IN SEARCH OF THE COLOURS OF THE FRESCOES IN THE PAINTED HYPOGEUM TOMB AT TOMIS-CONSTANȚA

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ABSTRACT

The painted hypogeum tomb in Tomis-Constanța, Romania, discovered in 1988, remains one of the most important proof of the existence of pre-Christians on the territory of nowadays Romania due to its frescoes and Christian hidden symbols. However, the frescoes are not seen by visitors, as visiting of the tomb is restricted to its curators only. The colour of the frescoes were never seen in the daylight, not properly photographed. In this article, we use hyperspectral imaging to perform a rendering of the colour images inside the tomb in controlled illumination and acquisition conditions, using a white reference and a colour checker. For data acquisition we used a SpecimIQ portable hyperspectral camera. For the processing of the data we rely on the standard linear colour formation model and assumed a D65 illuminant in order to render the colour images for the visualization and consequent study of colours. We show and discuss the experimental results obtained under the D65 illuminant assumption.

***Index Terms*—** hyperspectral imaging, colour rendering, colour appearance

1. INTRODUCTION

The hypogeum tomb at Tomis (Contanța, Romania), discovered in 1988 during urban expansion works, is one of the most important funerary monuments of Late Antiquity in Romania, both for its architecture and its exceptional painted decoration [1, 2]. The family tomb, featuring a dromos and a rectangular burial chamber, preserves an extensive iconographic programme executed in the *a secco* technique, comprising anthropomorphic, zoomorphic and phytomorphic representations, organised into a unified decorative ensemble. The scenes depicting doves, partridges, peacocks, the hare with grapes and the funeral banquet reflect the synthesis between the Greco-Roman artistic tradition and the new early Christian symbolism, illustrating the process of religious and cultural transformation characteristic of the 4th–5th centuries AD. Archaeological research has revealed the existence of four main burials and some secondary deposits, and the funerary inventory, although limited, allows the monument to be dated to the second half of the 4th century AD.

An analysis of the tomb's orientation, the funerary ritual and the iconographic repertoire supports the attribution of the tomb to an early Christian community, whilst not ruling out the possibility that it was a monument originally built in a pagan context that was later reused. Owing to its exceptional state of preservation and the artistic value of the paintings, the hypogeum at Tomis-Constanța is one of the most representative examples of funerary architecture and monumental art in Roman-Byzantine Dobruja (nowadays Dobrogea region in Romania), providing essential information on the evolution of funerary practices and religious symbolism during the transition period between Late Antiquity and Early Christianity.

The principal composition occupies the northern wall, where a ritual banquet is represented beneath the monumental painted arch. Around a circular table are seven male figures. Five of them recline on the characteristic Roman dining couch (klinē), while two standing figures, dressed in garments typical of the Late Roman period, hold vessels that probably served a ritual purpose. The background is composed of stylized Mediterranean trees and additional vegetal motifs, suggesting that the ceremony takes place outdoors. The eastern wall depicts two peacocks shown in profile, facing one another while pecking fruit from a basket. As in the previous scene, stylized Mediterranean trees and vegetal ornaments form the background. On the southern wall, above the entrance to the burial chamber, a scene depicts four doves drinking water from a cup. The birds are rendered in a remarkably naturalistic manner and are surrounded by stylized vegetal motifs. Continuing the sequence of zoomorphic and floral representations, the western wall contains two scenes featuring four partridges. Two birds are shown drinking from the same type of cup depicted in the previous scene, while the other two peck at the ground around it. Adjacent to this composition is a hare feeding on grapes spilling from an overturned basket. The entire vaulted ceiling is decorated with painted vine scrolls interspersed with additional vegetal motifs. The colour images are shown in Figure 1.



(a) Fresco on the North wall



(b) Fresco on the East wall



(c) Fresco on the West wall



(d) Fresco on the South wall

Fig. 1. Colour digital images of the frescoes of the tomb acquired with a Cannon 5D mark IV camera. Note that colour correction was applied using a linear transform as proposed in [3] [4]). Also a slight perspective transform was applied to images in order have a perpendicular view to the frescoes which was not possible to obtain during the acquisition because of the tight place and the hyperspectral camera.

