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SMARTPHONE COLORIMETRY OF FINE-PASTE WARE IN HINDU-BUDDHIST RITUALS

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Abstract

A smartphone and a commercial mobile application named ‘Colorimeter’ are combined for the colour classification of fine-paste ware used in Hindu-Buddhist rituals. With high L* values in the CIE colour space, the potsherds from 3 Buddhist temples as well as an ancient production site in southern Thailand are consistent with the white fine-paste ware. By contrast, the artefacts from an archaeological in north Sumatra of Indonesia are characterized by much lower L* and b*. Classified as the red fine-paste ware, the artefacts from Myanmar and India exhibit uniquely high a* values at their outer layer. The RGB space as well as chroma and hue angle can complement the CIE space in describing colours of religious artefacts but they are only effective in the case of distinct colours.

Keywords: Southeast Asia, fine-paste ware, smartphone, colorimetry, CIE colour space

1. Introduction

Fine-paste ware, dated back to 13th-14th centuries of maritime Southeast Asia, is an important type of earthenware in cultural history. Based on similar artefacts from different archaeological sites, the trade route during that period between modern-day Thailand and Indonesia is established [1, 2]. Moreover, these pottery artefacts have religious significance since they were parts Hindu-Buddhist rituals in Asia [1]. Whereas Hinduism is a theistic religion, Buddhism is nontheistic. However, both religions were originated in India and share some beliefs and values. Owing to their long-standing influences, the culture shaped-up by Hinduism and Buddhism has been evident in Southeast Asia. Since the 9th century, the fine-paste ware locally made in this region was mostly replaced by the celebrated Chinese glazed ceramics. The use of unglazed fine-paste ware in Southeast Asia remained only in the case of *kendi* [1]. The *kendi*, Indian ritual

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water-pouring vessel, had been used in Hindu-Buddhist worship ceremony for approximately one thousand year and became religious artefacts in Southeast Asia.

Religious and cultural ceramic artefacts have increasingly been analysed by modern scientific techniques. In addition to traditional petrography [2, 3], images of ceramic texture and pores are visualized by Scanning Electron Microscopy (SEM) [4, 5] and elemental compositions of clay are probed by (EDS) and X-ray Fluorescence (XRF) [1, 2, 6]. Phases are precisely characterized by Fast Fourier Transform Infrared (FTIR) spectroscopy [7] and synchrotron X-ray Absorption Spectroscopy (XAS) [5, 6]. By contrast, colour classifications of the earthenware still rely on the eye inspection and are referenced to the Munsell colour chart [8-15]. The enhanced colorimetry will be advantageous in identifying clay sources and firing temperatures.

Apart from their conventional uses in communication and multimedia access, smartphones have increasingly been developed into measurement tools for education and professional purposes. Oprea and Miron comprehensively explored and explained a variety of cases and lessons based on physical measurements made by smartphones [16]. Beyond the science education purpose, it becomes challenges to fully utilize high-accuracy sensors equipped in smartphones. There are several reports on facile measurements in smart farming, healthcare, engineering and geology using smartphones. For colorimetry, smartphones were used in the determination of fruit ripeness [17, 18] and chlorophyll contents [19]. However, there is no published article on pottery colours classified by smartphone.

In this work, the potential use of any smartphone in a classification of pottery artefacts is explored. Besides the archaeological investigation, this experiment is also aimed to engage the young generation in religious heritage.

2. Experimental

An Android smartphone (OPPO F9) and a commercial mobile application named ‘Colorimeter’ were combined for colorimetry in this study. To standardize this classification in CIE L*a*b* colour space, the measurements on purple and red papers by the smartphone were compared with the readings from the Hunter Lab spectrophotometer (MiniScan EZ). Darkness to lightness (L: 0-100), greenness to redness (-a* to +a*) and blueness to yellowness (-b* to +b*) according to the CIE L*a*b* colour space were obtained on the mobile application. The papers (and thereafter potsherds) were illuminated by white light from fluorescence bulbs.

