9th International Conference on NDT of Art, Jerusalem Israel, 25-30 May 2008
For more papers of this publication click: www.ndt.net/search/docs.php3?MainSource=65

SPECKLE AND CONSERVATION

Elaine Miles[1], Ann Roberts[1,2], Robyn Sloggett[2], Nicole Tse[2]
[1]School of Physics
[2]The Centre for Cultural Materials Conservation
University of Melbourne, Victoria, Australia 3010

ABSTRACT

The aim of this research is to demonstrate the usefulness of speckle, a trait of an expanded laser beam, for the non-destructive testing of artwork in both the imaging of subsurface structure and the quantitative detection of physical movement of canvas

Laser Speckle Contrast Method (LSCI) is a useful method for the viewing of subsurface layers and movement. By investigating the statistical properties of dynamic speckle it is possible to reveal drawings that are hidden beneath scattering layers such as the primary layer of paint or adhered paper. This is achieved by taking a series of speckle images captured in a short time frame and applying one of a number of post processing algorithms. We explore the limitations of this method when applied to various paper samples that have a sketch executed in various media beneath the top layer. The ability to resolve gray scale images was examined as well as looking at the dependence of the contrast of the revealed drawings to the temperature of the surface. Current work is being done on using LSCI to reveal indentations in artwork caused by the application process.

The successful use of Electronic Speckle Pattern Interferometry (ESPI) both in the laboratory and in-situ for the detection of in-plane movement of painted canvas due to humidity fluctuations and the out-of-plane movement of paint as it dries has also been demonstrated. Canvas paintings can be very susceptible to movement due to changes of the environment. ESPI is a non-destructive technique yielding sensitive results that can detect displacement on a surface of less than the wavelength of the illuminating coherent light source. While ESPI has been successfully applied to the in-situ study of painted frescoes, previous studies have employed tensile testers as a support for painted canvas. We have shown a portable version of ESPI to be of use in tropical environments in the Philippines, Malaysia and Singapore with original artworks where variations in humidity occur and the samples have not undergone special preparation before analysis, revealing significant directional movements. Furthermore, a simple variation in the direction of beams paths permits the characterisation of out-of-plane movement, specifically as the height of paint shrinks due to the drying process. We have used ESPI to view the drying process of alkyd resin paints over the time period of 24 hours.

INTRODUCTION

The classification and authentication of artwork is critical for artists, collectors, curators and museums. As forgers gain more insight and better tools for producing fraudulent pieces, it becomes even more important for conservation scientists to remain at the forefront of identifying and analyzing key elements of the artwork. Monitoring the structural integrity of paintings as they age is also important to avoid damage such as cracks and delamination. Here we explore two applications of laser based technology to conservation science; (i) LSCI (ii) ESPI.

The first technique presented in this paper is a method to look beneath the primary surface of a work on paper to view inscriptions, alterations and underdrawings if they are present, this is known as laser speckle contrast imaging (LSCI) [1]. LSCI is a frequently used technique in the biomedical field to distinguish fluid flow and movement beneath organic tissue such as skin and bone [2]. Primarily used with organic materials, we demonstrate that it can also be utilized with static samples such as artworks with graphite drawings beneath them.

As well as having specific identifiable attributes, canvas paintings are very susceptible to movement both initially during their construction and subsequently due to changes in the environment such as temperature and humidity. Electronic Speckle Pattern Interferometry

(ESPI) is a non-destructive technique yielding sensitive results that can detect displacement on a surface of less then the wavelength of the illuminating coherent light source [3]. Used to investigate artwork ESPI is a method of measuring physical changes in the dimension or surface of artwork. It has previously been successfully applied to the study of the structure of cultural materials such as painted frescoes [4], but previous uses of this method in the study of painted canvas have required the special preparation of the canvas on frames [5]. This has often led to the destruction of the artwork and, hence, is not suitable for art conservation practices. We have demonstrated that ESPI is in fact useful for the study of canvas stretched on their original supports that have experienced an environment of changing climate.

