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Application of shearography with thermal loading for structural inspection of Rembrandt's *Night Watch*

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ABSTRACT

The assessment of the structural condition of cultural heritage objects is important for conservation interventions and their long-term preservation. This investigation concerns *The Night Watch* (1642), a large-format 17^{th}-century canvas painting by Rembrandt van Rijn that is on display in the Rijksmuseum, Amsterdam. This painting, which has a complex treatment history, has various damaged areas and has undergone three wax-resin relinings. In 1975 the canvas was slashed twelve times with a serrated dinner knife, including several long slashes in the area of Captain Frans Banninck Cocq's breeches. In 2021, prior to a proposed new structural intervention involving retensioning of the canvas, it was important to evaluate the structural condition of the repaired slashes and of another repair, specifically an old canvas insert in the drum. For this, an in-situ inspection was carried out in the Rijksmuseum as a part of Operation Nightwatch. 3D shearography instrument with thermal loading was used to inspect these two areas of interest on the reverse of *The Night Watch*. The results showed that the out-of-plane strain in the breeches does not show any large deviations, which alleviated conservators' concerns about the adhesion of the lining canvas and stability of previous repairs in this region. The patch in the drum showed higher out-of-plane strain variations. This was explained by the lower quality of the patched canvas compared to the repaired slashes in the breeches of Banninck Cocq. Overall, 3D shearography provided valuable inspection results for assurances regarding the structural integrity of the 1975 repairs and the wax-resin lining in *The Night Watch*, reducing the risks and providing the confidence to proceed with the planned retensioning of the canvas.

Keywords: 3D shearography, thermal loading, NDT, *The Night Watch*, in-situ inspection, structural integrity

1. INTRODUCTION

The assessment of the structural condition of cultural heritage objects is important for conservation interventions and their long-term preservation. This investigation concerns *The Night Watch* (1642), a large-format canvas painting by Rembrandt van Rijn that is on display in the Rijksmuseum, Amsterdam[1]. *The Night Watch* has a complex treatment history including but not limited to numerous re-vanishings, varnish re-generations and wax-resin relinings[1–3]. In 1975 the canvas was slashed twelve times by a visitor with a serrated dinner knife, including several slashes of almost a meter long in the area of Captain Frans Banninck Cocq's breeches. During the subsequent structural treatment in 1975, the long slashes were repaired and the painting was relined with an additional canvas using a mixture of beeswax and resin. An old canvas insert in the drum of about 6×9.5 cm was also replaced[2,3]. Consequently, in 2021 prior to a proposed new structural treatment involving retensioning of the canvas, it was important to evaluate the structural condition of these regions of the painting, which is the main objective of this study. For this, an in-situ structural integrity inspection with shearography was carried out in the galleries of the Rijksmuseum as a part of Operation Nightwatch[4].

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Shearography[5,6] is an optical, non-contact and full-field inspection technique that can measure surface deformation at the micro-strain scale using scattered laser light and a shearing camera. Some form of loading is needed to deform the test object as only the relative strain can be measured and not the absolute shape and its variation (e.g. as with Electronic speckle pattern interferometry (ESPI))[7]. Historically, shearography has had a wide application for non-destructive inspections of composite materials in the aerospace industry[6,7]. Detectable defects include delaminations, debonding, cracks and fiber breakage. In the recent decade, shearography has raised increasing interest in the inspection of artworks including paintings[8–12], where it can reliably and repeatedly reveal delaminations and cracks and also exclude the human factor when compared with traditional inspection techniques (e.g., visual inspection and tapping test)[12].

The objective of this investigation is to evaluate the structural condition of Rembrandt's *Night Watch*. For this study, 3D shearography with thermal loading was used to inspect two areas of interest from the reverse of the painting during Operation *Night Watch* at the Rijksmuseum. The decision to use the full capability of 3D shearography was driven by the needs:

- To identify potential delaminations between the original canvas and the lining canvas that had been applied in 1975. Normally, delaminations are efficiently detected with the out-of-plane shearography configuration[6].
- To evaluate the quality of the repaired slashes considering them as in-plane structural features. These structural features normally affect the in-plane strain distribution, e.g. as cracks in wooden panels[6,9].

