A preliminary understanding of the behaviour of oil paintings in tropical Southeast Asia

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Abstract

Oil paintings in Southeast Asia present interesting conservation questions. This paper identifies the materials and techniques of early 20th century oil paintings from institutions in Malaysia, the Philippines, Singapore and Thailand and their related condition in view of the elevated temperatures and relative humidity. It considers problematic materials and mechanisms known to paintings conservation in tropical climates and assesses them in terms of canvas painting practice identified in four institutions. Methods of investigation include technical examination and Electronic Speckle Pattern Interferometry to illustrate in plane dimensional movement. ESPI proved to be a useful diagnostic tool for in situ analysis of paintings on stretched canvas.

Résumé

Les peintures à l'huile en Asie du Sud-Est soulèvent des questions intéressantes en matière de conservation-restauration. Cet article inventorie les matériaux et les techniques des peintures à l'huile du début du 20e siècle conservées dans des institutions en Malaisie, aux Philippines, à Singapour et en Thaïlande et leurs conditions étant donné les niveaux élevés de température et d'humidité relative. Il s'intéresse aux matériaux et mécanismes problématiques liés à la conservation-restauration des peintures dans les climats tropicaux et les évalue en fonction de la pratique de peinture sur toile identifiée dans les quatre institutions. Les méthodes d'examen comprennent l'examen technique et l'interférométrie de speckle électronique pour visualiser les mouvements dimensionnels dans le plan. L'interférométrie de speckle électronique s'est avérée un outil diagnostique très utile pour l'analyse in situ des peintures sur toile.

Synopsis

Las pinturas al óleo del Sudeste de Asia plantean cuestiones de conservación interesantes. Este artículo identifica los materiales y técnicas de las pinturas al óleo de principios del siglo XX de instituciones en Malasia, Filipinas, Singapur y Tailandia y su estado de conservación, en vista de la temperatura y humedad relativa elevadas. Aborda

Introduction

The history of oil paintings in Southeast Asia is relatively recent. While originating in Western Europe, the practice of oil painting spread to Malaya, the Philippines, the City of Singapore and Siam amid an era of religious conversion, colonialism, global trade and exchange in the 19th and early 20th centuries. While Southeast Asian painters were exposed to 'Western' oil painting practice, their adoption of Western materials and techniques did not necessarily result in mimetic copies. As such, conservators working in Southeast Asia are faced with two main issues. First what materials and techniques were adopted and secondly, what is their expected behaviour at high relative humidities and temperatures – conditions typical of the tropics? Conservation practice is, in the main, informed by research undertaken in Europe and North America and current research provides a preliminary understanding of the behaviour of canvas paintings in the tropics. This paper reports on the results of the examination of over 200 early 20th century canvas paintings which was undertaken as a joint research project with partners from National Art Gallery in Malaysia (Balai Seni Lukis Negara (BSLN: 55 works examined), the University of the Philippines JB Vargas Museum (UPVM: 63 works examined), National Heritage Board (NHB: 56 works examined) in Singapore and the National Gallery, Bangkok (34 works examined) and the Centre for Cultural Materials Conservation (CCMC), the University of Melbourne in Australia.

Focusing on the physical and dimensional behaviour of oil paintings, the project is split into two parts. The first includes the identification of the materials and techniques used and their behaviour. It relies on the assessment, within the context of current conservation research, of the paintings stress release mechanisms according to their identified materials and techniques. The second method of enquiry focuses on the non-destructive characterisation of in-plane strain movement of canvas paintings with Electronic Speckle Pattern Interferometry (ESPI). It also assesses the suitability of a mobile ESPI system employed in-situ to recognise subtle in plane movements of aged canvas paintings.

los materiales y mecanismos problemáticos conocidos en la conservación de las pinturas en climas tropicales y los evalúa en cuanto a la práctica de pintura en lienzo identificada en cuatro instituciones. Los métodos de investigación incluyen análisis técnicos e Interferometría Electrónica Modelo de Puntos para ilustrar movimientos dimensionales en planos. La ESPI demostró ser una herramienta de diagnóstico útil para el análisis in situ de pinturas en lienzos tendidos.

Background

According to the conservation literature, problematic materials in tropical climates are the canvas support as tension increases above 85% RH and a swelled glue size layers (Mecklenburg 1982), (Hedley, Villers and Mehra 1983). The oil paint, ground and varnish layers, in contrast, plasticise at high humidities where they have a low tangent modulus, can flow and thus accommodate stress from the canvas support (Mecklenburg 1980: 9). Hence paint failure is thought to be uncommon in these circumstances. It is therefore necessary to focus on the behaviour of these materials in the examined paintings mindful of what artists used in 20th century Malaya, the City of Singapore, the Philippines and Siam. All were reviewed in the context of the climatic conditions across the four collections as detailed below.