When paintings are produced they initially undergo chemical and mechanical changes due to the drying process and later movements induced by ageing effects and climate fluctuations. We observed the in-plane shifting of painted canvas due to changes in relative humidity both in a controlled laboratory environment and also in-situ in a South East Asian gallery. Normally used simply as a paint additive we also observed the drying process of Art Spectrum Liquol, a transparent alkyd resin, used as a rapid drying painting and glazing medium. A simple manipulation of the beam arms in ESPI allows for out-of-plane movement to be monitored which gave insight into the drying properties of Liquol.

BACKGROUND

LSCI is a simple process that involves illuminating a surface with an expanded laser beam and recording a stack of speckle images at a fast frame rate. Speckle results when spatially coherent light is either reflected from an optically rough surface or transmitted through a medium that has random refractive index fluctuations. As time progresses the speckle can be seen to fluctuate. By looking at the statistics of the light intensity I, at a specific point ij, in the imaging plane it is possible to characterize these fluctuations and relate them to the subsurface structure. The most commonly used method [6] for viewing subsurface movement is to use the temporal contrast method. This involves obtaining a series of images within a short time span and for each pixel calculating the mean intensity, $\langle I \rangle$, and standard deviation, σ, over the time period,

$$\langle I_{ij} \rangle = \frac{1}{N} \sum_{k=1}^{N} I_{ij}^{k} ,$$

$$\sigma_{ij} = \sqrt{\frac{1}{N-1} \sum_{k=1}^{N} \left(I_{ij}^{k} - \langle I_{ij} \rangle \right)^2} .$$

By dividing the deviation by the mean, it becomes possible to discriminate the fast and slow moving speckle. This method is commonly referred to as the Temporal method and is the most commonly used,

$$T_{ij} = \frac{\sigma_{ij}}{\langle I_{ij} \rangle} .$$

Unfortunately this method suffers from low resolution and contrast. A slightly more sophisticated method is the Fujii [7] technique, whereby the contrast of a pixel compared to its corresponding intensity is summed over the entire stack of images,

$$F_{ij} = \sum_{k=1}^{N-1} \left| \frac{I_{ij}^{k} - I_{ij}^{k+1}}{I_{ij}^{k} + I_{ij}^{k+1}} \right| .$$

The third and final method is the Arizaga [8] method. A much more rigorous technique it involves summing differences between frames but has an extra weighting function, $\rho(l)$**,** that can be varied to extract particular fluctuations. For example it would be possible to see slow shifts by setting ρ such that for high values of l the function has a value of 1 as opposed to low values which will set ρ to almost 0.

$$A_{ij} = \sum_{k=1}^{N} \sum_{l=1}^{N-k} \left| I_{ij}^{k} - I_{ij}^{k+1} \right| \rho(l)$$

In order to evaluate the effectiveness of each of the analytical methods the Michelson contrast factor is applied. The contrast C, is computed where O, is the object and B, is the background. Values of 1 indicate high contrast and 0 show no contrast is present.

$$C = \left| \frac{O - B}{O + B} \right|$$

Electronic Speckle Pattern Interferometry (ESPI) is a well-established method for the measurement of displacements in rigid surfaces. Two beams of expanded laser light illuminate the surface under investigation and either both beams are combined on the surface at the same angles for in-plane displacement or one beam is on the surface to be later recombined with a reference wave which shows out-of-plane displacement.

When a physical displacement of a surface occurs, the optical path lengths traveled by the light beams are increased or decreased. This shift changes the relative phase between the two beams at that particular point therefore leading to a change in the intensity of the resulting speckle. By taking an initial speckle pattern, inducing a mechanical change and taking a final image it is possible to view these displacements by a simple subtraction of the images. If movement has occurred this results in fringes that are similar to those seen in Moiré interferometry. The magnitudes of the displacements, d, measured are limited by the geometry of the setup as are described,

$$d_{in-plane} = \frac{1}{2} n\lambda \sin\gamma \qquad \text{n=1, 2, 3,…}$$

$$d_{out-of-plane} = \frac{1}{2} n\lambda \qquad \text{n=1, 2,3,…}$$

where, λ is the wavelength of the illuminating light and γ is the angle of illumination to the surface. It is possible to measure small displacements of less then the wavelength of the light used.

