the images are compensated using six neutral pathes (Method II) instead of the original 73% for the uncorrected images (third column in the table).

Figure 8. *Example of image used to validate the color matching block*

Table I. Some examples of color determination. The subjective archaeologist suggested color is compared with the algorithm results.

Image	Human identification	Without correction	Method I	Method I
9570	7.5 YR 7/4	10 YR 6/4	7.5 YR 6/4	5 YR 7/4
9579	10 R 7/6	5 YR 6/6	2.5YR 7/4	5 YR 7/3
9584	5 YR 6/2	10 YR 4/2	7.5 YR 6/2	5 YR 7/4
9591	5 YR 6/1	7.5 YR 5/2	10 YR 5/1	7.5 YR 5/2

The results obtained on four pottery sherds show on the one hand that the correction module is necessary and on the other hand that the coordinates obtained with method II seems more reliable. In order to generalize this result, the method will be tested with a wide set of artifacts. Two elements are fundamental in this approach: the variability of archaeological information, Munsell coordinates considered as reference, and the need to an experimental method for color specification and chromatic differences evaluation.

3.2 Color measurements

In order to quantify the variability of Munsell color identification, the coordinates coming from the visual evaluation of a statistical population composed of 25 archaeologists were analyzed. As an example, Figure 9 shows the distribution of the different coordinates individuated from population for two samples of the entire set (sherds identified from 9579 and 9584 code).

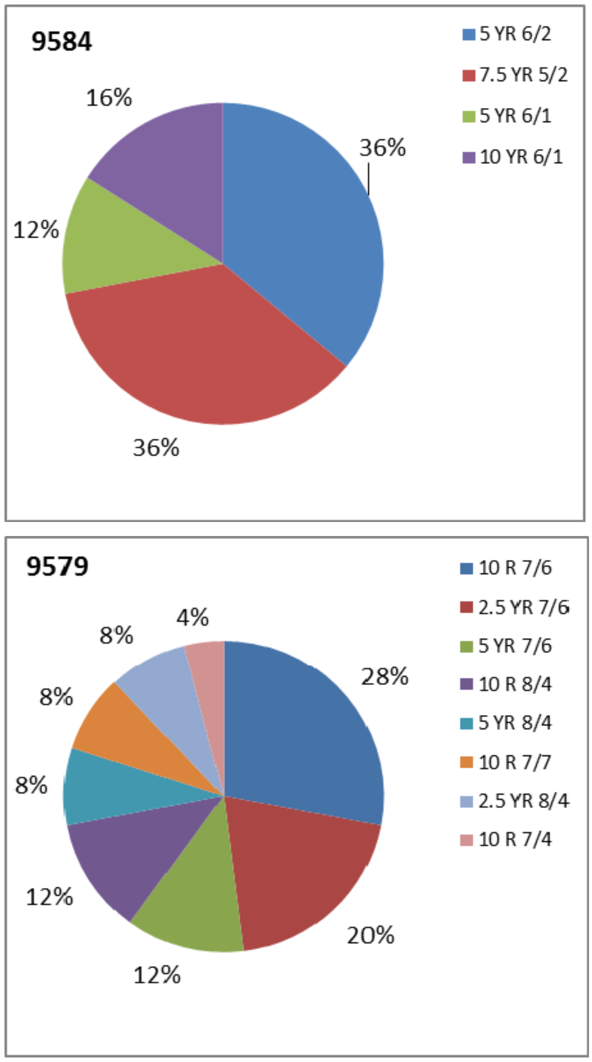

Figure 9. *Example of distributions of Munsell specification from a population composed from 25 archaeologists.*

In order to assess the chromatic differences between the previously evaluations, color measurements were performed with the contact spectrophotometric method using a portable Konica-Minolta CM2600D instrument, equipped with an integrating sphere in the geometry d/8° [14]. The measurements were made, after the usual procedures for black and with adjustment [15], selecting an area of 3 mm diameter (SAV condition). The data acquired were relative to the standard observer 10° and D65 illuminant, the colorimetric space chosen for the representation of the calculated chromatic coordinates was the CIELAB [11]. The chromatic differences were calculated in the same space considering the pottery measured data as target and measurements performed on Munsell charts corresponding to archaeologists' evaluation as samples.

Figure 10 shows the results for the same samples of Figure 9.

The color difference (ΔE) between the chromatic coordinates measured with the spectrophotometer and the data derived from the Munsell values identified by archaeologists are very high (ΔEmax = 32). The differences in chromatic plane, $\Delta_{ab} = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2}$, show a high variability of values between 2 and 12.

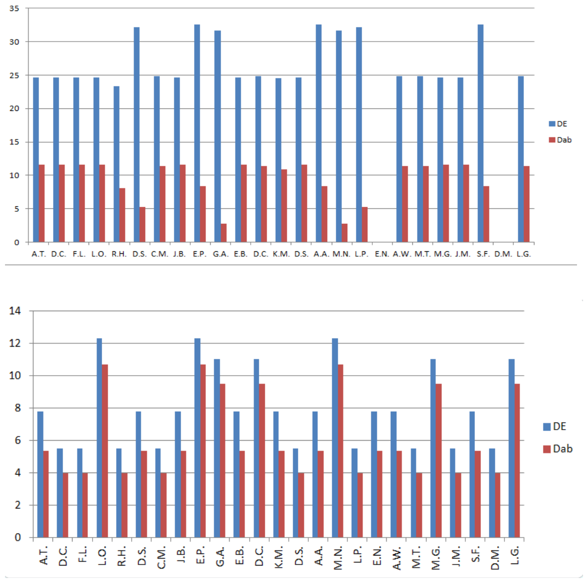

Figure 10. *Example of chromatic differences calculated between CIELAB coordinates of analyzed pottery (target) and Munsell color charts corresponding to archaeologists' evaluation (samples).*

These results underlined that a different approach must be followed for the continuation of the research. It is in fact necessary in the first place toalffj0 repeat the archaeologists' observation in controlled light conditions in order to reduce the variability of Munsell values, secondly, the reference data for the study must be the data obtained from the experimental specification by spectrophotometric method.

4 Conclusion

Considering that a specific aim of the research is the validation of the proposed tool and in the light of results here presented, the color difference evaluation will be made comparing the algorithm results exclusively with experimental data obtained by the spectrophotometric method. The images of pottery samples will be acquired including in the scene both the Macbeth chart, used as reference in digital imaging, and Munsell Soil Charts, used as reference by archaeologists. The comparison will be concern the algorithm results and the experimental colorimetric coordinates of the three series of data. The conversion between different colorimetric systems plays an important role in this future work.

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