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Color Calibration for Pre-Classification of Pottery

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Abstract *Every archaeological excavation must deal with a vast number of ceramic fragments. The documentation, administration and scientific processing of these fragments represent a temporal, personnel, and financial problem. We are developing an automated classification and reconstruction system for archaeological fragments. The goal is to relate different fragments belonging to the same vessel based on shape, material and color, thus the color information is important in the pre-classification process. In this work a color specification technique is proposed, which exploits the fact that the spectral reflectance of materials like archaeological fragments vary slow in the visible spectrum. We explain how the acquisition system is calibrated in order to get accurate colorimetric information with respect to archaeological requirements. Experimental results are presented for archaeological objects and for a set of test color patches.*

1 Introduction

Ceramics are one of the most widespread archaeological finds and are a short-lived material. This property helps researchers to document changes of style and ornaments. Therefore, ceramics are used to distinguish between chronological and ethnic groups. Furthermore ceramics are used in the economic history to show trading routes and cultural relationships. Especially ceramic vessels, where shape and decoration are exposed to constantly changing fashion, not only allow a basis for dating the archaeological strata, but also provide evidence of local production and trade relations of a community as well as the consumer behavior of the local population.

The purpose of classification is to get a systematic view of the material found and is used to relate a fragment 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 fragment to relate it to an excavation layer, age or even to a certain pot.

The classification of fragments can be divided into two main parts, shape features and properties. The *classification of shape* defines the process where archaeologists distinguish between various features like the profile [3], the dimensions of the object like diameter and type of surface [7], whereas the *classification of material* copes with different characteristics of a fragment like the clay, color [8] and surface properties.

Archaeologists determine the specific color of a fragment by matching it to the Munsell color patches [8]. Since this process is done ”manually” by different archaeologists and under varying light conditions the results differ from each other. In general, photos of fragments are taken in order to have color representations in the archive. Due to different camera characteristics and changing light conditions the color of a fragment in images varies. Figure 1 shows how a change in temperature may influence the RGB-output of a standard color camera (CCD-IKEGAMY ICD-700P) and thus cause inaccurate color information. The dotted line indicates the drifting of the RGB-Output. After four hours the temperature was changed from 30 to 20 degrees and the output of the green channel changed from 71.8 to 68.4 RGB-units.

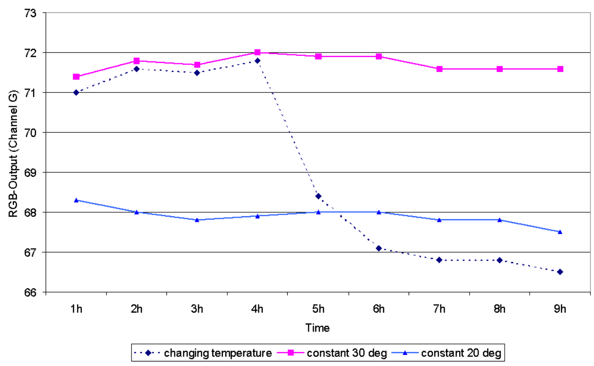

Figure 1: Color drifting caused by changing temperature

Archaeologists need digital color images of fragments for archivation purposes, thus the color information which is normally achieved with a color measurement instrument can be gained directly from the digital image for each pixel in

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the entire image. In practice, these advantages are offset by the difficulty of reliably translating the video camera‘s output into colorimetric variables.

We propose a solution to this problem assuming that the spectral reflectance of archaeological fragments vary slowly in the visible spectrum. We present an approach for accurate colorimetric information of fragments, performed on digital images containing archaeological fragments under different illuminants. A characteristic vector analysis [9] of the reference reflectance leads to an algorithm that computes the colorimetrically accurate reflectance out of a video digitizing system.

The paper is organized as follows: In Section 2 we describe the theoretical background, in Section 3 we explain how we specify the colorimetric variables in order to calibrate the acquisition system with respect to archaeological requirements. Experimental results are described in Section 4 and we conclude with a summary and outline the future work.