EXPERIMENT

A HeNe laser of wavelength 632.8nm was coupled to a fibre optic 50:50 splitter, which splits the light between two single-mode optical fibres. The light radiated from the cleaved ends of these fibres was then positioned to illuminate a 20×20 cm^2 area. Depending on the experiment being performed the beams are manipulated by the rotational stages to give the desired illumination path as illustrated.

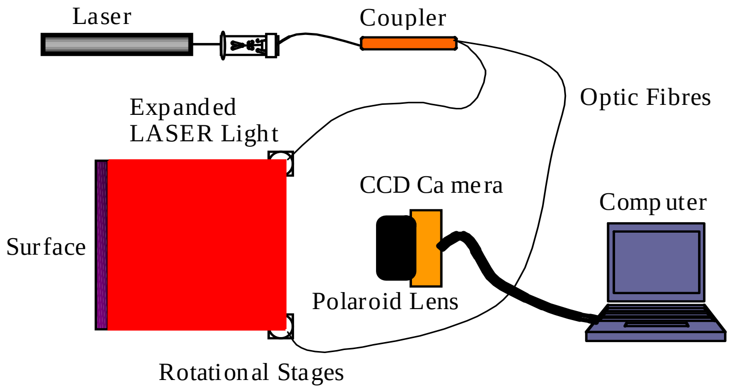

Figure 1: Experimental set-up for In-Plane ESPI

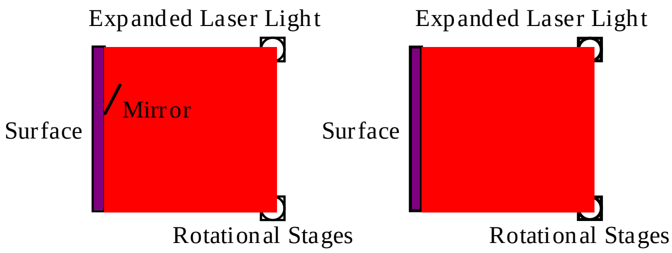

Figure 2: Beam alignment for (a) Out-of-Plane ESPI (b) LSCI

The imaging system consisted of a different camera for each experiment. Fitted onto both cameras was a 1:28, 50mm video lens with a 633nm narrow-band pass filter and an additional polaroid filter oriented in the same direction as the polarization of the output fibres. All images were saved in TIFF format and analyzed within the program Interactive Data Language (IDL).

For LSCI a monochrome FireWire 8-bit CCD camera (Sony, XCD-710) was implemented. Images were acquired with the software "Ultravision". A stack of 50, 640x480 pixels^2 images, covering an area of 16×12mm^2, was collected at 30 frames per second.

For the ESPI setup a CCD 12-bit camera (Photometrics Sensys) of 1317x1035 pixel^2 resolution using V++ software was used. An initial image was captured using the CCD camera and over the course of several hours subsequent images collected with the simultaneous recording of the humidity and temperature. Subtracting from each speckle pattern was an image obtained previously, revealing fringe patterns that can be related to the difference in climate between frames. The fringe patterns are further enhanced by applying Lee filtering to smooth out the grain.

RESULTS

Laser Speckle Contrast Imaging

Using a simple laser printed monochrome image turned upside down to mask the image, data was taken as described and the various algorithms applied. The distinct characteristics of each method is apparent in Figure 3. Both the Temporal and Arizaga method show significant darkening in the corners. However the Fujii appears grainier.