Climate exposure and behaviour

Across the four collections, the daily diurnal changes in temperature and relative humidity are reported in Table 1 and Table 2 surmises each countries historical weather readings. The data is incomplete, however it is a general representation of the indoor environments where the art works may have been kept. Compared to the levels and range of oscillations internationally recommended for collections, the values are higher and wider in Bangkok coinciding with monsoonal climates of dry and wet seasons (Thomson 2003: 268, Agrawal 1975). By contrast, Singapore and Kuala Lumpur have high temperatures and RH levels, yet they are over a narrower range of oscillations

Table 1. Average internal climatic readings

Location and Date	Min	Mean	Max	Range
The National Gallery Bangkok: 3 October to 7 October 2005 (datalogger) and 19 April to 1 May 2004 (datalogger)				
Temp °C	27.3	27.8	29.0	1.7
RH%	35.0	61.9	80.6	45.6
University of the Philippines JB Vargas Museum (UPVM): 9 to 29 October 2005 (datalogger) and 3 to 14 March 2003 (thermohydrograph charts)				
Temp °C	24.3	26.4	28.2	3.8
RH%	37.2	51.3	65.5	28.3
National Heritage Board Institutions since 1996 at SAM and 2000 at HCC (datalogger)				
Temp °C	23	23	23	–
RH%	65	65	65	–
Singapore Art Museum (SAM) Conservation Laboratory: 21 November to 1 December 2005 (datalogger)				
Temp °C	18.5	20.3	22.8	4.3
RH%	58.5	69.4	78.7	16.6
Singapore Art Museum (SAM): 1976 to 1995 (Chong Quek 2003 pers. comm.)				
Temp °C	By 11 am	Gallery 75%	Overnight increasing	
RH%	67%	Store 67%	RH	
National Art Gallery Malaysia (BSLN): 8 November to 16 December 2005 (datalogger)				
Temp °C	21.9	24.1	25.3	3.4
RH%	61.0	71.2	79.7	19.5
National Art Gallery Malaysia (BSLN): 15 February to 12 March 2003 (thermohydrograph charts)				
Temp °C	18		23	5
RH%	64		83	19

*Table 2. Historical climate readings from weather stations in Manila, Kuala Lumpur-Subang, Singapore-Paya Lebar, Bangkok, adapted from www.tutiempo.net/en/climate/Asia**

Location and Date	Mean Temp °C	Max Temp °C	Min Temp °C	Humidity %RH
Manila 1978–1987: weather station 984250	28.2	30.9	24.7	74.9
Singapore 1954–1963	26.6	30.9	23.5	83.9
Kuala Lumpur 1949–1958	26.2	30.8	23.2	83.2
Bangkok 1954–1963: weather station 484550	27.5	32.5	23.4	77.6

*The range of relative humidity oscillations was not available. Between each month there was greater variation in temperature and relative humidity values for Bangkok and Manila compared to relatively stable levels in Kuala Lumpur and Singapore. Over time temperatures appear to be rising which is also supported by recent research by Manton, Della-Marta and Haylock (2001).

for RH, which corresponds to an equatorial climate and when the overall stress magnitudes in a painting are low (Agrawal 1975). The levels reported for Manila are characteristic of monsoonal and equatorial climates.

Technical examination of materials and techniques and associated behaviour

The identification of the range of materials and techniques employed by 20th century Southeast Asian artists has been discussed in a previous publication (Tse and Sloggett 2008). From 2003 to 2005 the canvas paintings from the four national collections were subject to detailed examination and information was collated on a Filemaker Pro 5.5v2 database. A smaller sample set of material analysis was undertaken at CCMC. Primary source material including interviews and a review of documentary sources helped reconstruct the types of materials and techniques employed.

Auxiliary supports, canvas support and tensioning

Given the current understanding of canvas supports at high relative humidities, they are clearly at a greater risk when they are under positive tension, thereby increasing their chances of critical fatigue. Our assessment of canvas supports commonly utilised in Malaya, City of Singapore, Thailand and the Philippines, indicates that canvas supports are generally not under positive stress and strain (33% of works as determined by technical examination). The potential for the negative effects of relative humidity is therefore reduced. There are two possible explanations. The first is that strainers represent 56% of examined works, and appear to be more commonly employed by 20th century Southeast Asian artists. Hence after initial loss of tension in the canvas support, no further loads are applied through the expansion of the corner joins. Further anecdotal evidence suggests that it was not common practice to pre-stretch canvases with only 18% of canvases apparently undergoing this. (Choong 2003, Florencio 2005, Sarasek 2005). A second explanation is that when stretchers were employed, represented in 40% of the examined works, they were not keyed out. Of the paintings on stretchers, 30% had no keys inserted. For the remaining stretchers with keys, they were not distorted around their point insertion suggesting the stretcher had not been repetitively expanded. It can be surmised then that stretchers in Malaya, the Philippines, City of Singapore and the Philippines were not generally being used according to Western practice.