2 Theory and Notation

In order to perform accurate colorimetric information using video devices many approaches can be found in literature. Much of human color-vision research focuses on color constancy since it is the perceptual ability that permits us to discount spectral variation in the ambient light and assign stable colors: Maloney and Wandell [5] considered that both lighting and spectral reflectance are unknown, whereas Lee [4] simplified that problem by assuming that spectral illumination is known. Conversion from camera RGB triples to tristimulus values was done by [1, 2, 8].

In order to provide a device independent color specification we use reference colors from the MacBeth Color chart [6] (Figure 2). The color checker is a checkerboard array of 24 scientifically prepared colored squares in a wide range of colors. It is designed to help to determine the true color balance or optical density of any color rendition system. Each 13/4" color square represents a natural object like human skin, foliage, and blue sky. They reflect light the same way in all parts of the visible spectrum. The MacBeth Color checker patches are representative samples for common reflectance characteristics.

The choice of the color checker or any other statistical sample drawn from the population of color standards clearly imposes a bias on the characteristic vector analysis. If the resulting basis vectors ultimately yield spectral reflectance that are colormetrically accurate over a wide range of chromaticities, then the color checker will be satisfactory for these purposes.

Our approach rests upon Lee‘s method assuming that spectral illuminant is known and that the spectral reflectance of our material varies slow in the visible spectrum. This means that small changes of RGB values should lead to small changes in reflectance. Prior knowledge about the illuminant leads to chromaticity and luminance information.

Each RGB pixel in a digitized image has a value proportional to weighted integral over the visible spectrum. This integral depends on three spectral variables. These are the *spectral irradiance* $E(\lambda)$, which describes the energy per second at each wavelength λ. The proportion of light of wavelenght λ reflected from an object is determined by the *surface spectral reflectance* $S(\lambda)$. We assume that there are k distinct channels in the digitizing system, we use $k = 3'$ for red, green and blue. We denote the spectral response of the kth channel as $R_k(\lambda)$ and a pixel value for the kth color channel as p_k.

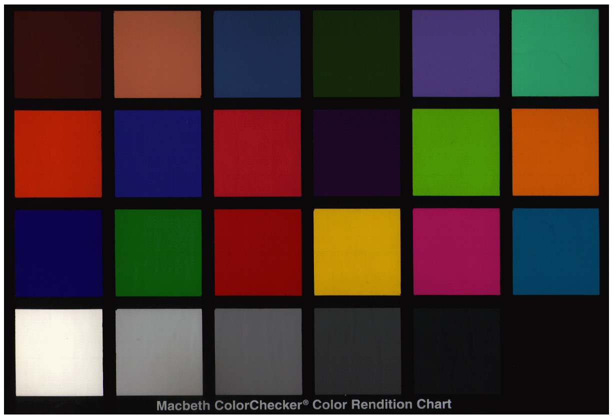

Figure 2: Macbeth ColorChecker

$$p_k = \int S(\lambda)E(\lambda)R_k(\lambda)d(\lambda) \quad (1)$$

Eq. 1 describes the relationship between pixel values and spectral quantities. We approximate the three integrals above as summations over wavelength, using values every $10nm$ in the visible spectrum from $400nm$ to $700nm$. If you subsume the proportionality factor in the $R_k(\lambda)$, you can construct the following matrix equation (Eq. 2), where m denotes the steps to be taken in the spectrum.

$$p = SER \quad (2)$$

p . . . 1 by 3 row vector (RGB pixel values at a given location)

S . . . 1 by m row vector, whose elements represent the surface reflectance

E . . . m by m diagonal matrix, whose nonzero entries represent the spectral irradiance

R . . . m by 3 matrix, representing the digitizing system spectral transfer function

If we know elements of two of the arrays on the right side of Eq. 2 and the corresponding RGB pixel values on the left side, we can solve the unknown array. Since only an approximated knowledge of the system function R is assumed, we split the whole procedure into two steps:

1. specify the system transfer function R more accurately by analyzing color samples with known reflectance of the MacBeth Color patches.

2. use this new information to find the unknown spectral reflectance of other samples illuminated by the same light source.