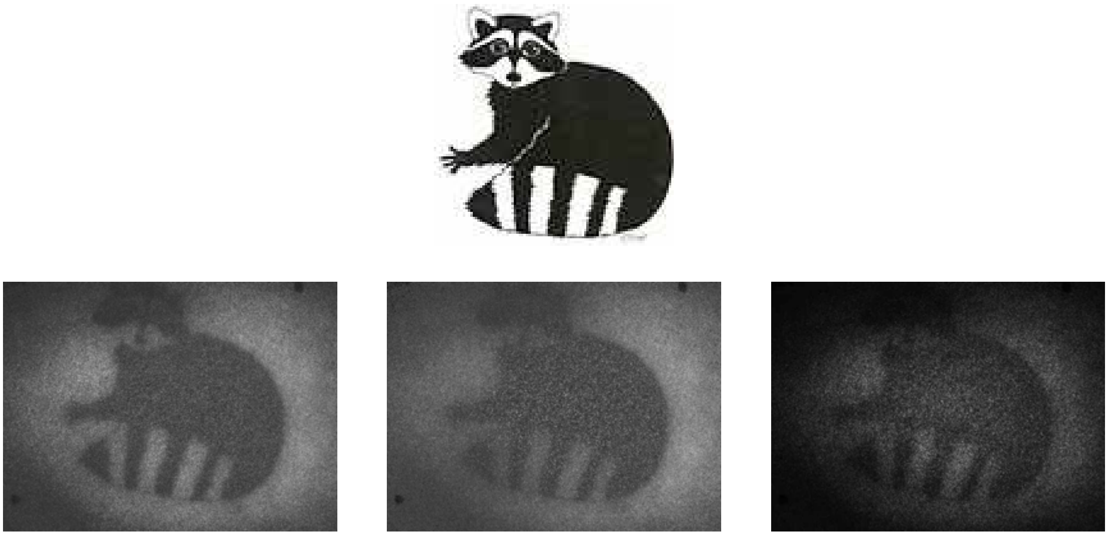

Figure 3: The three analysis techniques compared side by side
(a)Original Image (b)Temporal (c)Fujii (d)Arizaga

A more quantitative analysis was applied by using the various samples previously described. Each sample consisted of a 2x2 cm^2 white card, half left blank the other coated in one of the media in the table. Adhered to the top was one of either Paper, White Card, Grey Card or White Paint. The LSCI process was repeated for every combination of media and surface available and the contrast between the blank section and coated was calculated. The results are tabulated in Table1.

Medium	Surface	Temporal	Fujii	Arizaga
Background		0.02	0.00	0.06
Black Ink	Paper	0.21	0.16	0.37
	White Card	0.16	0.15	0.30
	Grey Card	0.02	0.00	0.05
	White Paint	0.03	0.01	0.06
Conte	Paper	0.17	0.15	0.30
	White Card	0.18	0.16	0.30
	Grey Card	0.02	0.00	0.04
	White Paint	0.03	0.00	0.08
Charcoal	Paper	0.18	0.13	0.35
	White Card	0.18	0.18	0.34
	Grey Card	0.03	0.00	0.05
	White Paint	0.03	0.02	0.07
Pencil	Paper	0.16	0.16	0.32
	White Card	0.21	0.17	0.35
	Grey Card	0.02	0.00	0.05
	White Paint	0.02	0.01	0.06
Red Ink	Paper	0.01	0.01	0.04
	White Card	0.02	0.01	0.05
	Grey Card	0.02	0.00	0.05
	White Paint	0.02	0.01	0.05

Table 1

On a visual level, contrast values less then 0.1 did not reveal the underdrawing, this is apparent by comparing the levels of a medium to the background. It is clear that the Arizaga method provided the greatest contrast and so was used for the remaining experiments.