Poor canvas tension is still an issue for upper media layers. Technical examination of the two hundred paintings reveals that paint layers are thinly applied and the 94 cross sections indicated a range of paint thickness from 30 µm to 500 µm thick. Furthermore, as paint and ground layers become

increasingly plastic at high relative humidities they can accommodate the stress imposed on them from the canvas support below (Hedley 1993). It is proposed then, that the thin, flexible paint layers are at less of a risk even though they are supported by a loose canvas support.

Sizing layers and behaviour

The identification of a size layer was less conclusive, yet when imported commercial canvases were employed, it can be assumed that they contained glue, it being a common ingredient in early 20th century artists colourman preparations. This is true for 16 stamped commercially-prepared supports identified and possibly a further 36 works on linen that appear to have the uniform priming layers typical of artists' colourman preparation. The presence of protein sizing layers were further tested with Amido black (AB2) as outlined by Martin (1977) and of the 15 canvases analysed, 13 were protein tagged. Given the identification issues with microchemical tests, it was prudent to view the protein tagged works with some reservations and it was important to corroborate this evidence with other avenues of investigation.

The 13 works protein tagged, were on linen supports indicative of imported artists' colourman preparation. Four had corner bisector cracks which are normally associated with desiccation of the glue size layer. When paint loss had occurred, it was at the support ground junction and likely to be due to a swelled glue layer exposed to an RH above 85%. In these circumstances, clearly the use of glue sizing is problematic in tropical climates. Traditional knowledge of the brittle behaviour of glues such as buffalo and cow hide, however was known in Southeast Asia and when used, it was with caution (Choong 2003, Sarasek 2005). Given the absence of desiccation cracks in paint-ings that appear to be on locally prepared supports (48%), it is possible that glue sizing was not part of local artistic practices. This is also supported by dis-cussions with the commercial art shops such as Straits Commercial in the City of Singapore and Nanyang Art Supply in Kuala Lumpur, who state there was only a limited supply of rabbit skin glue (Long Nan Sing 2003, Lian Warn Jian 2004).

Paint behaviour

As noted by Mecklenburg, plasticisation of paint layers at high RH minimises paint failure (Mecklenburg 1982). Physical evidence of paint failure in the canvas paintings in the four collections was thus identified and assessed against historical climate levels. Table 3 details the proportion of paintings having paint failure and the type of crack patterns identified. Paint failure appears to be more common for the UPVM collection and the National Gallery, Bangkok (taking into account the smaller proportion of works examined in Bangkok). In contrast a higher proportion of no paint failure was recorded from the BSLN and NHB collections.

The disparate paint behavior across the four collections may be explained by climate. As known the rate of reaction and polymerisation of paint doubles with a 10 °C rise in temperature leading to an increased likelihood of material failure (Feller 1994). High and low RH over a wide range, produces elastic and plastic material behaviour, respectively stiffening and making them more flexible. Table 1 shows daily high to low RH levels and increased temperatures for the National Gallery, Bangkok and UPVM which may explain the higher proportion of recorded paint failure in their collections. Further Bangkok's climate is wet and dry. It was also noted that characteristics typically associated with low relative humidity such as corner bisector cracks and central cracks along the shorter painting dimension, were more common in the National Gallery, Bangkok and UPVM.

Furthermore, it is proposed that the higher RH levels in Singapore and Kuala Lumpur has led to the plastic behaviour paint, causing less paint failure in the NHB and BSLN collections. Further their reported range of relative humidity levels in Table 1 and equatorial climates, are centred around 50% to

Table 3. Paint failure across the four collections

	Proportion from the total examined works	Proportion between the collections
Major paint failure (80% of the surface layer cracked)	18% (37 of 208)	24% National Gallery, Bangkok* 29% UPVM 24% BSLN1 6% NHB
No paint failure	19% (41 of 208)	14% National Gallery, Bangkok* 24% UPVM 31% BSLN 36% NHB
Corner bisector cracks	21% (44 of 208)	17% National Gallery, Bangkok* 28% UPVM 13% BSLN 25% NHB
Central cracks perpendicular to the longer dimension	20% (42 of 208)	21% National Gallery, Bangkok* 35% UPVM 19% BSLN 14% NHB
Corner draws	0.9% (2 of 208)	0.9% BSLN

*A smaller proportion of works were examined from the National Gallery, Bangkok, therefore the obtained ratios are likely to be less.

80% RH when the overall stress magnitudes in a painting are low. Overall though, this is preliminary data for future comparable tests to be undertaken.

