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DIGITAL IMAGE COLORIMETRY OF ARCHAEOLOGICAL EARTHENWARE UNDER DIFFERENT LIGHTING SOURCES

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Abstract

*This study investigated the effect of lighting sources on the smartphone colorimetry of 23 archaeological earthenware samples. Comparable RGB and L*a*b* colors were obtained using both fluorescent room lighting and smartphone flashlight in a closed box for most samples, although some showed substantial differences likely due to variations in measurement points. Averaging readings from different areas of each sample could reduce this uncertainty. Using the color values to classify the earthenware, five coarse-paste wares averagely exhibited higher R, G, and L* values than 18 fine-paste wares made of fine-grained clay regardless of the lighting used. The L* is recommended as the parameter of choice, as RGB values substantially varied from one sample to another. In addition to the color parameters, the effect of lighting depends on the samples measured as the variations in average L*a*b* values were smaller for the fine-paste ware.*

***Keywords**: Digital image colorimetry; Smartphone; Lighting; Archaeological earthenware*

Introduction

Ceramics are often discovered through archaeological excavation and are essential to cultural heritage collections. These archaeological ceramics are of cultural significance to a particular group or region because human cultures and societies in the past could be studied from ceramics production, utilization, and trade. Petrography with visual inspection or optical microscopy is traditionally used to examine mineralogical and textural characteristics, like studies of rocks and minerals. For earthenware objects, petrography is useful for identifying the type of clay used and the firing conditions [1, 2]. Glazes or pigments can also be probed. To increase accuracy and efficiency, the composition and structure of clay, impurities, and decorative materials are determined by X-ray fluorescence (XRF) [2, 3], Energy-dispersive spectroscopy (EDS) [3-5], Fourier Transform Infrared (FTIR) spectroscopy [3, 4], X-ray diffractometry (XRD) [4, 5], and Raman spectroscopy [6].

Color is a distinguished attribute related to raw materials and their processing [7, 8]. In addition to spectrophotometry, digital image colorimetry has been increasingly implemented in cultural heritage studies [9]. For archaeological ceramics, photographs taken by a digital camera

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are analyzed for their colors using computer software. In addition to Red-Green-Blue (RGB) color components, the CIELAB color space characterized by darkness to lightness (L^* from 0 to 100), greenness to redness ($-a^*$ to $+a^*$) and blueness to yellowness ($-b^*$ to $+b^*$) is often used. Comparative colorimetry can effectively classify stained glasses [10], glazed tiled [11], and potsherds [12]. Moreover, color measurements can be useful for heritage restoration as demonstrated with Iberian Peninsula's roofing tiles [13]. The advantage of digital image colorimetry was highlighted by transforming a digital camera into a colorimeter for fieldwork settings [14].

In recent years, smartphones have been increasingly implemented in studies of cultural heritage. For example, a smartphone augmented reality application (*Smart Eye*) was developed for cultural heritage applications [15]. Smartphone colorimetry is one of the emerging applications of smartphone sensors [16,17]. The combination of smartphone camera and mobile application provides a more accessible and cost-effective alternative to traditional colorimetry methods, which often require expensive equipment and extensive expertise. The smartphone colorimetry was demonstrated on earthenware artifacts that historically been used in Southeast Asia [18], to complement petrography and characterizations by X-ray in understanding of their provenance and production [2, 19]. The smartphone image analysis and non-destructive standardized approaches were compared to the color characteristics analysis of prehistoric siliceous artifacts from Camaleño in Spain. This study demonstrated that the smartphone image analysis method is a valid and appropriate one [20]. However, the color measurements have limitations because of their dependence on lighting condition, camera setting, and many other parameters [21]. Some influential factors in digital image colorimetry have been addressed and controlled specifically for archaeology and cultural heritage [22, 23].

In this study, the effect of lighting in smartphone colorimetry is investigated. The RGB and $L^*a^*b^*$ color values of earthenware using fluorescent room lighting and smartphone flashlight in a closed box as a light source are compared. The results reveal the uncertainty and limitation of the method and could also be useful for color measurements of other types of specimens.