The responses due to the actual media are of interest as it allows for the limitations of this method to be examined. The contrast was greatest for the thinnest paper as it allows for the most light to be reflected back, making for a substantial variation in the fluctuations. In the cases of the matte white paint and grey card the contrast was similar to that of the background value, hinting that there was no reflection taking place. Looking at the response of the media, the black ink and charcoal were the greatest as they absorb more of the radiation then the white ground surface. Red ink predictably indicated the lowest value as it reflects the red light back. The varieties of surfaces that can be explored using this method could be expanded by using a near infrared laser source. As light with a longer wavelength scatters less, it can penetrate more deeply into surfaces. Also an underdrawing media that is highly concentrated with carbon, such as charcoal and graphite, will absorb this energy more readily. Both of these results would lead to a greater variation in the statistics of the fluctuating speckle leading to greater contrast. This is the basic principle for infrared reflectography which is practiced by illuminating samples with this longer wavelength and capturing the reflected irradiance with an infrared camera.

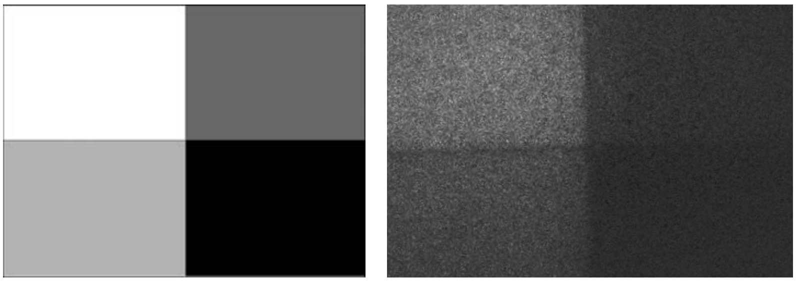

Figure 4: Arizaga result from the grey scale image that shows variations in the shading

A gray scale laser printed image of four rectangles of varying degrees of grey and the HeNe laser was used to see if variations in shading could be resolved. Using the Arizaga method, very specific detail resulting from variations in the shading can be seen in Figure 4. This is useful as mediums are rarely applied evenly during the construction process and so the subtleties and variations of the work can be observed. Efforts have been applied to 8-level images but the gray tones are hard to distinguish due to the small field of viewing.

In-Plane ESPI

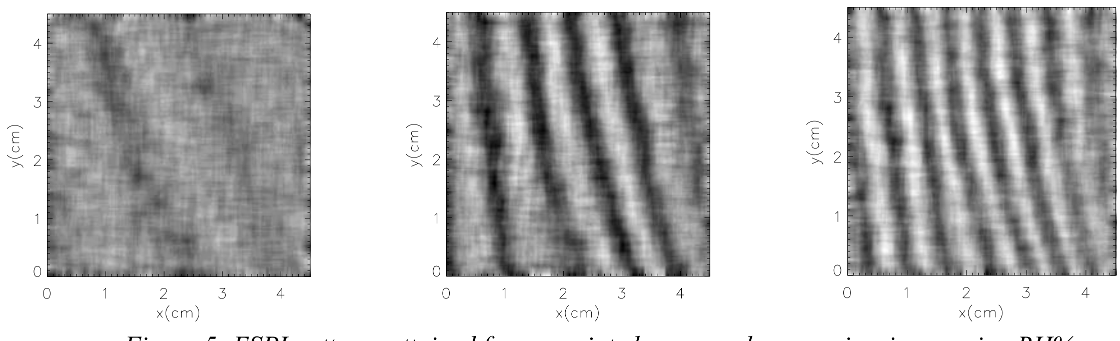

Figure 5: ESPI patterns attained from a painted canvas edge experiencing varying RH%
a. ΔRH% = 9.8 b. ΔRH% = 11.1 c. ΔRH% = 11.9

In-plane ESPI was applied to a oil paint canvas housed within a perspex container and surrounded by petri dishes filled with analytical grade sodium chloride salt mixed with deionised water. This enclosure was a means to maintain constant temperature while varying the relative humidity as the salt/water solution reached an equilibrium point. On closing the lid the RH% was 45%. Images were taken every minute for 2 hours at 1500ms exposures. An ARC data logging device was left inside to constantly record the RH% and temperature. The temperature of the chamber stayed at a constant (20.3 ± 0.1) ˚C during the time that images were acquired and the only measurable environmental change was the variation in the RH from 52.3%-64.7%.