The goal of the first step is to improve the transfer function R which leads to R_{new} (Eq. 3).

$$R_{new} = RR_1 \tag{3}$$

Therefore we digitize an image of the color chart, which is illuminated by the same light source that will be used when we evaluate unknown color samples. The digitization gives a q by 3-matrix P containing RGB values, where q denotes the number of patches of the color checker. Since we know the illumination E and the set of q reflectances S, we can form the q-by-3 matrix SER_{new}. This leads to Eq. 4. For the unknown R_1 a least square solution is used, which leads to an improved estimate of the system's spectral transfer function.

$$P = SERR_1 \tag{4}$$

The goal of the second step is to calculate the reflectances of unknown color samples. We use the RGB-values from the digitized color samples p, the improved transfer function R_{new} and the spectral irradience E in order to calculate spectral reflectances S (See Eq. 2).

Since $S(\lambda)$ varies smoothly for archaeological finds we can accurately represent the spectral reflectance of a set of color standards with the first few components of a characteristic vector analysis [9]. In effect, this analysis allows us to reduce the dimensionality of S and leads to an algorithm that gives colorimetrically accurate spectral reflectance from red-green-blue output of the video digitizing system.

S_{mean} is defined as mean vector (1 by m) from the color checker reflectances at $m = 30$ equally-spaced wavelengths across the spectrum. S_{basis} (n by m matrix) denotes the characteristic vectors used. We use $n = 3$ characteristic vectors to represent the original data. A 1-by-n vector of basis weights (denoted B) is calculated when solving Eq. 5 by inserting the digitized RGB values into p.

$$B = (p - S_{mean}ER)(S_{basis}ER)^{-1} \tag{5}$$

When we multiply S_{basis} by the appropriate vector B and add the result to S_{mean}, we can reconstruct any spectral reflectance S in our set of colors (Eq. 6). For a more detailed description of the algorithm see [4].

$$S = S_{mean} + BS_{basis} \tag{6}$$

The technique used is a method of examine a number of sets of multivariate response data and determining linear transformations of the data to a smaller number of parameters which contains essentially all the information in the original data.

3 Color estimation process

First, the three spectral variables irradiance of the lightsource $E(\lambda)$, camera transfer function $R_k(\lambda)$ and reflectance $S(\lambda)$ of the MacBeth reference chart have to be initialized.

We use Tungsten Halogen Floodlamps 7700 (150W) and TL-light as lightsources. The spectral distribution was given by the manufacturer. Figure 3 shows the typical spectral distribution of TL-82 and TL-95 with slight differences between these two lamps.

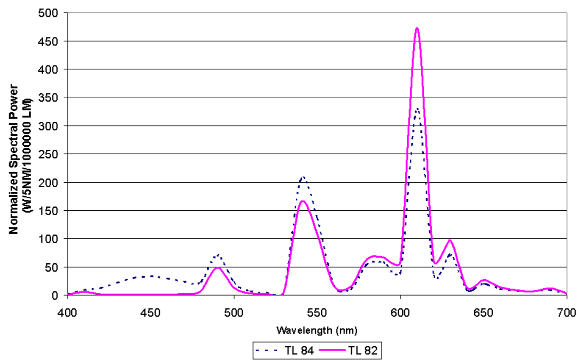

Figure 3: Spectral irradiance of TL-82 and TL-95

The video camera used is a 3CCD DONPISHA XC-003P and a CCD-IKEGAMY ICD-700P. The Ikegamy camera is a single CCD-color CCTV camera that employs a 1/2-inch CCD solid-state imaging device with about 390.000 picture elements, which is used to give out Y/C (chrominance/ luminance) separation signals. The Sony camera is a color video module, which uses a CCD for the pick up device. It has an RGB signal output. Both cameras are one chip cameras. Figure 4 shows the spectral response curve of the DONPISHA camera. The data was provided by the manufacturer.

