Multispectral Photogrammetry: 3D models highlighting traces of paint on ancient sculptures

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Abstract
The Ny Carlsberg Glyptotek and Rigsters 3D are exploring the potential of merging photogrammetry and multispectral imaging (MSI). MSI is a widely employed photographic method of analysis in studies of ancient polychromy. The collaboration has resulted in the first 3D model including visible-induced infrared luminescence (VIL) imaging, illustrating the distribution of the ancient synthetic pigment Egyptian blue. The collaboration illustrates how the combination of methods developed in the fields of humanities, natural sciences, and digital industries can contribute to knowledge exchange as well as the development of new ways of disseminating scholarly research in museum exhibitions as well as online and for teaching purposes.

Keywords: Ancient polychromy, photogrammetry, multispectral imaging, VIL imaging.

1 Introduction

[HUMlab] at the Copenhagen University Library aims at introducing the digital humanities to students and staff at the University by building new data competences and establishing collaborations with other institutions and private companies. Thus, [HUMlab] reached out to the polychromy research team at the Ny Carlsberg Glyptotek, who have welcomed [HUMlab] in their efforts to develop educational activities for students with an interest in digital archeology and dissemination of cultural heritage. Concurrently, [HUMlab] was contacted by the innovative start-up company Rigsters, which is a 3D scanning and photogrammetry studio providing 3D digitisation services. This resulted in an educational partnership, which has been a great opportunity to exchange ideas, knowledge, and technical experience and is thus an excellent example of digital humanities applied in practice.

In addition to working with students via [HUMlab], the Glyptotek and Rigsters have engaged in a joint collaboration exploring the potential of merging photogrammetry and multispectral imaging (MSI). Thus, the Glyptotek and Rigsters have embarked on a joint venture producing the first 3D model including visible-induced infrared luminescence (VIL) imaging.

2 Polychromy research

Polychromy research aims at uncovering and describing ancient polychromy in order to deepen our knowledge of the ancient Mediterranean cultures and their art. ‘Polychromy’ is derived from the Greek words *poly* (many) and *chroma* (colour), i.e. multicoloured. Describing colourfully decorated sculpture and architecture, the term typically refers to painted decoration. However, ‘polychromy’ also includes e.g. glazed surfaces, inlaid materials, and details in coloured marble. Although white marble has generally been considered a typical image of antiquity, the lack of colour has no relation to ancient aesthetics. In fact, the ancient Greeks and Romans cultivated a wealth of colours and their expression in arts and crafts is thus essential to our understanding of these ancient cultures.

Assessing Greco-Roman polychromy is, however, anything but simple. Paint layers are fragile and easily decompose when exposed to the elements or when buried in the Mediterranean soil for centuries. Furthermore, many artefacts – particularly marble sculptures – have been persistently cleaned after excavation removing any visible traces of painted decoration. Thus, the remaining traces of paint are very small and few in number. Bearing the general state of Greco-Roman marble artefacts in mind, it is no wonder that the misleading notion of white marble as a Classical ideal is so widespread and tenacious.

For over a decade polychromy research has been conducted in the outstanding collection of antiquities of the Ny Carlsberg Glyptotek [1]. Targeting minute and, often, very degraded traces of paint, polychromy research is highly interdisciplinary drawing on a number of fields including archaeology, conservation science, chemistry, physics, geology, and geochemistry. Of all the techniques employed in polychromy research, the single most important tool is multispectral imaging (MSI). It offers the cheapest, least time-consuming, and least destructive way of gaining insight into the fading traces of ancient polychromy. By utilising near-ultraviolet, visible, and near-infrared wavelengths, these photographic techniques can detect and map the distribution of pigments which are no longer visible [2, 3, 4]. Therefore, MSI techniques form the basis of every investigation conducted within the field of polychromy research [2, 5].