The colour palette of the entire decorative program follows the classical tradition, employing shades of red, yellow, green, blue, white and black. However, the true colours of the frescoes were never revealed by the previous image acquisitions in the tomb. On 7 July 2026 we entered the tomb and performed the image acquisition in controlled illumination and acquisition conditions, deploying a SpecimIQ hyperspectral camera, halogen lamps, tripods, a white reference and a colour checker. The main goal of the article is to render the colour images of the frescoes assuming a daylight illumination, which, due to the nature of the monument, will never occur. In addition, the consequent goal is the democratization of the digital images of the frescoes of the hypogeum tomb in Constanța, Romania, for the future analysis and studies.

The article is structured as follows. In Section II we describe the camera used for the acquisition of the hyperspectral data and the processing used for the rendering of the colour images for the visualization of hyperspectral data. Section III presents the experimental results, while Section IV concludes the paper.

2. DATA ACQUISITION AND PROCESSING

To acquire the hyperspectral data, we used a hyperspectral SpecimIQ camera. SpecimIQ is a portable snapshot hyperspectral camera that captures 204 spectral bands in the visible and near-infrared spectral range (approximately 400-1000 nm). Its spatial resolution is 512×512 pixels, with a field of view (FOV) of $31^\circ \times 31^\circ$. The illumination used within the tomb was close to the CIE standard illuminant A.

For the visualization of the colour images based on the hyperspectral data, we considered the linear model given by equation (1) [5]. For a pixel at any position (x, y) the acquired intensity in the resulting image is computed as the integral of the product between the spectral reflectance $R(\lambda)$ of the (x, y) point in the real scene, the power spectral distribution $L(\lambda)$ of the illuminant and the spectral sensitivity $C(\lambda)$ of the observer or imaging sensor.

$$I(x,y) = \int_{\lambda_{min}}^{\lambda_{max}} C_R(\lambda) L(\lambda) R_{(x,y)}(\lambda) d\lambda \qquad (1)$$

For the spectral sensitivity curves of the imaging sensor one can use theoretical or ideal curves, in order to simulate the image formation process. An alternative would be to use the actual sensitivity curves of a specific sensor, which can be measured according to the approach proposed in [5].

The illuminant can be modelled, either by considering a standard illuminant or measuring the real one by means of spectrophotometry. In colorimetry, a D65 illuminant is very often preferred, as it corresponds to a bright summer day light. In this article we assume first that the illuminant is constant (which is an ideal, non-realistic case), then the illuminant is D65 (see Figure 2).

Concretely, considering an ideal illuminant (constant spectral reflectance over the entire interval of wavelengths),

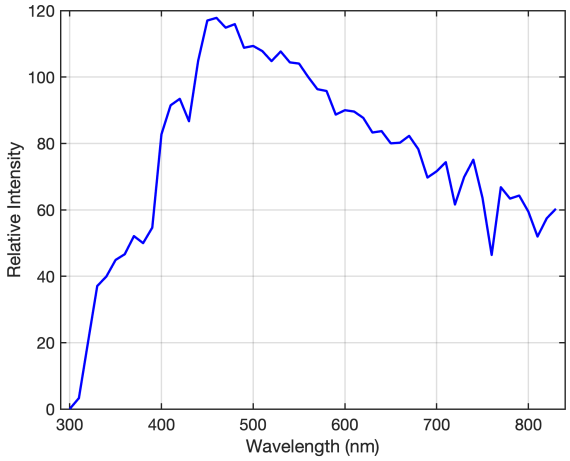


Fig. 2. Spectral distribution of the D65 standard illuminant.

we converted the spectral data into chromaticity coordinates computing the XYZ coordinates [6] as:

$$\begin{cases} X &= \int_{\lambda_{min}}^{\lambda_{max}} R_{Cn}(\lambda)\overline{x}(\lambda)d\lambda \\ Y &= \int_{\lambda_{min}}^{\lambda_{max}} R_{Cn}(\lambda)\overline{y}(\lambda)d\lambda \\ Z &= \int_{\lambda_{min}}^{\lambda_{max}} R_{Cn}(\lambda)\overline{z}(\lambda)d\lambda \end{cases} \quad (2)$$

where $\overline{x}(\lambda)$, $\overline{y}(\lambda)$ and $\overline{z}(\lambda)$ are the CIE 1931 colour matching functions [7] depicted in Figure 3.