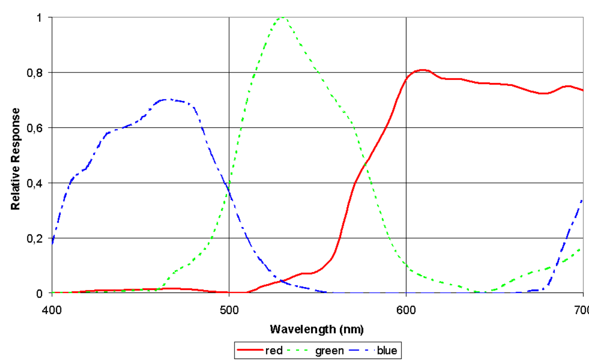

Figure 4: Typical spectral response of a Sony-camera

The spectral reflectance is scaled in equally-spaced wavelengths (every 10nm) across the spectrum. 12 colors of the MacBeth color checker are used as reference set and 12 are used for evaluation purposes. Their reflectance is measured using a spectroradiometer. For our reference set we choose colors which have a similar spectral distribution to the colors of our archaeological findings in order to maximize the achievable accuracy of the vector analysis. Figure 5 shows the spectral reflectance of four selected MacBeth-patches (Dark Skin, neutral 5, neutral 3.5 and white).

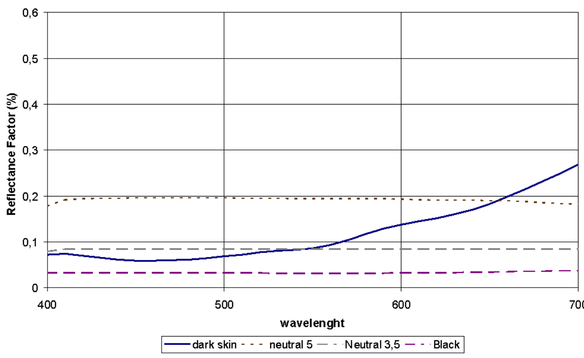

Figure 5: Measured spectral reflectance of four MacBeth patches

Next we grab an image of an archaeological fragment, which leads to RGB values. Test regions are manually specified and their RGB-Values are used to reconstruct the reflectance. Figure 6 shows two different test regions A and B.

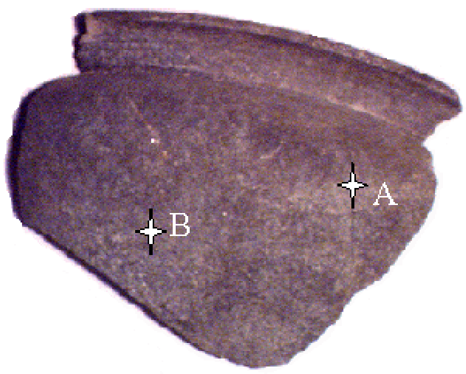

Figure 6: Test regions A and B

4 Results

Two experiments are presented: the first example with MacBeth Colors and the second with real fragments. In a first experiment we use the measured reflectance of 12 MacBeth color patches as reference and try to estimate the reflectance of the other 12 patches using the reference set. The resulting reflectance is compared to previous measured values. Figure 7 shows the result for patch 1 (dark skin). In that case the correlation equals $0,98$. The computed reflectances of the other 11 patches correlated between and $0,85$ and $0,98$ to their corresponding measured reflectance with an average correlation of $0,92$. The more the reflectances of the color patches vary the lower the correlation gets since the characteristic vectors are less capable of matching the reflectance curve shape differences. The change of the spectral character of the illumination leads to inaccuracies, since we have claimed that the spectral illumination is accurately known.