Case studies

Fernando Amorsolo's (1892–1972) consistent preparation of paint materials is supported by technical examination and art historical evidence (Tse and Sloggett 2008, Roces 1975:130). Of 12 of his examined works, seven were positively tagged using a potassium iodide starch test, suggesting a flour paste ground and ten were on cotton supports. Amorsolo's techniques were influential in artistic circles, and his students at the UP School of Fine Arts were taught to apply one layer of cooked starch as thin as a handkerchief otherwise cracking would result and then a final layer of white household oil paint, likely to be lead based (Concepcion 2005). However, a review of Amorsolo's works show that paint failure is common, which is not typical for plasticised paint layers at high humidities, suggesting other mechanisms (Mecklenburg 1982: 9). Of the 12 examined works, paint failure occurred for nine, where eight had corner bisector cracks and of these, four had a large network of cracks and paint loss at the canvas layer. Such characteristics are indicative of a ground layer with high elastic modulus as the humidity decreases. Recent research by Carlyle and Young shows that flour paste grounds crack prematurely indicating that they initially have high stress magnitudes (Carlyle and Young 2008). This theory is also supported by the technical examination of Amorsolo's works which remain positively stretched without the use of keys and have a thick hardened ground layer. Art historical evidence also suggests Amorsolo mixed Japanese driers with linseed oil which would explain the increased brittleness of his paint films and premature failure at high relative humidities (Roces 1975). The increased temperatures of Manila too are another consideration for paint failure, as was the case in Bangkok where cracking was more pronounced compared to the other institutions.

In plane movements with electronic speckle pattern interferometry (ESPI)

ESPI was employed to show in-plane dimensional movement of the canvas support according to changes in RH and temperature. ESPI measures surface

deformation of materials, in this case the upper paint or varnish layers however the role of the canvas support, possible size and ground layer is also measured as they transfer stress to the upper surfaces. In 2005 a transportable in-plane ESPI unit was built and configured for use and transportation to the four institutions where climatic conditions ranged from non climate controlled to intermittent or continuous use of air conditioning. Twelve canvas paintings were tested and the surrounding climatic conditions logged to consider what gave rise to he ESPI results.

Theory

ESPI is a highly sensitive non destructive optical technique that relies on the interaction of coherent light back scattered from an object's surface. Resulting speckles are characteristic of the roughness of an object's surface and if strain deformation occurs, the optical path lengths of light are increased or decreased and lead to a change of intensity of the speckle and represent points of high strain concentration (Jones and Wykes 1983). ESPI has been successfully applied to panel paintings and biaxial testing of canvas paintings (Paoletti and Spagnolo 1993, Young 1999). For in situ testing the requirement is a positively tensioned canvas painting, as well as the dampening of external vibrations and air currents as these cause speckle decorrelation. A rough surface is illuminated with two coherent optical beams and the resulting interference speckle pattern recorded with a digital camera. When consecutive speckle images are obtained, provided they can register, a fringe pattern of dark and light bands is produced with software analysis. The locations of the resulting bright and dark bands represent characteristic transverse strains which can be analysed to provide a spatial map of the strain field.

Experimental

An ESPI system was first constructed in a climate-controlled chamber on a vibration-isolated table. Before it was modified for in-situ use, it was tested on a canvas painting subjected to changes in temperature and relative humidity.[1] Figure 1 illustrates the transportable ESPI system assembled on an aluminium plate. The camera was connected to a PC and image acquisition