2. EXPERIMENTAL INSPECTION SYSTEM

The Night Watch is a large oil on canvas painting with overall dimensions of 3.795×4.535 m (Figure 1). The original canvas support consists of three horizontal strips of canvas with two seams. Two inspected areas, including the Captain's breeches (0.5×1 m) and the drum (0.2×0.5 m), are marked in green and red rectangles. To minimize the exposure of the paint layers to the light and heat from the shearography heating source, these two areas were inspected from the reverse of the painting.

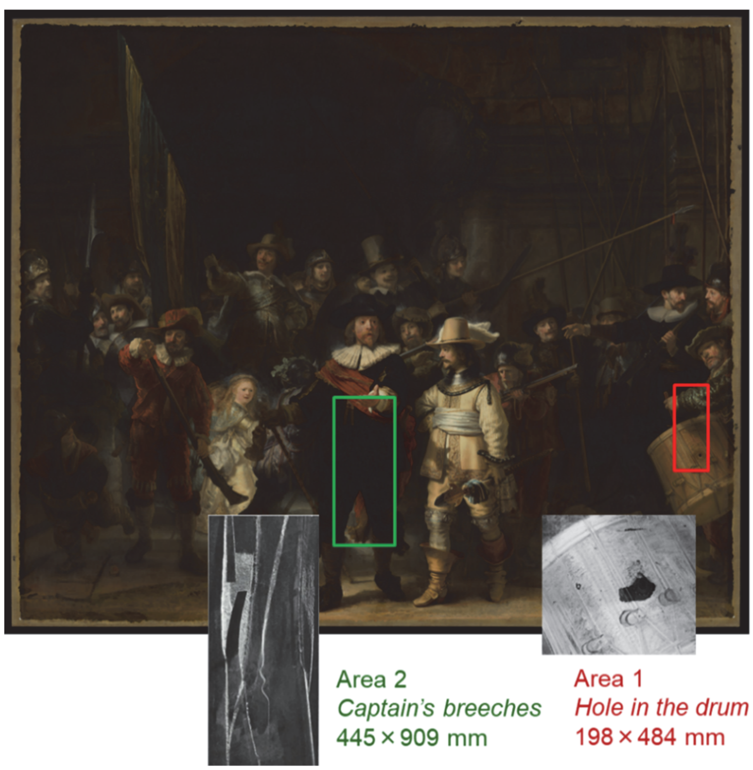

Figure 1. Rembrandt van Rijn, *Officers and other civic guardsmen of District II in Amsterdam, under the command of Captain Frans Banninck Cocq and Lieutenant Willem van Ruytenburch, known as 'The Night Watch',* 1642, Rijksmuseum, Amsterdam[2,4].

For the in-situ inspection of *The Night Watch*, the previously reported 3D shape shearography instrument[13,14] was adapted and fixed on a motorized rigid platform (Figure 2) to enable controlled scanning of the painting and further image stitching. A fourth shearing camera was added to the instrument close to parallel to the laser beam to provide pure out-of-plane surface strain measurement. Two halogen lamps with a maximum power of 1 kW each were used to heat the painting. During the inspection in the Rijksmuseum, the lamps were set at 60% of total power for 2.6 seconds which resulted in the average temperature increase of the lining canvas by 1.5 °C which was monitored by IR camera (FLIR A655).

The painting was illuminated with the Torus 532 laser (optical power set to 150 mW, wavelength of 532 nm by Laser Quantum) through expansion optics, including a diffuser ED1-S20-MD by Thorlabs. The speckle pattern was imaged by four Pilot piA2400 cameras by Basler with Linos MeVis-C 1.6/25 lenses. Each camera has a Michelson shearing interferometer with temporal phase-shifting realised by a piezo-electric actuator PSH 4z (Piezosystem Jena). The individual field of view of each camera was approximately 210×180 mm. The suitable shear distance of 2.1 mm (approximately 24 pixels) in the horizontal and vertical directions was experimentally identified to produce reliable phase maps. Given that the shear amount was significantly smaller than the distance to the painting, an assumption was made that the shearography phase maps correspond to the in- and out-of-plane surface strain components.

Figure 2. 3D shape shearography instrument positioned behind *The Night Watch* in the galleries of the Rijksmuseum

Thermal heating caused strain variations at the reverse of the painting. These strain variations were continuously monitored during cooling with the shearing cameras simultaneously to result in shearography phase maps, which were further processed and stitched together to result in continuous inspection maps. Each phase map was also compensated to remove the significant global deformation of the canvas[15,16].