Experimental

Twenty-three earthenware samples used in this study were sourced from Phra Mahathat Monastery (Fig. 1a) located in Nakhon Si Thammarat Province of Thailand (8°24′41″N; 99°58′00″E). In the first archaeological excavation ever at the monastery in 2009, bricks and a number of earthenware and porcelain sherds in several test pits dated to around the middle to late thirteenth century were discovered [24]. All earthenware samples, belonging to Basket 7 of Pit PT.09.04 from this excavation, were mounted with epoxy for analyses, as shown in Figure 1b. Based on their clay texture, the samples were classified into fine-paste ware and coarse-paste ware. The coarse-paste ware, which have rougher clay texture, are samples 005, 006, 009, 027 and 031. The fine-paste ware samples, made of fine-grained clay without observable temper, include 001, 002, 003, 004, 007, 008, 011, 012, 015, 021, 022, 023, 024, 025, 026, 028, 029 and 030. Notably, some of these samples, namely 001, 002, 003, 004, 005, 006 and 008, also have traces of clay slips.

An android smartphone (Realme 3™), which has a 13 MP camera (f/1.8) and a colorimetric application (*Color Grab*), was used for colorimetry. The smartphone was placed on a stand 13cm above each sample, and a photograph of each sample's cross-section was taken with the crosshairs focused on the center of earthenware. The *Color Grab* application provides both RGB and $L^*a^*b^*$ color values simultaneously. To investigate the effect of lighting, measurements taken using a smartphone flashlight as the light source in a closed box were compared with colorimetry under a fluorescent lamp in ambient lighting.

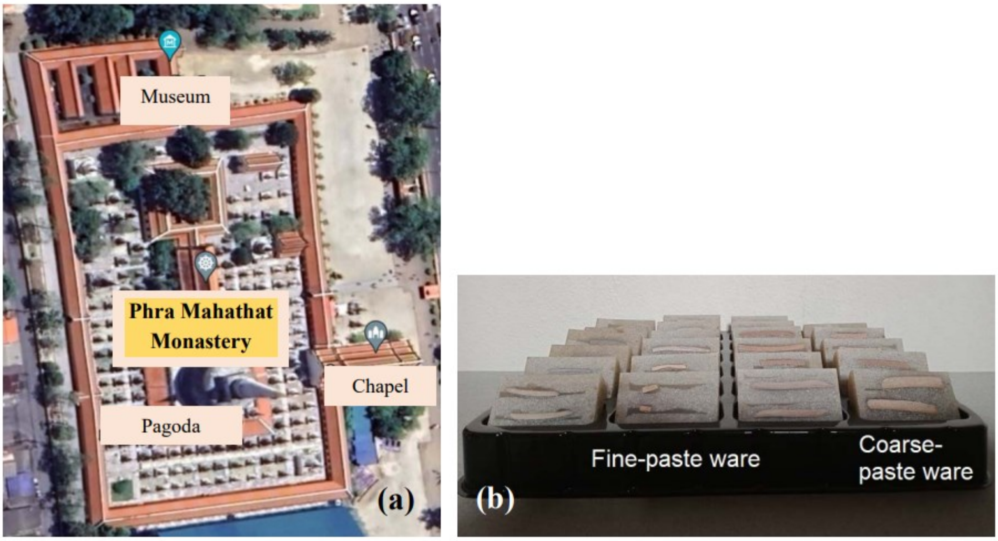

Fig. 1. Images of: (a) Phra Mahathat Monastery from Google Earth and (b) earthenware classified as 18 fine-paste ware samples and five coarse-paste ware samples

Results and discussion

In Figure 2, the difference in measuring RGB colors under ambient light and smartphone flashlight is shown by the data distribution corresponding to 23 samples. Most data points are slightly above the y = x lines, indicating higher color values in the case of smartphone flashlight as a light source. The finding corresponds to a slightly higher light intensity of smartphone flashlight. In each color, there are also a few data points with a large deviation above the y = x line. By contrast, there are four data points exhibit an opposite trend with higher color values under the ambient light. These outlines are likely to be due to the variation in points of measurement. While the smartphone and samples are aligned capture the image at the center retaining the same measurement area, the change in measurement points from one set-up to another is inevitable. Overall, the RGB reading under two different lightings are still comparable and measuring several areas on each sample to obtain the average value is recommended to reduce the outliners.