The potsherds are from seven different sites in four countries. Four sites are in the south of modern-day Thailand. Firstly, Kok Moh (KOM) in Sa Thing Phra has been renowned for the pottery production since the ancient kiln was discovered. Three other sites in southern Thailand are Buddhist temples in Nakhon Si Thammarat, namely Thao Khot (TK3), Phra Mahathat (PT7) and Suan Luang (SL5). The age of artefacts is dated to approximately 13^{th}-14^{th} centuries comparable to Chinese glazed ceramics from Southern Song to Early Yuan Dynasties.

The region in north Sumatra of modern-day Indonesia included in this study is Kota Cina (KTC). From the late 11th to the late 13th century, this site was a prominent trading port in maritime Southeast Asia linking Indonesia to southern Thailand as shown in Figure 1. The site in modern-day Myanmar is 'Pottery Hills' Otein Taung (OTT), a part of ancient Bagan city where specimen OTT-011 was collected. In addition to Southeast Asia artefacts, specimen TND-010 was obtained from Periyapattinam of Tamil Nadu, a major port on the eastern coast of the Gulf of Mannar in southern India. All artefacts, once parts of *kendis* like that in Figure 1 inset, have been mounted in blocks of resin, revealing their cross-sections.

Cross-sectional potsherds were photographed by the smartphone with a crosshair focus on the point of interest. The 'Colorimeter' application simultaneously distinguished colours of artefacts based on both RGB and CIE L*a*b* colour space. The chroma and hue angle were also recorded. The values were averaged from 2 points around the centre of each artefact. In the case of inhomogeneity, the colours were additionally measured on the edge of potsherds and separately listed.

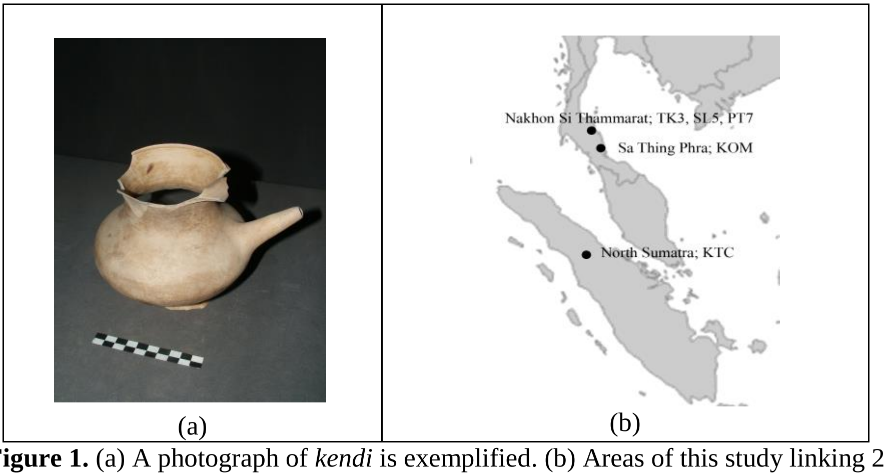


Figure 1. (a) A photograph of *kendi* is exemplified. (b) Areas of this study linking 2 countries. Kota China (KTC) is in north Sumatra in present-day Indonesia. Three Buddhist temples (TK3, SL5, PT7) in Nakhon Si Thammarat province as well as Kok Moh (KOM) in Sa Thing Phra are on the east coast of peninsular Thailand.