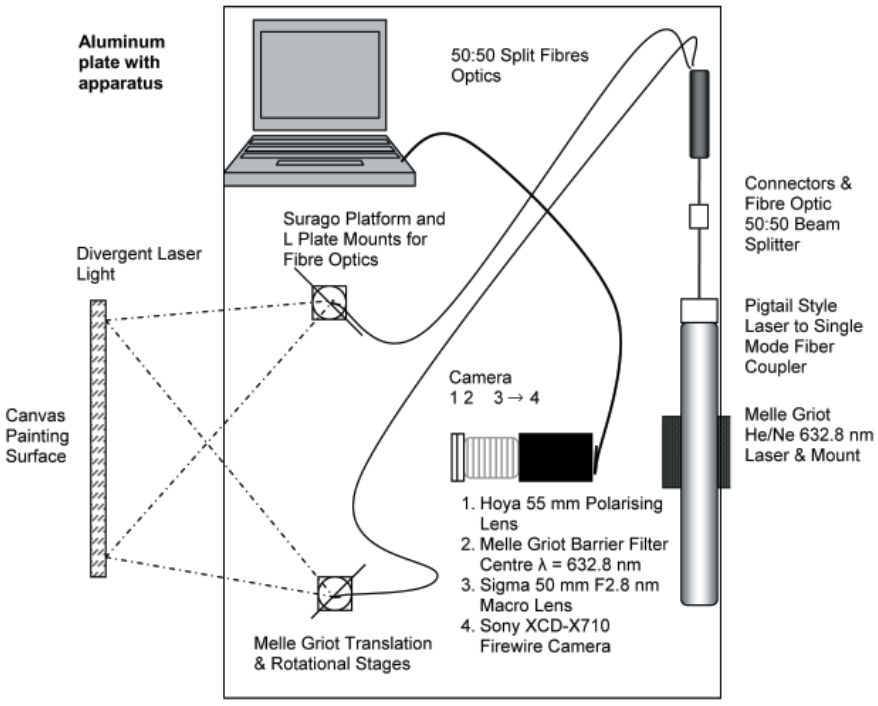

Figure 1. Mobile ESPI set up

Figure 2. In situ ESPI at the Singapore Art Museum. Chia Mia Tee, Eating Bananas Leaves *1977, Oil on canvas, 810 × 940 mm, National Heritage Board*

was driven by CMU 1394 camera driver software and captured by Image J. A plug-in was written to automate acquisition and analysis with Image J with various subtraction and filtering techniques. A 632.8 nm 30 mW laser was coupled into an optical fibre attached to a 50/50 fibre coupler. The light emitted from each fibre was linearly polarised and the fibres oriented so that the light radiated from each fibre was vertically polarised. The camera was used with a polarising filter to isolate light polarised parallel to the light radiated by the fibres. A narrow-band filter centred on 632.8 nm was attached to the camera so that images could be acquired in ambient lighting conditions. The power output from each optical fibre was 3.18 to 3.7 mW over 4 cm^2 and when multiplied by its exposure time in seconds gives the energy exposure in mJ. According to the literature and total energy exposure calculations for each test, this was within safe limits (Schaeffer 2001). To further limit exposure the laser was also turned off between images. Figure 2 shows the in-situ set up with the aluminum plate attached to a camera tripod and weighted to minimise vibrations. Environmental readings were measured throughout with an ACR datalogger.

ESPI Results

Figures 3–4 illustrate the ESPI fringe patterns obtained from tests at the Singapore Art Museum and the National Art Gallery in Malaysia. The associated environmental trends are in Figure 5. Clearly fringe patterns can be

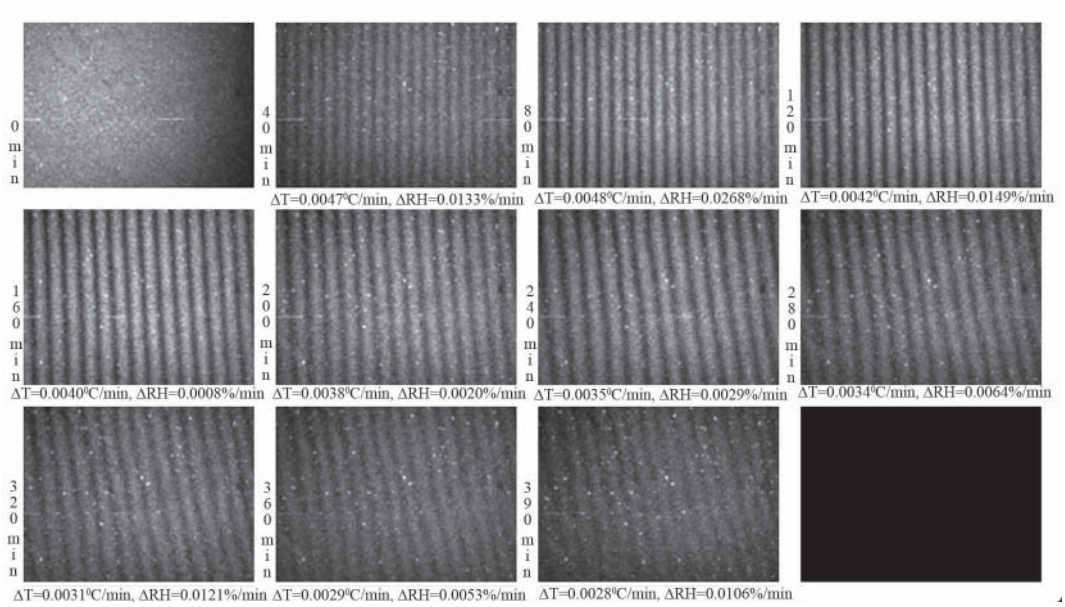

Figure 3. Results of ESPI fringe patterns at 40 minute intervals (test of 390 minutes, consecutive images every 10 minutes processed relative to 8.57 pm image)