The difference in colors may be used to support the classification of earthenware. Figure 3 compares fine- and coarse-paste wares' RGB colors measured under smartphone flashlight and ambient fluorescent room lighting. The coarse-paste ware exhibits significantly higher R, G, and B values when the smartphone flashlight is used as a light source. By contrast, such differences between two groups are less marked under the ambient light. However, the standard deviations from the measurements of 18 fine-paste ware samples are remarkably high. Nevertheless, all average color values form the fine-paste ware are not sensitive to the light source used. By contrast, the B value averaged from the coarse-paste ware samples is substantially reduced in the case of ambient fluorescent light. The discrepancy can be related to different light spectra of the fluorescent lamp and the smartphone flashlight. Both light sources are designed to provide a full spectrum of visible light with that closely approximates natural daylight. Unlike the excitation of phosphor in fluorescent lamps, the smartphone flashlight utilizes white light-emitting diodes (LEDs) which provide relatively continuous and have a more even distribution of wavelength across the visible spectrum.

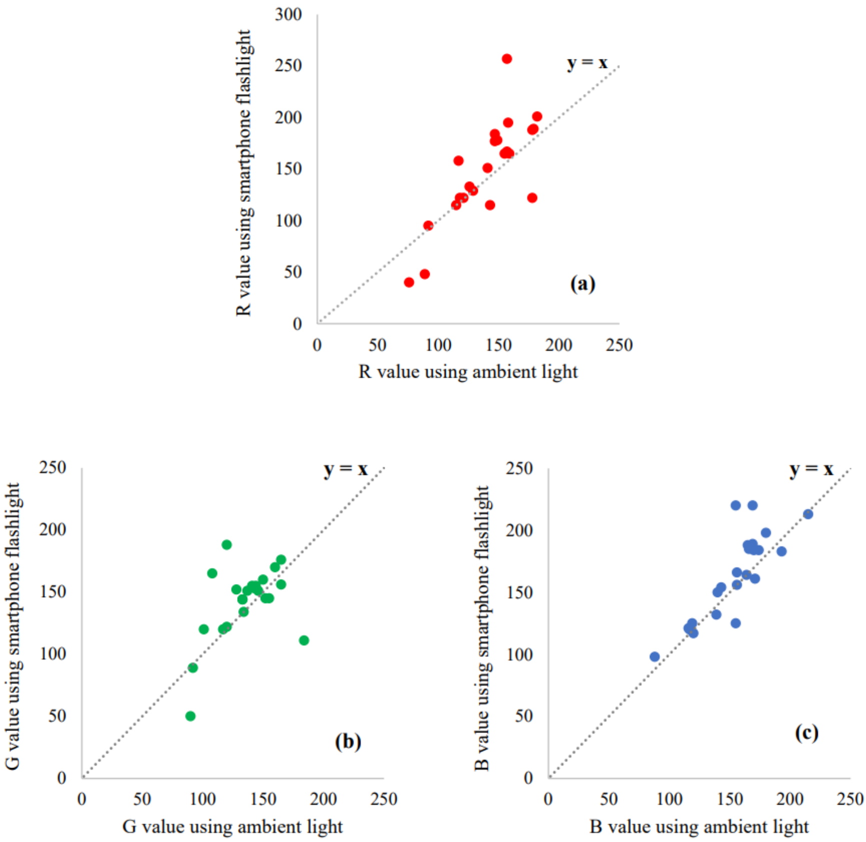

Fig. 2. Plots of: (a) R values, (b) G values, and (c) B values measured under smartphone flashlight in a box against those using ambient fluorescent room lighting