3. Results and discussion

3.1. Comparison between smartphone colorimetry and CIE spectrophotometer

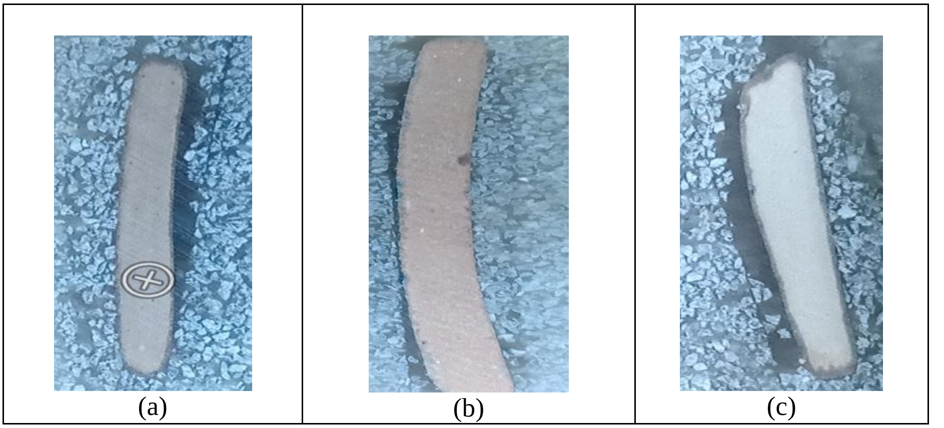
The purple and red papers were used as references in comparing CIE L*a*b* colours measured by the smartphone to the values from the Hunter Lab spectrophotometer. According to Table 1, the L* values are very much in good agreement. Whereas b* exhibits the largest variation between 2 methods, the difference in a* is minimal in the case of red colour measurement. Overall, the comparable readings suggest the versatility of smartphone as colorimeter which can also be focused on a small area of less than 1 cm^2. It was previously pointed out that the smartphone colorimetry is highly susceptible to the lighting condition. Nevertheless, such colour classifications without the precise control of light sources offer the qualitative refinement over the eye inspection and are applicable for both indoor and outdoor inspections.

Table 1. CIE L*a*b* colours of the purple and red papers measured by the smartphone compared to the values from the Hunter Lab spectrophotometer.

Measurement	**'Purple' reference**			**'Red' reference**		
	L*	**a***	**b***	**L***	**a***	**b***
Hunter Lab spectrophotometer	47.84	17.90	-28.33	48.87	34.50	12.34
Smartphone colorimetry	46.00	23.20	-35.80	48.90	33.90	9.80

3.2. Colour classification of artefacts from Buddhist temples

From Table 2, the RGB colour space can distinguish only a few cases of artefacts. It is inferred that the CIE colour space is prominent in classifying fine-paste ware colour. The L* values of all artefacts from 3 temples exemplified in Figure 2 are over 50 corresponding to their lighter colours, hence the name white fine-paste ware.



(a) (b) (c)

Figure 2. Photographs of cross section of white fine-paste ware from 3 Buddhist temples: (a) Thao Khot (TK3), (b) Phra Mahathat (PT7) and (c) Suan Luang (SL5).

The L* value as high as 87.15 is obtained in SL5 artefacts. The different clay sources are primarily characterized by the variation in -b* to +b* values (blueness to yellowness) listed in Table 2. The hue angles around 200 are mostly consistent with b* down to -12 but tend to fluctuate in some cases. Interestingly, the b* values of the PT7 artefacts exhibit large variations and 6 specimens can be divided into 2 groups. Whereas other specimens have negative b* similar to artefacts from 2 other temples, specimens PT7-014 and PT7-016 have positive value. Both artefacts are reddish brown, signified by the high a* value. It is consistent with the hue angles of 1.1 and 12.1. This reddish brown stems from iron oxide in the clay [5]. Colours of artefacts excavated from each site may differ by variations in clays and firing temperatures. Also, it is possible that the fine-paste ware from different places of production may end up at the same site as a result of regional trading.

Table 2. Colours of white fine-paste ware classified by the combination of an Android smartphone (OPPO F9) and a mobile application 'Colorimeter'.

