Automated Color Specification of Archaeological Objects

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Abstract

The classification of ancient pottery plays an important role in the field of archaeology. The classification of shape, material and color is used to relate a sherd to existing parts in the archive, thus the color information is important in the pre-classification process. In this work a color specification technique is proposed, which determines the color of specific regions of archaeological objects grabbed with a CCD camera. We explain how the acquisition system is calibrated in order to have a reference color system with respect to archaeological requirements. Experimental results are presented for archaeological objects and for a set of test color patches.

1. Introduction

The archivation of sherds (fragments of pots) is the process starting from finding the objects, cleaning and measuring them to the presentation in the museum or archive catalogue. This procedure is called *classification process* and is carried out for each sherd found at an excavation site. The classification of shards is divided into the following parts:

- Shape classification (profile, diameter of a fragment) [1,2,3,4]
- Classification of the material
- Color classification (paintings, relief color)

The classification of shape, material and color is used to relate a sherd to existing parts in the archive. The color information is very important in the pre-classification process. The archaeologists use the color information of a sherd to relate it to an excavation layer, age or even to a certain pot.

In order to determine the specific color of a sherd archaeologists estimate the color of each sherd by matching it to the Munsell color patches. The *Munsell Color System* is defined by the three parameters *Hue, Value* and *Chroma*, [5,6] Two charts are visualized in Figure 1. For each sherd the Munsell color specification is archived together with all other properties (shape, profile, relief etc.). Since this process is done "manually" by different archaeologists and under varying light conditions the results differ from each other. In general photos of sherds are taken in order to have color representations in the archive. Due to different camera characteristics and changing light conditions the color of a sherd in images varies.

In this work an approach for a color specification of sherds, performed on digital images containing archaeological sherds gained by a CCD camera is presented. Archaeologists need digital color images of sherds in any case and therefore the information which is normally achieved with a color measurement instrument can be gained directly from the digital image. Thus it is possible to determine the color for each pixel in the entire image. A straight forward approach is proposed using a linear color camera calibration technique with a post refinement process.

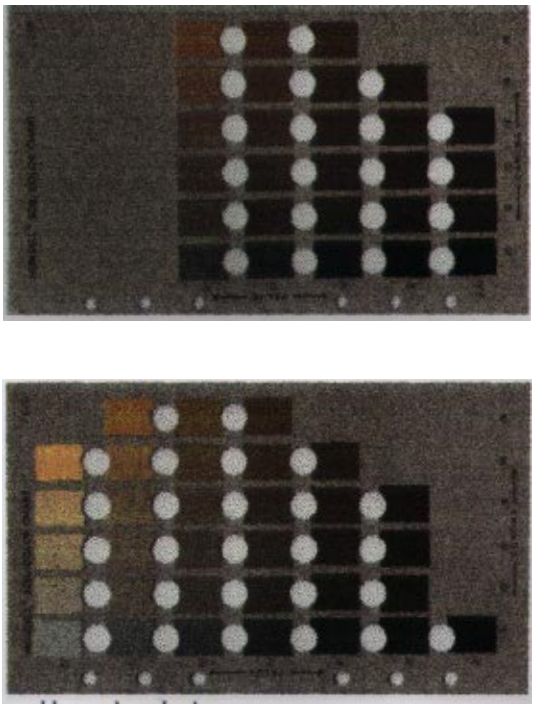


Figure 1. Munsell color charts used by archaeologists

The paper is organized as follows: In section 2 we explain how we calibrate the acquisition system in order to have a reference color system with respect to archaeological requirements. Experimental results are described in section 3 and we conclude with a summary and outline the future work.

2. Color Specification Process

In order to perform color specification of various objects out of digital color images calibration techniques play an important role. A lot of work has been done in computational approaches using color calibration techniques. One specific problem regarding color specification is color con-

stancy.[7,8,9,10] Novak and Shafer used color charts to supervise color constancy,[11] whereas Skrzypek and Gunger tried to determine lightness constancy out of luminance contrast.[12] In the field of color vision one possible reference color set is the *Macbeth* color chart. This chart contains 24 colors, which are specified in the 1931 *CIE XYZ* color system.[5] In order to provide a device independent color specification of a sherd reference colors are used, which are grabbed by a 3CCD color vision camera module together with a sherd. For that purpose we divide the measurement area into two parts: the object area and the reference color area, which can be seen in Figure 2.