3 VIL imaging: highlighting traces of Egyptian blue

One of the most important imaging techniques employed in polychromy research today is based on visible-induced (infrared) luminescence (VIL). Developed in the late 2000s by Dr Giovanni Verri at the British Museum, the technique has now been adopted by a vast number of researchers examining ancient sculpture and architecture in collections as well as on site [6, 7, 8]. Similar to the well-known phenomenon ultraviolet fluorescence (UVF), VIL is radiation which is absorbed and then immediately reemitted at a lower wavelength. In the case of UVF, absorbed UV radiation appears as a luminescence phenomenon in the visible part of the electromagnetic spectrum. In the case of VIL, the absorbed radiation is visible light and the luminescence phenomenon occurs in the near-infrared (NIR) part of the spectrum. Only the three ancient vitreous pigments Egyptian blue, Han blue, and Han purple and the modern pigments cadmium yellow and cadmium red exhibit very strong VIL properties [9, 10, 11]. Since Han pigments were only in use in China during the Warring-States Period (475-221 BCE) and the Han Dynasty (208 BCE-220 CE) and the cadmium pigments were first synthesized in the early 19th and early 20th centuries respectively, the only strongly NIR luminescent pigment employed in the Classical world is Egyptian blue (Fig. 1a-b) [12]. Thus, VIL identified on ancient artefacts from the Mediterranean region is a strong indicator of Egyptian blue. The IR emission exhibited by Egyptian blue is unusually intense. In fact, it is the strongest emission ($\Phi EM = 10.5\%$) known for a molecule-level chromophore emitting in the 800-1,100 nm range ($\lambda max = 910$ nm). This makes Egyptian blue ideal for VIL imaging, allowing detection of single pigment grains, even when concealed by surface coatings or patina (Fig. 2a-b) [10, 11, 13].

Fig. 1a-b. Slag with pellets of Egyptian blue pigment (left) and terracotta fragment with Egyptian blue coating (right). From Memphis, Egypt, 1st century BCE. Ny Carlsberg Glyptotek, inv. nos. ÆIN 1185 and 1262.

Besides revealing distinct traces of polychromy where none are discernible to the naked eye, VIL imaging is useful when assessing authenticity. Egyptian blue is a synthetic pigment, the manufacture of which requires very specific knowledge and skills. Hitherto, the pigment was thought to have been of little importance outside of Egypt and Mesopotamia. However, due to the employment of VIL imaging and instrumental analyses such as Raman spectroscopy and scanning electron microscopy coupled with energy dispersive spectroscopy (SEM-EDS), we now know that Egyptian blue was used extensively in the Mediterranean region throughout antiquity. In addition to blue paint layers, Egyptian blue is found in a range of pigment mixtures forming white, green, purple, brown, and black paint layers on ancient artefacts. Interestingly, Egyptian blue is only rarely found on artefacts dating from later periods, suggesting that the know-how for the manufacture was lost sometime after the Roman era [12, 14]. The first modern synthesis of the pigment was published in 1959 [15]. This did, however, not lead to a production of commercially available Egyptian blue. Considering the fact that Egyptian blue has been overshadowed by azurite and lapis lazuli in the centuries past and that it has not been commercially available until very recently, it is highly unlikely that forgers would have made use of the pigment. Thus, the presence of Egyptian blue on an artefact acquired before the widespread use of the pigment was realized, is indicative of an ancient origin [16].

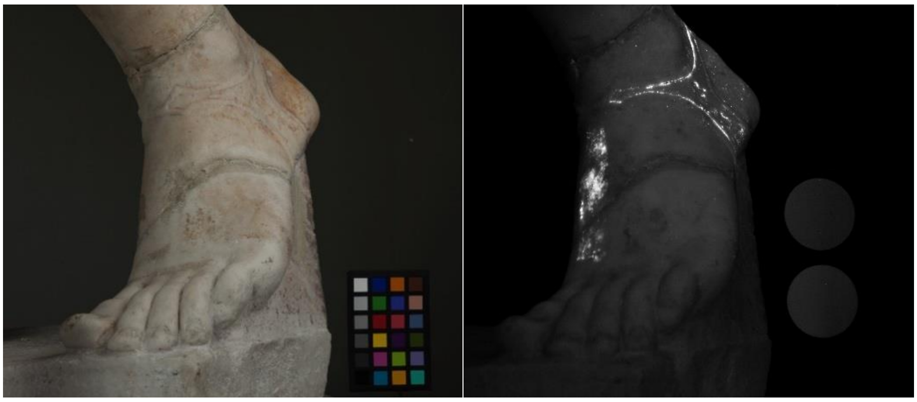

Fig. 2a-b. Photo and VIL image (right) of the left foot of the marble statue of an Amazon. Ny Carlsberg Glyptotek, inv. no. IN 1568. 2nd century CE. Photos: Maria Louise Sargent.

4 VIL in 3D for the first time

In collaboration with Rigsters entirely new avenues of multispectral imaging are being explored. By merging imaging techniques used in polychromy research with photogrammetry, we have succeeded in creating a 3D model showing the distribution of Egyptian blue. To our knowledge, the VIL 3D model presented in this paper is the first of its kind in the world.