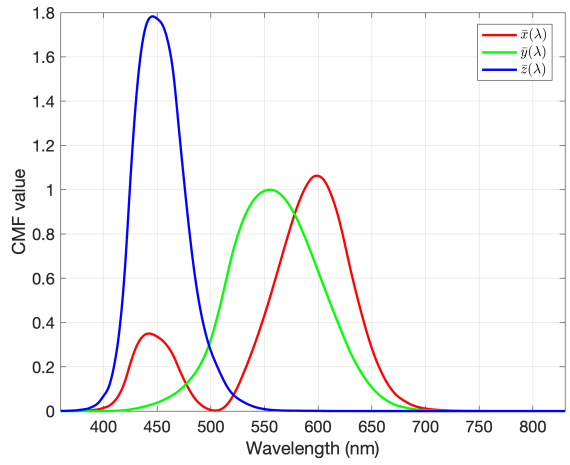


Fig. 3. CIE 1931 colour matching functions employed for the spectral integration of the hyperspectral reflectance data.

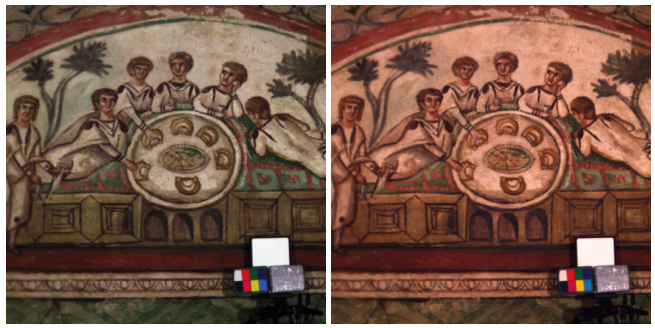
In this way, the resulting image is in XYZ colour space. For the conversion from XYZ to linear RGB, we used the following transformation:

$$\begin{bmatrix} R_{lin} \\ G_{lin} \\ B_{lin} \end{bmatrix} = \begin{bmatrix} 3.2410 & -1.5374 & -0.4986 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.05556 & -0.2040 & 1.0570 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (3)$$

The resulting linear RGB values were clipped to the interval [0,1] for visualization.

3. EXPERIMENTAL RESULTS

In Figure 4 we show three visualizations of the hyperspectral data acquired for the fresco depicting the funerary banquet.



(a) Colour RGB composite with band selection and brightness correction (b) Colour RGB composite based on the constant illuminant assumption



(c) Colour RGB composites based on the D65 illuminant assumption

Fig. 4. Visualization of the banquet scene.

First the band selection performed using the bands 88, 54 and 23, corresponding to wavelengths of 651.92 nm (R),



(a) Hare (b) Peacocks (c) Doves

Fig. 5. D65-based visualizations of the hypogeum frescoes on the West, East and South walls.

551.49 nm (G) and 460.96 nm (B) for which a linear brightness correction was applied (a); secondly, the colour RGB image assuming a constant, ideal illuminant (b) and the colour RGB image obtained using the D65 illuminant (c). Using the processing described in Section II and assuming the D65 illuminant, the other three hyperspectral images were visualized, as presented in Figure 5. Figure 6 (a) shows the spectral signatures of the eight colour patches of the colour checker extracted from the hyperspectral data of the banquet scene, which were used for the evaluation of the quality of image acquisition (see Section 4). These spectra are further analysed against two reference sets.

4. DISCUSSION

Figure 6 (b) presents the theoretical spectral signatures of the eight selected colours from colour checker. These spectral signatures are used as reference spectra for comparison with the corresponding spectra extracted from the hyperspectral image. However, the actual colour checker may not exhibit the ideal colours, given that the colours may vary due to age, temperature and that wrinkles appeared on the colour checker during the acquisition process given the high humidity maintained in the tomb (over 80%). Therefore, Figure 6 (c) presents the spectral signatures of the colour checker used during the data acquisition in the hypogeum tomb under the same halogen illuminant in laboratory conditions. The spectral signatures of the selected colours were acquired using the AvaSpec-ULS2048CL-EVO spectrometer, after normalization with the spectrum of the illuminant.