Figure 2. sherd together with reference colors

In a first experiment nine reference colors are used. The *CIE* tristimulus values for these colors are taken directly from the Macbeth color chart or with a color measurement instrument. The *CIE XYZ* values of the used Macbeth patches are depicted in

Table 1 and the chromaticity values (x,y) are visualized in Figure 3 (a) as filled circles.

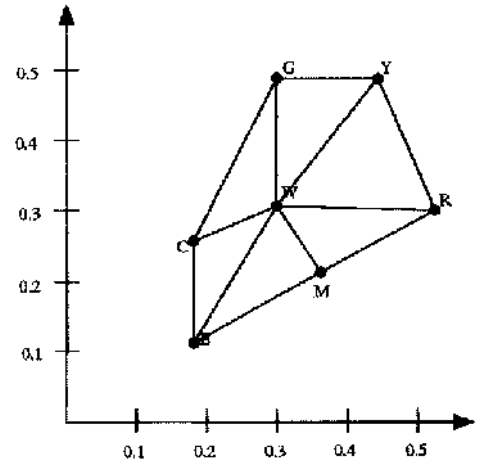
Table 1: Macbeth Reference Colors

	W	R	B	G	C	Y	M	Bl	Gr
X	88	21	9	15	15	56	31	3	19
Y	90	12	6	23	20	59	20	3	20
Z	107	6	32	1 1	43	10	34	4	23

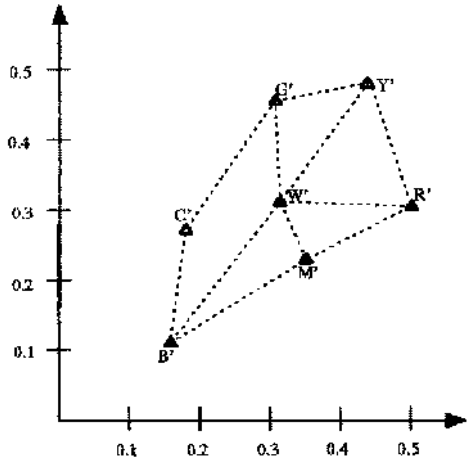
Since archaeologists are interested in Munsell color values a look-up table for the transformation from *CIE XYZ* into the Munsell Color System is used.[5]

The grabbed digital *RGB* image containing the sherd with the reference colors has to be transformed into the *CIE XYZ* color system. For that purpose a calibration process, establishing a relation between the device dependent camera *RGB* system and the device independent *CIE* system, has to be performed. Although this relation has a non-linear behavior we try to use a linear transformation as an approximation which is refined in a post processing step. The matrix A for this transformation (1) is determined by finding a best fit solution for the *CIE XYZ* values of the Macbeth reference colors and the corresponding *RGB* values of the reference colors grabbed by the CCD camera. The linear transformation from the *RGB* values to the *CIE XYZ* values is defined by

$$A\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} \tag{1}$$



a) Actual values



(b) Linear transformed values

Figure 3. Macbeth chromaticity values

Since this transformation is linear we do not get the exact *CIE XYZ* values of the Macbeth reference colors. The achieved values are visualized im the chromaticity diagram in Figure 3 (b) as small triangles. The inaccuracies between the actual *X,Y,Z* and the calculated *X'Y'Z'* values are corrected in a postprocessing step. Using the Macbeth reference colors two corresponding tetrahedral structures are build by using both the actual K Y,Z and the calculated *X',Y',Z'* values. For an actual *RGB* value of the sherd the enclosed *X'Y'Z'* -tetraeder is determined. This tetraeder is transformed to the corresponding *XYZ*-tetraeder, meaning that all points which are inside are corrected regarding to the four corner points. For the correct alignment of these two tetraeders an amine transformation is applied with matrix *B*

$$\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}, \quad (2)$$

where the coefficients b_{ij} are determined from the two sets of corner points. Finally the obtained *X,Y,Z* values are transformed into the Munsell Color System by using the look up tables.