The capture process used for creating the VIL 3D digital replica of the artefact involved two sets of capture stages. In the first stage, photographs for the geometric reconstruction of the artefact were taken with a digital camera and large ambient visible light sources. Approximately 400 overlapping images from multiple angles were taken. In the second capture stage, VIL emitted by Egyptian blue was recorded in a blackout room using an infrared-sensitive camera fitted with an external filter with an infrared

Fig. 3. Sequence illustrating the stages of the 3D digital replica including VIL imaging. From left to right: A: Original artefact. B: wireframe image. C: VIL wireframe image (grey scale). D: VIL wireframe image with luminescence coloured. The replica is based on a Greek terracotta figurine from the 3rd century BCE. Height: 40 cm. Ny Carlsberg Glyptotek, inv. no. IN 895.

sensitivity range of c. 800-1,000 nm and LED lamps exclusively emitting visible light [10, 11]. Due to long exposure times, the camera had to be mounted on a tripod for the VIL images. The process was made possible by placing the artefact on a turntable. This ensured that the distance between the object and the camera lens could be maintained fairly constant, thus reducing focus adjustments to a minimum. Considering that focusing is done manually and requires removal and remounting of the external filter, this was definitely a great timesaver. The 400 photographs were later aligned with the VIL images. The conventional 3D model and colour texture were reconstructed using the regular photographs from the first set. The aligned VIL images were then used to project the VIL patterns onto the 3D model. Colouring the patterns in blue and overlaying that texture on the final model highlights the distribution of Egyptian blue in 3D (Fig. 3-4).

Fig. 4. The finished 3D digital replica illustrating the presence of Egyptian blue.

5 The potential of MSI 3D models

Conveying results obtained in polychromy research has proved a very challenging task. Words simply do not suffice when dealing with visual expressions which are no longer visible to the naked eye. Thus, communicating ancient polychromy requires visual means [17]. In its capacity as an image-based methodology, MSI is a phenomenal tool for answering research questions as well as conveying research results to lay and academic peers alike. In mapping the distribution of pigments such as Egyptian blue, MSI techniques are essential whether highlighting the actual traces of polychromy or embarking upon reconstructive initiatives. The 3D VIL model presented in this paper takes MSI to a whole new level by greatly improving the overview and impression of the distribution of Egyptian blue. Surely, implementing 3D models such as this would be beneficial for the purpose of education and other communication. In the exhibition, the use of 3D models would make the visual comparison between the actual sculpture and the MSI findings easier than with the 2D images used hitherto. Furthermore, when accessed online, 3D models lead to a much better understanding of the artefact and the current pigment distribution than is afforded by 2D images [18]. Thus, there is much to gain from continuing the development of MSI 3D models.

6 [HUMlab]

There exists a definite curiosity about using new digital methods at the Faculty of Humanities at the University of Copenhagen, but there are virtually no curricular programmes that focus on digital methods. Thus, digital humanities still constitutes a niche at the edge of the research and teaching environment. [HUMlab], part of the Copenhagen University Library, was therefore established to support the establishment of digital humanities at the University. It functions as a meeting place for students and employees, giving them an actual platform where they can learn, teach, and use data, digital methods, and various programmes and software. Indeed, the aim of [HUMlab] is to be a place where like-minded digital humanists can meet across various subjects and interests, thus generating inspiration and new knowledge. The activities of [HUMlab] are developed through a dynamic, informal dialogue with people interested in the digital humanities. The activities help students and staff gain a better understanding of the concepts related to digital humanities, making it possible to advise on how to work with data and to apply digital methods to research – as well as offering a space for sharing knowledge by giving staff and students an opportunity to experiment with digital projects.

7 Conclusion

This collaboration illustrates how the combination of methods developed in the fields of humanities, natural sciences, and digital industries can contribute to knowledge exchange as well as the development of new ways of disseminating scholarly research. An excellent example of digital humanities applied in practice and the potential of joint ventures, this fruitful collaboration is hoped to spark interest inspiring students to make use of the facilities offered by [HUMlab]. We are looking forward to continuing our collaboration exploring the existing possibilities lying ahead. Next step is to develop a version showing the artefact as it appears when exposed to ultraviolet radiation (UVF).