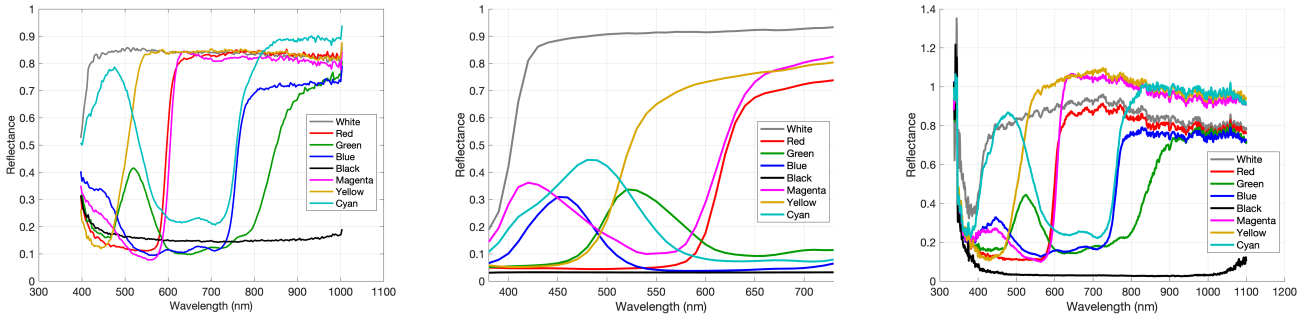
To evaluate the similarity between the spectra of the colour checker patches extracted from the hyperspectral image and their corresponding reference spectra, several distances were used: the Spectral Angle Mapper (SAM), Spectral Information Diverge (SID) and Spectral Correlation Mapper (SCM) [8] and [9]. The results are presented in Tables 1 and 2 for the ideal reference spectra and the real reference spectra, respectively. As expected, better results are obtained when the real colour checker spectra are used. However, given the very difficult conditions for the acquisition, one may consider alternative ways for referencing the colours instead of using the regular paper-based colour checkers.

Colour	**SAM (°)**	**SID**	**SCM**
White	2.286	0.0025	0.9892
Red	13.378	0.1477	0.9646
Green	20.399	0.1996	0.7362
Blue	22.126	0.1767	0.8435
Black	10.331	0.0275	0.5114
Magenta	9.244	0.0377	0.9650
Yellow	7.331	0.0518	0.9851
Cyan	9.286	0.0387	0.9794

Table 1. Similarity metrics between the ideal and real spectra for the colours on the colour checker (SpecimIQ data).

	SAM (°)	**SID**	**SCM**
White	3.7396	0.0047	0.8046
Red	3.4658	0.0066	0.9930
Green	5.5308	0.0225	0.9870
Blue	4.7460	0.0171	0.9906
Black	7.1778	0.0126	0.9514
Magenta	3.1542	0.0054	0.9940
Yellow	2.8111	0.0056	0.9933
Cyan	3.0960	0.0038	0.9917

Table 2. Similarity metrics between real spectra for the colours on the colour checker (SpecimIQ vs AvaSpec data).



(a) Spectral signatures of each colour patch from the colour checker from the Specim data

(b) Ideal spectral signatures of the theoretical spectra for the colour on the colour checker

(c) Spectral signatures of the real colour checker, acquired with the AvaSpec spectrometer in laboratory conditions

Fig. 6. Comparison of the colour checker spectral signatures.

5. CONCLUSIONS

After almost 40 years since its discovery, we entered the hypogeum painted tomb in Tomis-Constanța and performed the hyperspectral data acquisition for the frescoes inside the tomb, in controlled conditions. We acquired representative portions of the all four walls frescoes, given the physical constraints given by the tight space, the possibility to install the tripods for the halogen lamps and the camera, as well as the fixed focal distance of the acquisition system. We deployed the SpecimIQ portable hyperspectral camera to perform the data acquisition. Based on the linear colour formation model, we performed the colour image rendering for the visualization of the frescoes. Using the assumption of the D65 illuminant, we visualized the colour images based on the hyperspectral data, in order to visualize the colours of the frescoes as if they were admired during the day light. We also performed an evaluation of the quality of the image acquisition using several metrics and the spectra of the colour patches of the colour checker.

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