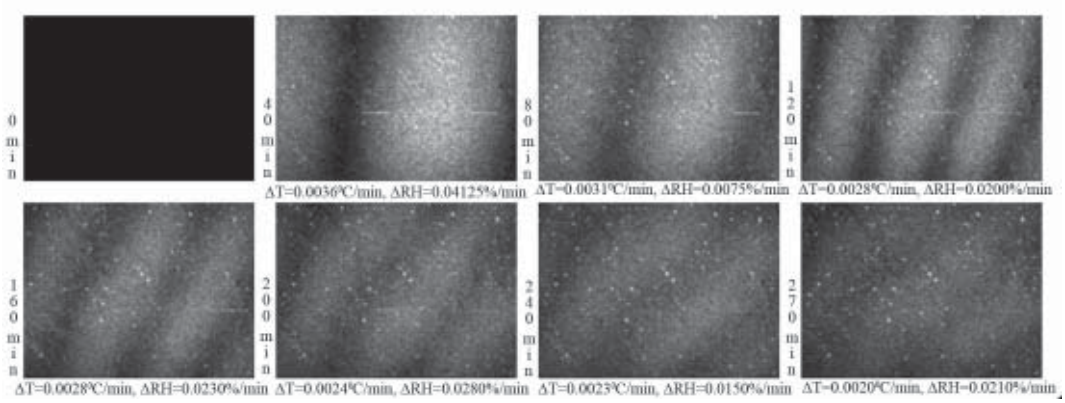

Figure 4. Results of ESPI fringe patterns at 40 minute intervals (test of 270 minutes, consecutive images every 10 minutes processed relative to 10.57 pm image)