As can be seen in Figure 5 there is definite movement of the canvas occurring due to the absorption of water vapour by the canvas. The decreasing fringe separation suggests that the canvas is expanding as it absorbs moisture.

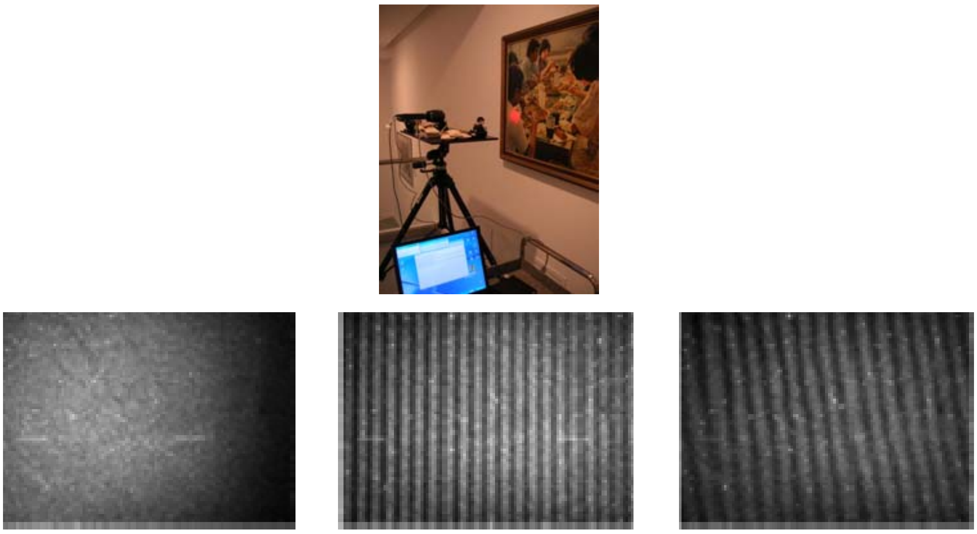

Figure 6. Portable ESPI at the Singapore Art Museum
a. Left edge of Painting ESPI patterns attaining from humidity changes of b. ΔRH% = 3.6 c. ΔRH% = 2.0

The apparatus was transported and used in the Singapore Art Museum. Figure 6 demonstrates the movement of an oil painting on canvas, produced by Chua Mia Tee. The illumination was focused on the left edge of the painting and over the course of a night speckle images were recorded where the room environment experienced a constant temperature of 23°C and fluctuations in relative humidity of 50-60%. We can see with the changes in humidity movement has occurred, with indications that a small change in Relative Humidity leads to a small in-plane displacement of the surface as indicated by the larger fringe spacing.

Out-Of-Plane ESPI

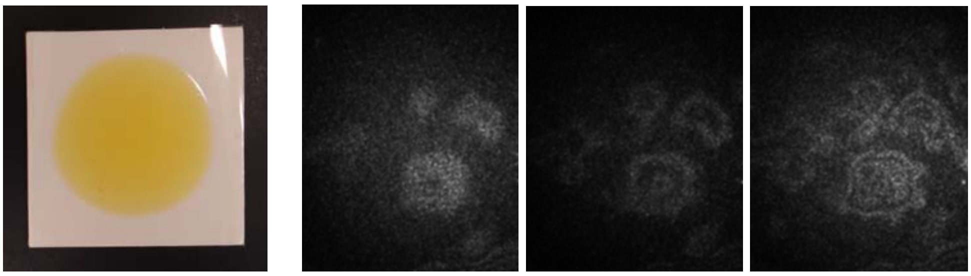

Figure 7:a. Image of Liquol pour and ESPI fringes of gas release after the pour at b.Δt =965mins c.Δt =980mins d. Δt =995mins

A 12cm radius circular pour of 15ml Liquol was applied to a piece of laminate board and inserted to the sample area of the out-of-plane ESPI setup. Over the course of the initial 48 hours of drying, speckle images were captured every 5 minutes. Significant movement was not seen throughout the experiment but after approximately 16 hours non-periodic fringes could be observed (see Figure 7). An hour later these fringes vanish indicating the Liquol has returned to its initial state. These fringes have been attributed to the release of gases as the Liquol oxidizes with the surrounding air.