Site	Artefact	RGB			CIE			Hue angle	Chroma
		R	G	B	L*	a*	b*		
TK3	002	170.5	182.0	192.5	73.5	-1.9	-6.7	208.6	7.01
	004	185.5	212.5	230.5	83.7	-5.2	-11.9	204.0	12.95
	005	156.5	156.5	168.5	64.9	2.4	-6.3	240.0	6.68
PT7	014	153.0	133.0	132.5	57.3	7.6	3.1	1.1	8.17
	016	153.0	140.0	136.5	59.3	4.3	3.6	12.1	5.60
	017	154.0	159.0	166.5	65.3	-0.3	-4.5	217.0	4.56
	018	182.5	196.5	206.5	78.6	-2.8	-6.7	205.0	7.21
	019	199.0	204.5	203.5	81.7	-2.0	-0.2	110.0	2.68
	020	145.0	148.5	144.0	61.1	-2.1	1.9	108.0	2.95
SL5	003	177.5	191.5	196.5	76.7	-3.8	-4.2	196.0	5.61
	004	214.0	220.0	221.0	87.2	-1.9	-1.3	186.0	2.25
	005	160.0	179.5	186.0	71.7	-5.4	-5.6	195.0	7.75
	006	136.0	151.0	158.0	61.4	-3.9	-5.5	199.1	6.73
	007	181.0	200.0	214.0	79.7	-3.6	-9.2	205.7	9.89
	008	112.0	125.5	135.5	51.7	-2.7	-7.1	205.5	7.61
	009	193.0	209.5	213.0	82.8	-4.9	-3.7	189.2	6.18
	011	186.5	206.0	214.0	81.6	-5.0	-6.2	197.4	7.95
	012	187.5	197.0	200.5	78.8	-2.6	-2.9	197.2	3.88
	013	140.5	149.5	154.5	61.0	-2.1	-3.7	209.6	4.29
KOM	002	198.0	206.5	202.5	82.2	-3.6	1.0	126.0	4.18
	004	188.5	186.5	178.0	75.7	-0.8	4.6	62.0	4.81
KTC	002	88.0	117.5	134.5	47.9	-6.2	-12.7	202.0	14.13
	004	77.0	111.5	137.5	45.4	-5.0	-18.2	205.8	18.81

3.3. Comparison of artefacts from Thai and Indonesian archaeological sites

To confirm the production sites and trade routes of *kendis* used in the temples, the colours of artefacts from 2 other Thai and Indonesian archaeological sites in Figure 3 are discussed. The potsherds from Kok Moh (KOM), an ancient pottery production site in Sa Thing Phra, exhibit the large b* of 75.7 and 82.2 corresponding to their lighter colours. Much lower a* and b* values are obtained in the artefacts from Kota China (KTC) in north Sumatra of Indonesia. The L* value in this artefact drops to less than 50, consistent with its darker colour. Only with this dark tone, readings in the RGB space are highly reproducible. The contrast between KOM and KTC artefacts can also clearly be separated by low and high hue angles as well as chroma values. The colours of both artefacts are not comparable to the potsherds excavated from 3 temples (TK3, PT7 and SL5) discussed in 3.2. From this evidence, *kendi* used in the Buddhist ritual were not produced from the nearby Kok Moh (KOM) kilns. Instead, they were likely produced locally in Nakhon Si Thammarat. Unlike elemental composition of clay, the potsherd colours from different archaeological sites do not confirm the maritime trade route proposed in the literature [1, 2].