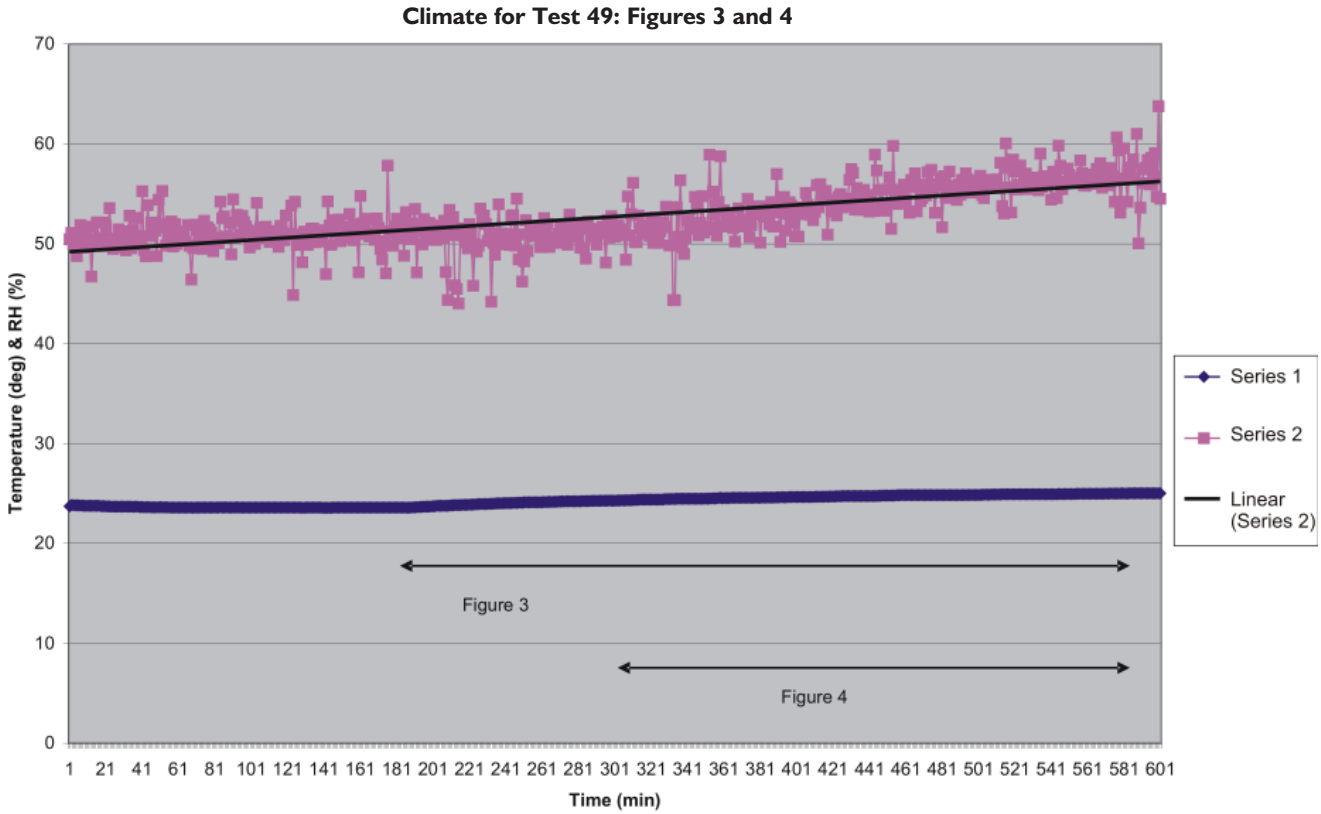

Figure 5. Climatic readings for Figure 3 and 4

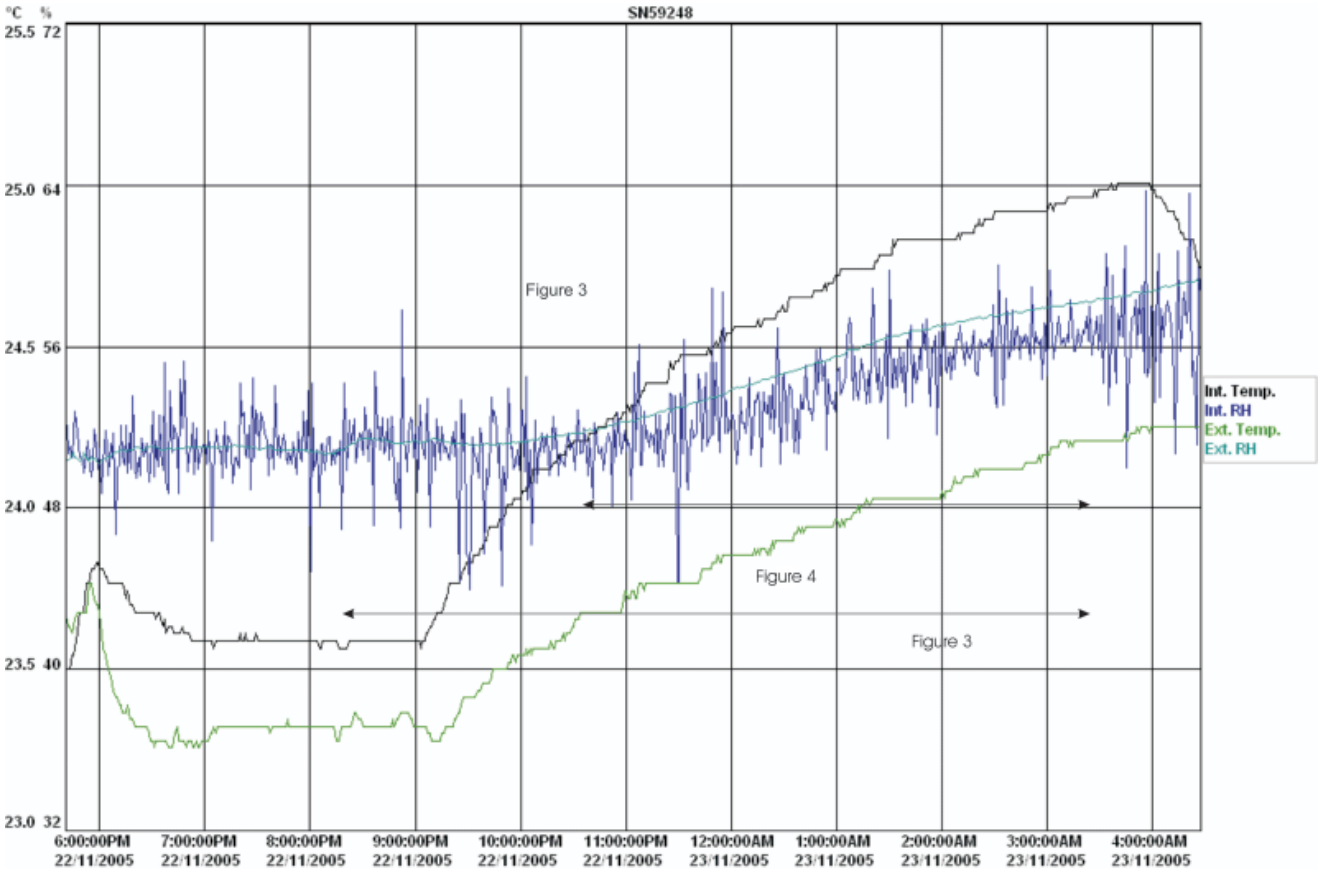

Figure 6. Climate readings for Figure 3 and 4

produced from the in situ testing of canvas paintings without much speckle decorrelation. Figures 3 and 4 are from the same test but represent a different time frame and relative image. The change in temperature calculated for each image generally corresponds to the frequency of fringes, however there is no direct relationship with RH. Furthermore, the RH values are higher for Figure 4 even though more widely spaced fringes were produced. This suggests a delayed reaction of the materials to RH fluctuations however further data needs to be acquired to show this.