CONCLUSION

LSCI is a simple and useful technique that would be a simple complement to more rigorous laser based techniques. It has the ability to divulge the subsurface drawing executed in various media beneath adhered paper materials, down to variations in the renderings of the underdrawing. This is attributed to the idea of areas where there is more dark material causing the speckle to fluctuate more. However, as the obscuring materials at a higher temp scattering and absorption properties increase speckle correlation the resolution and contrast of the underdrawing decreases until only noise is observable. Future directions in this technique are the application of LSCI to parchment pieces, such as documents glued together, as the smoothness of the top surface has been demonstrated to give meaningful results

In-plane ESPI is an effective tool for the qualitative and quantitative measurement of movement in canvas as the surrounding temperature and humidity vary. Particularly in the monitoring of movement induced by humidity chambers and by tropical conditions found in Asian galleries. A portable version of ESPI has been used effectively to watch canvas movement over the course of 24 hours during the wet season in gallery situations in Singapore. 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 was used in-situ to map the strain field of canvas paintings.

Out-of-plane ESPI has been shown as a useful tool for the characterisation of the drying process of Liquol where gas releases can be observed over time. Further work would include extending this experiment over a longer period of drying time and also looking at a previously aged piece and observing bulge formation due to exposure to heat and daylight.

ACKNOWLEDGEMENTS

This study is part of a larger ARC Linkage project on The Characterisation of Western Canvas Paintings in Tropical Environments with the Chief Investigators Dr. Ann Roberts, School of Physics and Associate Professor Robyn Sloggett, Director of The Centre for Cultural Materials Conservation.

The project involves five industry partners including the National Art Gallery in Malaysia, the Heritage Conservation Centre in Singapore, the National Gallery of Victoria in Australia, the Vargas at the University of the Philippines Museum supported by the Australian Embassy in Manila and the National Gallery of Fine Arts in Bangkok supported by the Australian Embassy in Bangkok.

A special thanks to Katherine Rosenthal, previous CCMC Masters Student, associated with this project.

The University of Melbourne’s “Postgraduate Overseas Research Experience Scholarship” scheme also helped to support this research.

BIBLIOGRAPHY

1. R. Nothdurft and G. Yao, “Imaging obscured subsurface inhomogeneity using laser speckle”, Opt. Express 13, 10034–10039 (2005).
2. Y. Aizu and T. Asakura, “Bio-speckle phenomena and their application to the evaluation of blood- flow”, Optics and Laser Technology 23, 205–219 (1991).
3. G Cloud, *Optical Methods of Engineering Analysis*, New York: Cambridge University Press (1995).
4. D Paoletti and G Spagnolo, “Interferometric Methods for Artwork Diagnostics”, *Progress in Optics*, 35, 197-255 (1996).
5. C Young, “A comparison of the physical properties of 19th-century canvas lining with acid aged canvas”, *ICOM Committee for Conservation*, vol. 1, pp. 353-361 (1999).
6. J. Briers and A. Fercher “Flow visualization by means of single-exposure speckle photography”, Opt. Commun. 37, 326–329 (1981).
7. H. Fujii, , H. Ikawa, K. Nohira, T. Ohura and Y. Yamamot, “Evaluation Of Blood-Flow By Laser Speckle Image Sensing”, Appl. Opt. 26, 5321–5325 (1987).
8. R. Arizaga, N. L. Cap, H. Rabal and M. Trivi, “Display of local activity using dynamical speckle patterns”, Optical Engineering 41, 287–294 (2002).

Back to Top