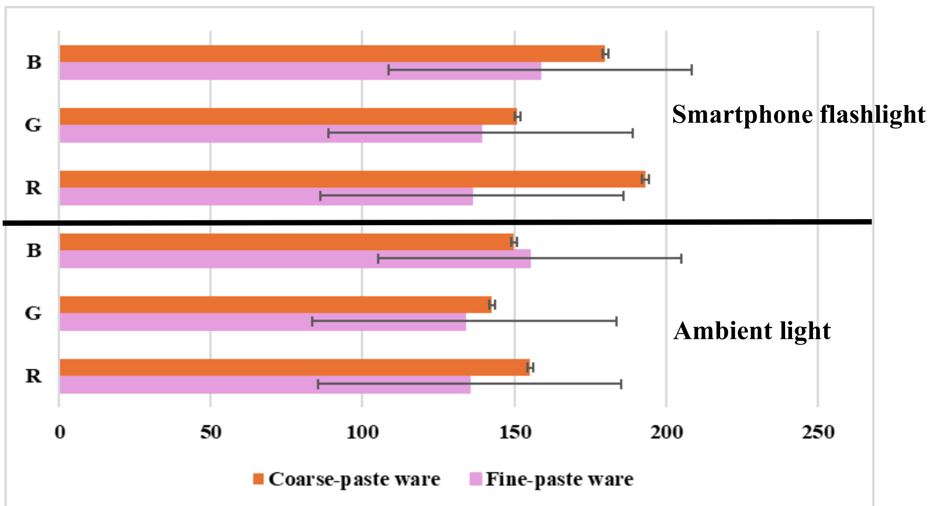

Fig. 3. Comparison of fine- and coarse-paste wares' RGB colors measured under smartphone flashlight and ambient fluorescent room lighting.

For the CIELAB color space, the distribution of L^* data points mostly above the y = x line in Figure 4a. This trend is consistent with the overall higher RGB values in Figure 2, reflecting a higher intensity of smartphone flashlight. Figure 4b reveals small positive a^* value, corresponding to the redness of the earthenware. The measurements under smartphone flashlight also tend to yield higher values. By contrast, the majority of b^* values are negative and scatter below the y = x line indicating the decrease under smartphone flashlight.