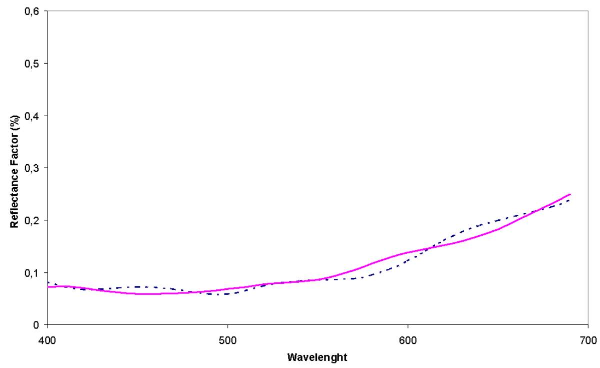

Figure 7: Measured and estimated spectral reflectance of a MacBeth Color Patch

In the second experiment we grab an image of a fragment and specify two test regions A and B (Figure 6). The reference set was chosen from MacBeth color checker. The spectral reflectance of A and B is computed and visualized in Figure 8. For evaluation purposes we calculate CIE tristimulus values using a linear transformation and compare the values achieved with cromaticity coordinates measured from a Chroma Meter CR-200b. Table 1 shows the results which are influenced by the linear transformation used. Therefore we plan measurements using a spectroradiometer in order to allow direct comparison between measured and computed reflectances.

	Comp. A	Meas. A	Comp. B	Meas.B
x	0.44	0.33	0.48	0.40
y	0.36	0.34	0.40	0.37
Y	13.3	11.1	24.6	21.0

Table 1: Measured and computed cromaticity coordinates

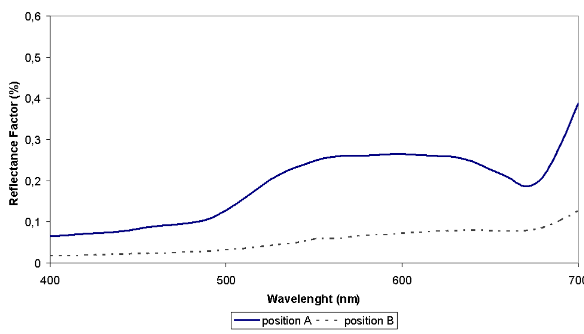

Figure 8: Calculated spectral reflectance of positions A and B

5 Conclusion and Outlook

In this work we presented a technique for accurate color estimation, which plays an important role in the classification process for archaeological fragments. We proposed an application using a straight forward approach using a linear color calibration technique. Since the color specification of a fragment is gained by different archaeologists and under varying lightning conditions the results differ from each other. The results obtained give a good initial estimate to the archaeologists. Future work will be directed towards color calibration without known illuminants in order to allow color estimation outside laboratory conditions and measuring the spectral distributions with a spectroradiometer.

References

[1] M. S. Drew and B. V. Funt. Natural Metamers. *Computer Vision, Graphics and Image Processing*, 56(6):139–151, 1992.

[2] M. K. Horn. Exact Reproduction of Coloured Images. *Computer Vision, Graphics and Image Processing*, 26(1):135–167, 1984.

[3] M. Kampel and R. Sablatnig. On 3d Modelling of Archaeological Sherds. In *Proceedings of International Workshop on Synthetic-Natural Hybrid Coding and Three Dimensional Imaging, Santorini, Greece*, pages 95–98, 1999.

[4] R. L. Lee. Colormetric calibration of a Video Digitizing System. *Colour Research and Application*, 13(3):180–186, 1988.

[5] L. T. Maloney and B. A. Wandell. Colour Constancy: a method for recovering surface spectral reflectance. *Journal of the Optical Society of America*, 3(1):29–33, 1986.

[6] C. S. McCamy, H. Marcus, and J. G. Davidson. A Colour-Rendition Chart. *Journal of Applied Photographic Engineering*, 2(3):95–99, 1976.

[7] C. Menard and R. Sablatnig. Computer based Acqusition of Archaeological Finds: The First Step towards Automatic Classification. In H. Kamermans and K. Fennema, editors, *Interfacing the Past, Computer Applications and Quantitative Methods in Archaeology*, number 28, pages 413–424, Leiden, March 1996. Analecta Praehistorica Leidensia.

[8] C. Menard and I. Tastl. Automated Color Determination for Archaeological Objects. In *Is&T Fourth Color Imaging Conference, Scottdale*, pages 160–163, 1996.

[9] J. L. Simonds. Application of characteristic vector analysis to photographic and optical response data. *Journal of the Optical Society of America*, 53:968–974, 1963.