3. Evaluation of the Results

The aim of this work is to automate the process of color specification of archaeological objects. Until now this process is carried out by archaeologists by comparing specific parts of a shard with Munsell color charts. The values of the patch, which is most similar are taken for archivation. A visual color matching as well as an automated color specification has been performed for four different test regions, which are visualized in Figure 4 (A,B,C,D). The results can be seen in Table 2. The Munsell Values (Hue, Value, Chroma) visually obtained by an archaeologist are compared with the Munsell Values determined by our method before and after the refinement step. Column 3 of Table 2 contains the Munsell Values based on *CIE* tristimulus values measured with a Chroma Meter CR-200b. The improvement of the refinement step compared to the results of the linear transformation are obvious. The final results are in the close neighborhood of the "measured" Munsell Values.

Another possibility to evaluate the quality of the color specification process is to take Munsell Color Charts used by archaeologists which are visualized in Figure 1. An image is grabbed, the Munsell Values are calculated and compared with the values referenced on the charts. This kind of evaluation is more adequate for a scientific exact evaluation. The error for saturated colors is small whereas in regions with low saturation the error increases.

Table 2.

	Visually estimated Mun. Val.	Mun. Val. based on measured XYZ	x´ y´ Y´	Calc. Munsell Val.	x y Y	Final Munsell Val.
A	10R 4/8	2.5YR 4/6	0.50 0.28 15.7	2.5 YR-5YR 5/6	0.51 0.39 14.31	2.5 YR 5 YR 4/8
B	2.5 YR 5/8	2.5 YR 4/6	0.50 0.39 16.5	5 YR 5/6	0.51 0.39 15.20	2.5 YR-5YR 4/8
C	10R 4/8	2.5 YR 4/6	0.50 0.39 16.5	5 YR 5/6	0.51 0.39 15.20	2.5 YR-5YR 4/8
D	2.5 YR 5/8	2.5 YR 4/6	0.50 0.39 16.5	5YR 5/6	0.51 0.39 15.20	2.5 YR-5YR 4/8

Table 3.

Actual Munsell Values	x´ y´ Y´	Calculated Munsell Values	x y Y	Final Munsell Values
7.5 YR 5/8	0.48 0.40 24.6	5 YR-7.5 YR 5/8	0.48 0.40 23.5	5 YR-7.5 YR 5/8
7.5 YR 6/8	0.45 0.39 32.8	5 YR 6/8	0.46 0.40 30.8	7.5 YR 6/8
7.5 YR 7/8	0.43 0.38 40.8	5 YR 7/6-8	0.42 0.37 44.1	5 YR 7/6
7.5 YR 4/4	0.43 0.37 17.5	5 YR 5/6	0.43 0.39 16.2	7.5 YR 5/4-6
7.5 YR 3/3	0.38 0.36 12.5	7.5 YR 4/2-4	0.38 0.37 12.0	7.5 YR 4/2-4
2.5 YR 5/8	0.46 0.36 25.0	10R 6/8	0.48 0.37 20.5	2.5 YR 5/8
2.5 YR 6/8	0.44 0.35 32/5	10R-6/8	0.48 0.34 34.1	2.5 YR 6/6-8
2.5 YR 3/6	0.41 0.35 15.6	10R-5/4-6	0.48 0.36 13.2	2.5 YR 4/4-6

Figure 4. Different test regions

4. Conclusion and Outlook on Future Work

In this work we presented a color specification technique for archaeological objects, which plays an important rote in the classification process for archivation of ancient pots. We proposed a straight forward approach using a linear color calibration technique with a post refinement process. Since the color specification of a sherd is gained by different archaeologists using the Munsell color charts, the results differ from each other. The results obtained by our method gives a good initial estimate to the archaeologists.

Future work goes towards a color specification system using more reference colors, automated highlight detection on the surface and towards an improvement by modeling the 3D structure of the object.

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