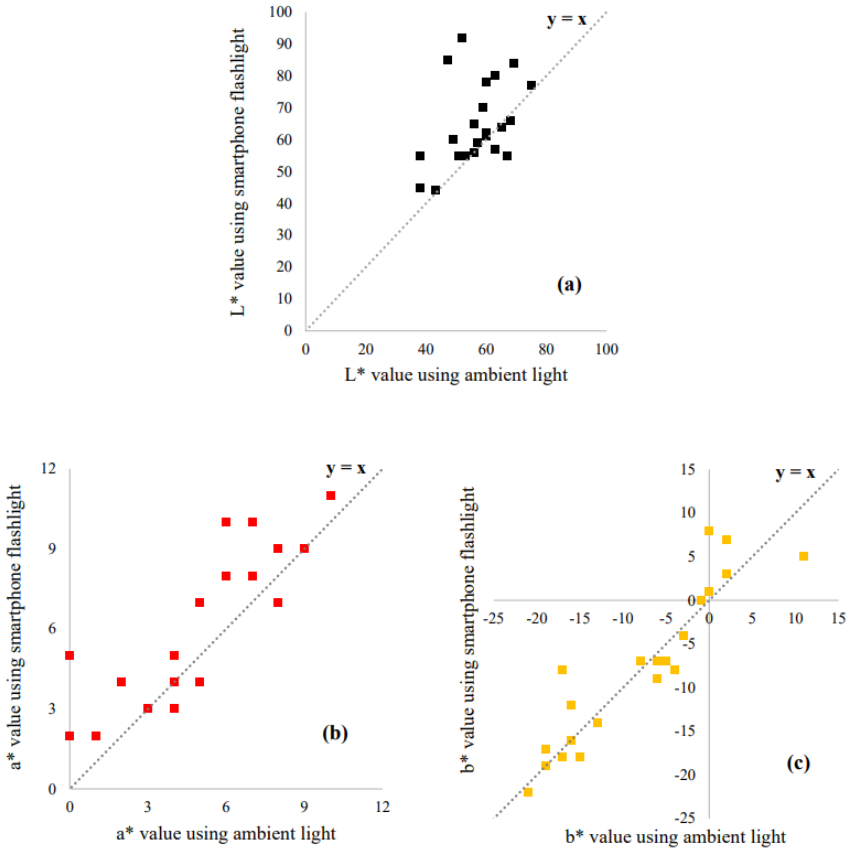

Fig. 4. Plots of (a) L^*, (b) a^*, and (c) b^* values measured under smartphone flashlight in a box against those using ambient fluorescent room lighting

Figure 5 compares fine- and coarse-paste wares' $L^*a^*b^*$ colors measured under smartphone flashlight and ambient fluorescent room lighting. The coarse-paste ware samples have a higher average L^* value corresponding to their brighter appearances. The results are influenced by the measurement lighting. Although the smartphone flashlight gives rise to higher L^* values, the difference between fine- and coarse-paste ware samples remains rather constant. Interestingly, the standard deviations from the measurements of 18 fine-paste ware samples and five coarse-paste ware samples are modest regardless of the light source. Because of the slight difference in the a^* value, it is not an effective parameter for the earthenware classification by smartphone colorimetry. Like RGB values, the average b^* value from fine-paste ware is not sensitive to the light source used but greatly varies in the case of coarse-paste ware. It follows that the b^* is not as reliable as the L^* parameter to classify the fine- and coarse-paste ware samples.

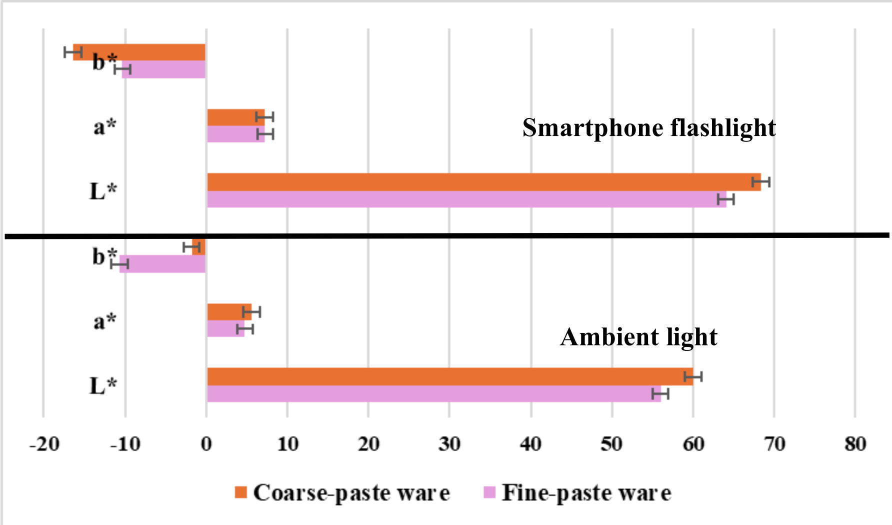

Fig. 5. Comparison of fine- and coarse-paste wares' *L*a*b** colors measured under smartphone flashlight and ambient fluorescent room lighting.