The fringe patterns in Figures 3–4 are qualitative interpretations and at the time of testing temporal phase shifting was not initially incorporated into the ESPI system to quantify the strain field and its direction. In addition some results proved to be invalid due to decorrelation of speckle in unsuitable test conditions. Results were only successful in still environments.

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Conclusion

According to the identified materials and techniques, not all Western art practices were employed by artists of the early 20th century in Malaya, the City of Singapore, the Philippines and Thailand. Consideration of the observed condition of works allows for suggestions as to the mechanisms underpinning their mechanical responses. In some cases standard conservation practices can be applied, whilst others can not. Concerns relating to the stress developments of a canvas support at high relative humidities may not be an issue, if artists continue the practice of using strainers or 'unkeyed' stretchers. In the case of sizing layers, those on commercially prepared imported artists colourman canvases are likely to contain a glue size layer and there is some evidence that this is problematic. Although the ESPI results did not expand our understanding of the in plane dimensional movement of canvas paintings in tropical environments, it has proved to be a useful diagnostic tool. ESPI can be used in situ to map the strain field of canvas paintings and now with the minor equipment and software modifications in place, it is being employed. Overall this preliminary study has raised some important issues unique to canvas paintings in tropical climates, but like other conservation studies, it returns to the importance of artistic practice and materials as the basis to conservation methodologies.

Note

1 In 2004 ESPI research was undertaken by Elaine Miles, then an Honours Physics student. With the current ESPI system she calculated the linear coefficient of thermal expansion for aluminium as $(2.29 \pm 0.6) \times 10^{-5}\ K^{-1}$, which is in agreement with the published result of $2.33 \times 10^{-5}\ K^{-1}$ (Grigoriev and Meilikhov 1973).

References

Agrawal, O. 1975. Conservation in South and South-east Asia. *Museum,* 27(4), 155–212.

Carlyle, L and Young, C. 2008. The mechanical response of flour paste grounds, in *Preparation for painting: the artist's choice and its consequence*, Archetype Publications, British Library, London.

Choong, K. 2003. Interview Transcript on 'Western' Art Materials in Malaysia by Nicole Tse, Kuala Lumpur, Malaysia, 6 August.

Concepcion, F. 2005. Interview Transcript on 'Western' Art Materials in the Philippines by Nicole Tse, Manila, Philippines, 13 October.

Hedley, G, Villers, C and Mehra, V. 1993. Artists' Canvases: Their History and Future, in *Measured Opinions*, United Kingdom Institute for Conservation, London, 50–56.

Jones, R and Wykes, C. 1983. Holographic and speckle interferometry: a discussion of the theory, practice and application of the techniques, Cambridge and New York: Cambridge University Press.

Lian Warn Jian. 2004. Interview Transcript on Nanyang Art Supply Company, Kuala Lumpur, Malaysia, 21 December.

Long Nan Sing. 2003. Interview Transcript on Straits Commercial Art Supply Shop in Singapore. Singapore, 30 May.

Martin, E. 1977. 'Some Improvements in Techniques of Analysis of Paint Media'. *Studies in Conservation* 22, 63–67.

Mecklenburg, M. 1982. *Some aspects of the Mechanical behaviour supported paintings*. Internal report. Smithsonian Institution, Washington DC (unpublished).

Ng Chong Quek. 2003. Interview Transcript on the Materials and Techniques of 'Western' Art Materials in Singapore, Singapore, 1 August.

Paoletti, D and Spagnolo, S. 1996. Interferometric Methods for Artwork Diagnostics, *Progress in Optics*, 35, 198–255.

Roces, A. 1975. *Amorsolo*. Makati City: Filipinas Foundation Inc.

Sarasek, P. 2005. Interview transcript on 'Western' Art Materials in the Thailand by Nicole Tse, Bangkok, Thailand, 4 September.

Schaeffer, T. 2001. Effects of Light on Materials in Collections: Data on Photoflash and Related Sources, Los Angeles, The Getty Conservation Institute.

Thomson, G. 2003. *The Museum Environment*, 2nd edn, Butterworths Heinemann, London.

Tse, N and Sloggett, R. 2008. Southeast Asian Oil Paintings: Supports and preparatory layers, in *Preparation for painting: the artist's choice and its consequence*, Archetype Books, London.

TuTiempo.net 2006. *Historical Weather Records Asia*, viewed 11 September 2006, <http://www.tutiempo.net/en/Climate/asia.htm>.

Young, C. 1999. Measurement of the biaxial properties of nineteenth century canvas primings using electronic speckle pattern interferometry, *Optics and Lasers in Engineering*, 31(2), 163–70.