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References

1. Homepage of the polychromy research team, http://trackingcolour.com/, last accessed 2018/1/16.
2. Dyer, J., Verri, G. Cupitt, J.: Multispectral Imaging in Reflectance and Photo-induced Luminescence modes: A User Manual. British Museum. London (2013). www.britishmuseum.org/pdf/charisma-multispectral-imaging-manual-2013.pdf
3. Dyer, J., Sotiropoulou. S.: A technical step forward in the integration of visible-induced luminescence imaging methods for the study of ancient polychromy. In: Heritage Science 5(24). DOI: 10.1186/s40494-017-0137-2 (2017).
4. Kakoulli, I., Radpour, R., Lin, Y., Svoboda, M., Fischer, C.: Application of forensic photography for the detection and mapping of Egyptian blue and madder lake in Hellenistic polychrome terracottas based on their photophysical properties. In: Dyes and Pigments 136, pp. 104-155 (2017).
5. Sargent, M.L., Therkildsen, R.H.: The Technical Investigation of Sculptural Polychromy at the Ny Carlsberg Glyptotek 2009-2010 – An Outline. In: Østergaard, J.S. (ed.) Tracking Colour: The polychromy of Greek and Roman sculpture in the Ny Carlsberg Glyptotek. Preliminary Report 2, pp. 11-26. Ny Carlsberg Glyptotek. Copenhagen (2010). www.trackingcolour.com/assets/d/0/1207/Tracking_Colour_2_final.pdf.
6. Winkels, A.: Konservierung und Präsentation von Stuck und Wandmalerei. In: Schmidt-Colinet, A., al-As'ad W. (eds.) Palmyras Reichtum durch weltweiten Handel: Arkäologische Untersuchungen im Bereich der hellenistischen Stadt 1, pp. 252-259. Holzhausen, Vienna (2013).
7. Ganio, M., Salvant, J., Williams, J., Lee, L., Cossairt, O., Walton, M.: Investigating the use of Egyptian blue in Roman Egyptian portraits and panels from Tebtunis, Egypt. In: Applied Physics A 121(3), pp. 813–821. DOI: 10.1007/s00339-015-9424-5 (2015).
8. Thavapalan, S., Stenger, J., Snow, C.: Color and Meaning in Ancient Mesopotamia: The Case of Egyptian Blue. In: Zeitschrift fürAssyriologie und Vorderasiatische Archäologie 6(2). DOI: 10.1515/za-2016-0014 (2016).

9. Bridgeman, C.F., Gibson, H.L.: Infrared luminescence in the photographic examination of paintings and other art objects. In: Studies in Conservation 7(3), pp. 77-83 (1963).
10. Verri, G.: The application of visible-induced luminescence imaging to the examination of museum objects. In: Pezzati, L., Salimbent, R. (eds.) Optics for Art, Architecture, and Archaeology II, Proceedings of SPIE 7391. SPIE, Bellingham. DOI: 10.1117/12.827331 (2009).
11. Verri, G.: The spatially resolved characterisation of Egyptian blue, Han blue and Han purple by photo-induced luminescence imaging. In: Analytical and Bioanalytical Chemistry, 394(4), pp. 1011-1021 (2009).
12. Eastaugh, N., Walsh, V., Chaplin, T., Siddall, R.: Pigment Compendium – A Dictionary of Historical Pigments. Elsevier Butterworth-Heinemann, Oxford (2004).
13. Verri, G., Saunders, D., Ambers, J., Sweek, T.: Digital mapping of Egyptian blue: conservation implications. In: Conservation and the Eastern Mediterranean: Contributions to the Istanbul Congress. The International Institute for Conservation of Historic and Artistic Works, London, pp. 220-224 (2010).
14. Skovmøller, A., Brøns, C., Sargent, M.L.: Egyptian blue: modern myths, ancient realities. In. Journal of Roman Archaeology 29, 371-387 (2016).
15. A. Pabst: Structures of some tetragonal sheet silicates. In: Acta Crystallographica 12, 733-739 (1959).
16. Brøns, C., Hedegaard, S.B., Rasmussen, K.L.: The Real Thing? Polychromy research employed in authenticity studies. In: Studi Etruschi 79, 195-223, ill. LX-XLIV (2018).
17. Hedegaard, S.B., Brøns, C.: Lost in Translation: the challenging task of communicating long-lost polychromy on Graeco-Roman marble sculptures. In: Analecta Romana Instituti Danici (forthcoming).
18. Galeazzi, F., Di Giuseppantonio, F., Matthews, J.L.: Comparing 2D pictures and 3D replicas for the digital preservation and analysis of tangible heritage. In: Museum management and curatorship 30 (5), pp. 462-483 (2015).