Conclusions

The color measurements using smartphones were compared to fluorescent light in the room and smartphone flashlight in a closed box. While the RGB values substantially varied among 23 earthenware samples, the measurements under different lighting were comparable for most samples. The difference could be reduced by averaging the reading from different areas of each sample. Interestingly, the *L*a*b** values exhibited much smaller variations from one sample to another. The smartphone colorimetry was also used to support the classification of fine- and coarsepaste ware samples. The high R, G, and *L** values distinguished the coursepaste ware from the fine-paste ware. It follows that, the *L** with a much smaller standard deviation in the measurements emerges as an essential parameter for earthenware classification. The variation in the average values of *L*a*b** of fine-paste ware with the light source was much smaller than that in coarse-paste ware. Based on this finding, the effect of lighting on the smartphone colorimetry also depends on the objects measured. Beyond the academic community, the use of smartphones in the classification of archaeological ceramics could draw attention of younger generation and becomes the intersection of technology and cultural heritage for education.

Acknowledgments

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References

[1] D. Sharmin, *Technological interpretation of traditional ceramic materials on thin-section petrography*, **International Journal of Conservation Science**, **11**(2), 2020, pp. 539-556.

[2] K. Ueda, J.N. Miksic, S.C. Wibisono, N. Harkantiningsih, G.Y. Goh, E.E. McKinnon, A.M.Z. Shah, *Trade and consumption of fine paste ware in Southeast Asia: Petrographic and portable X-ray fluorescence analyses of ninth to fourteenth-century earthenware*, **Archaeological Research in Asia**, **11**, 2017, pp. 58-68, DOI:10.1016/j.ara.2017.05.004

[3] S.S. Panda, G.N. Jena, D.B. Garnayak, *Characterization of representative ancient potteries: Chemical, mineralogical and morphological studies*, **International Journal of Conservation Science**, **10**(2), 2019, pp. 317-326.

[4] A.P. Kanth, M.R. Singh, K. Ganaraj, *Spectroscopic and X-ray based microstructural investigation of the early-Harappan potsherds and estimation of firing temperature from Kunal archaeological site, India*, **International Journal of Conservation Science**, **13**(1), 2022, pp. 131-146.

[5] W.K. Elghareb, *Analysis and restoration of pottery artefacts from Tell El-Hir, North Sinai, Egypt: A case study*, **International Journal of Conservation Science**, **12**(4), 2021, pp. 1327-1342.

[6] I.E. Grammatikakis, E. Kyriakidis, K.D. Demadis, A. C. Diaz, L. Leon-Reina, *Mineralogical characterization and firing temperature delineation on Minoan pottery: Focusing on the application of micro-Raman spectroscopy*, **Heritage**, **2**(3), 2019, pp. 2652-2664, DOI: 10.3390/heritage2030163

[7] M. Gaiani, F.I. Apollonio, A. Ballabeni, *Cultural and architectural heritage conservation and restoration: Which colour?*, **Coloration Technology**, **137**(1), 2021, pp. 44-55, DOI: 10.1111/cote.12499

[8] D. Tamburini, *Colour Analysis: An introduction to the power of studying pigments and dyes in archaeological and historical objects*, **Heritage**, **4**(4), 2021, pp. 4366-4371, DOI:10.3390/heritage4040241

[9] W.S. Yoo, J.G. Kim, K. Kang, Y. Yoo, *Extraction of colour information from digital images towards cultural heritage characterisation applications*, **SPAFA Journal**, **5**, 2021, DOI: 10.26721/spafajournal.2021.v5.690

[10] N. Capobianco, M.O.J.Y. Hunault, C. Loisel, B. Trichereau, F. Bauchau, N. Trcera, L. Galoisy, G. Calas, *The representation of skin colour in medieval stained glasses: The role of manganese*, **Journal of Archaeological Science-Reports**, **38**, 2021, article number: 103082, DOI: 10.1016/j.jasrep.2021.103082.

[11] J. Fahim, E. Ghasemi, M. Hosseini-Zori, *A study on the colored glazed tiles of Soltaniyeh Dome: An analytical approach*, **Progress in Color Colorants Coating**, **16**, 2023, pp. 113-124, DOI: 10.30509/PCCC.2022.167010.1182

[12] A.Z. Gebremariam, P. Davit, M. Gulmini, L. Maritan, A. Re, R. Giustetto, S. Massa, C. Mandelli, Y. Gebreyesus, A. Lo Giudice, *The contribution of colour measurements to the archaeometric study of pottery assemblages from the archaeological site of Adulis, Eritrea*, **Acta IMEKO**, **11**(1), 2022, article number: 17.