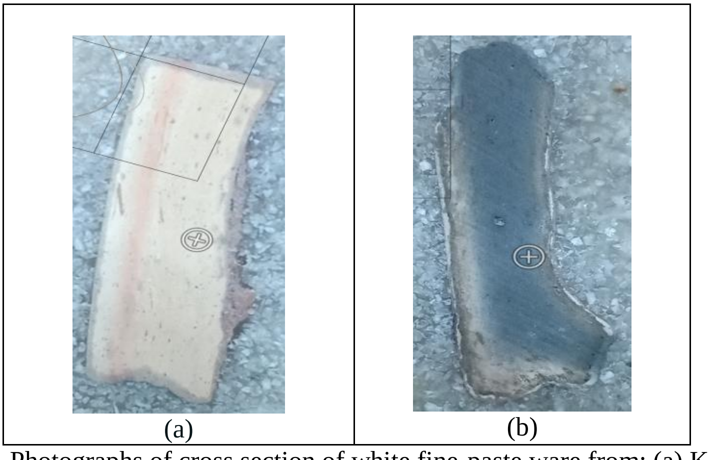


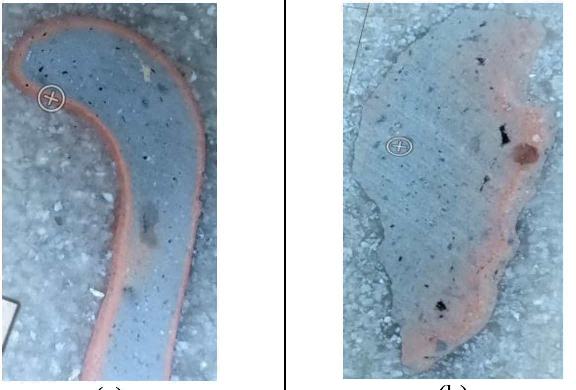
Figure 3. Photographs of cross section of white fine-paste ware from: (a) Kok Moh (KOM) and (b) Kota China (KTC).

3.4. Colour classification of artefacts from Myanmar and India

Fine-paste ware artefacts have also discovered in modern-day Myanmar. Due to their distinct reddish brown, these potteries are referred to a different class as red fine-paste ware [2]. The cross-sectional inspections of artefacts from Otein Taung (OTT) in Figure 4a reveal the colour inhomogeneity. Whereas the core has colour value in Table 3 comparable to those of Indonesian and Thai artefacts in Table 2, the outer layer has exceptionally high a* in the CIE space, consistent with the reputation of Otein Taung as the red fine-paste ware consumption site. The colour inhomogeneity is also characterized by the large negative b* of the core against the positive b* of the outer layer. This large colour distribution on the cross-section is similarly observed in an artefact from Periyapattinam in Tamil Nadu (TND) of India shown in Figure 4b. It is noted that R and B values in the RGB space successfully differentiate the outer layer and core colours only in one case. The hue angle and chroma are also not effective for both cases. The similar results from CIE space in the case of OTT-008 and TND-010 in Table 3 correspond to the trade between Myanmar and India. It also confirms the Indian influences in forms of both tangible and intangible religious heritage in Southeast Asia.

Table 3. Colours of red fine-paste ware classified by the combination of an Android smartphone (OPPO F9) and a mobile application 'Colorimeter'.

Artefact	Layer	RGB			CIE			Hue angle	Chroma
		R	G	B	L*	a*	b*		
OTT-008	Core	141.0	179.5	210.5	71.4	-5.5	-19.9	206.7	20.62
	Outer	143.5	119.0	121.0	53.3	9.9	2.5	355.0	10.22
TND-010	Core	92.0	117.0	130.5	47.8	-5.7	-10.3	199.9	11.87
	Outer	161.0	132.0	133.0	57.8	11.4	3.75	174.0	12.71



(a) (b)

Figure 4. Photographs of cross section of red fine-paste ware from: (a) Otein Taung (OTT) in Myanmar and (b) Periyapattinam, Tamil Nadu (TND) in India.

4. Conclusions

Smartphones can be attractive tools to engage the young generation in studies of religious artefacts. In this study, potsherds from 7 different archaeological sites dated back to 13^{th}-14^{th} centuries of maritime Southeast Asia were characterized by commercial mobile application named 'Colorimeter' on an Android smartphone. Cross-sectional colours were quantified and compared according to the CIE L*a*b* space. The RGB space as well as chroma and hue angle were also recorded but proved less effective in colour classification. The different clay sources were effectively characterized by the variation in b* value and large L* values correspond to lighter clay used to produce the white fine-paste ware in Thailand. Much lower L* and b* values were obtained in the artefacts from north Sumatra of Indonesia. The artefact from Myanmar revealed outer layer with very high a* value, consistent with the reputation of red fine-paste ware consumption in this area. Interestingly, the comparable colours in a potsherd from Tamil Nadu provided an evidence of Indian influence in forms of tangible religious heritage in Southeast Asia.

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