[13] B. Prieto, P. Ferrer, P. Sanmartín, V. Cárdenes, B. Silva, *Color characterization of roofing slates from the Iberian Peninsula for restoration purposes*, **Journal of Cultural Heritage, 12**(4), 2011, pp. 420-430, DOI:10.1016/j.culher.2011.02.001

[14] P. Sanmartín, E. Chorro, D. Vázquez-Nion, F.M. Martínez-Verdú, B. Prieto, *Conversion of a digital camera into a non-contact colorimeter for use in stone cultural heritage: The application case to Spanish granites*, **Measurement**, **56**, 2014, pp. 194-202, DOI: 10.1016/j.measurement.2014.06.023.

[15] K. Efkleidou, D. Kaimaris, T. Roustanis, P. Patias, S. Andreou, K. Klimantakis, I.A. Karolos, M. Pappa, N. Kouidis, *Smart Eye: An application for in situ accessibility to "Invisible" heritage sites*, **Journal of Computer Applications in Archaeology**, **5**, 2022, pp. 286-298, DOI: 10.5334/jcaa.100

[16] M. Grossi, *A sensor-centric survey on the development of smartphone measurement and sensing systems*, **Measurement**, **135**, 2019, pp. 572-592, DOI: 10.1016/j.measurement.2018.12.014

[17] Y.J. Fan, J.W. Li, Y.P. Guo, L.W. Xie, G. Zhang, *Digital image colorimetry on smartphone for chemical analysis: A review*, **Measurement**, **171**, 2021, article number: 108829, DOI: 10.1016/j.measurement.2020.108829

[18] C. Sirisathitkul, K. Ekmataruekul, Y. Sirisathitkul, W. Noonsuk, *Smartphone colorimetry of fine-paste ware in Hindu-Buddhist rituals*, **European Journal of Science and Technology**, **16**(3), 2020, pp. 179-186.

[19] J. Jutimoosik, C. Sirisathitkul, W. Limmun, R. Yimnirun, W. Noonsuk, *Synchrotron XANES and ED-XRF analyses of fine-paste ware from 13th to 14th century maritime Southeast Asia*, **X-ray Spectrometry**, **46**(6), 2017, pp. 492-496, DOI: 10.1002/xrs.2780

[20] M. Ramacciotti, G. Gallello, S. Columbu, D. Fancello, A. Diez-Castillo, O. García-Puchol, A. Pastor, M.L. Cervera, *Smartphone photos as a non-destructive approach to characterise siliceous artefacts*, **Science and Technology Archaeologial Research**, **9**(1), 2023, article number: e2240175, DOI:10.1080/20548923.2023.2240175

[21] A. Plutino, G. Simone, *The limits of colorimetry in cultural heritage applications*, **Coloration Technology**, **137**(1), 2021, pp. 56-63, DOI: 10.1111/cote.12500

[22] F.L.M. Milotta, F. Stanco, D. Tanasi, A.M. Gueli, *Munsell color specification using ARCA (Automatic Recognition of Color for Archaeology)*, **ACM Journal on Computing and Cultural Heritage**, **11**(4), 2018, article number: 17, DOI: 10.1145/3216463.

[23] M. Trombini, F. Ferraro, E. Manfredi, G. Petrillo, S. Dellepiane, *Camera color correction for cultural heritage preservation based on clustered data*, **Journal of Imaging**, **7**(7), 2021, article number: 115, DOI: 10.3390/jimaging7070115

[24] W. Noonsuk, *The urban development in Nakhon Si Thammarat (Peninsular Thailand) based on preliminary results of excavations*, **Bulletin de l'Ecole Francaise d'Extrême-Orient**, **99**, 2012-2013, pp. 331-349, https://www.jstor.org/stable/43733941

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