3. INSPECTION RESULTS

The final inspection results include the in- and out-of-plane phase maps with the shear in the *x*- (horizontal) and *y*- (vertical) directions corresponding to the surface relaxation during cooling. These phase maps were calculated using the calibration information about the instrument geometry and 3D shearography processing methods[13,14].

The inspected area of the drum with the canvas insert and the canvas seam in the original support is shown in Figure 3 (a). The seam and the canvas insert are detectable in the in-plane $\partial v/\partial y$ and the out-of-plane $\partial w/\partial y$ phase maps with the shear in the *y*-direction (Figure 3 (e, f)).

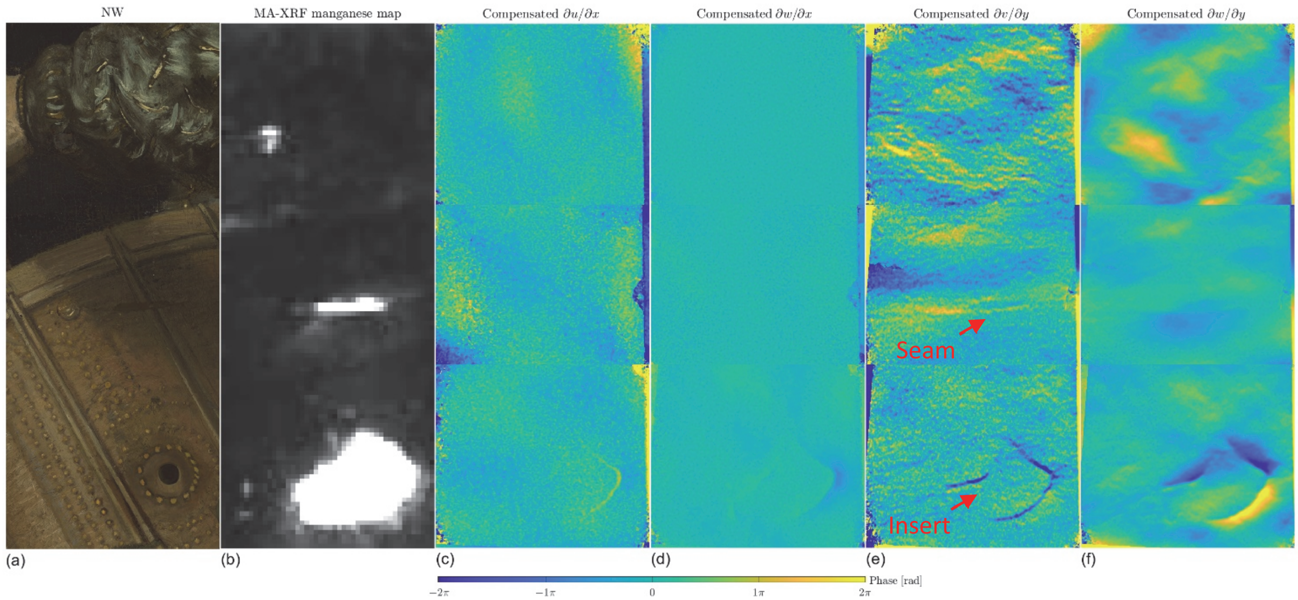

Figure 3. 3D shearography inspection results of the drum area with the canvas seam and insert (198×484 mm). (a) white light image with corrected intensity levels, (b) manganese (Mn-K) map, macro X-ray fluorescence scanning spectroscopy (MA-XRF) associated with the pigment umber used during the restoration, (c) the in-plane phase $\partial u/\partial x$ and (d) the out-of-plane phase $\partial w/\partial x$ with the shear in the x-direction (horizontal), (e) the in-plane phase $\partial v/\partial y$ and (f) the out-of-plane phase $\partial w/\partial y$ with the shear in the y-direction (vertical).

The area investigated in the breeches of Captain Banninck Cocq (445×909 mm) was significantly larger than the drum area (198×484 mm), therefore inspection of the full area with 3D shearography was found not to be efficient from the time and effort point of view. The entire breeches area was inspected with the out-of-plane configuration of the instrument (Figure 4 (d, f)) to identify possible delaminations between the original canvas and the lining canvas given the slashes incurred in 1975 in this area were the largest. A smaller area, which was considered the most critical was inspected with 3D shearography (Figure 4 (c, e)).

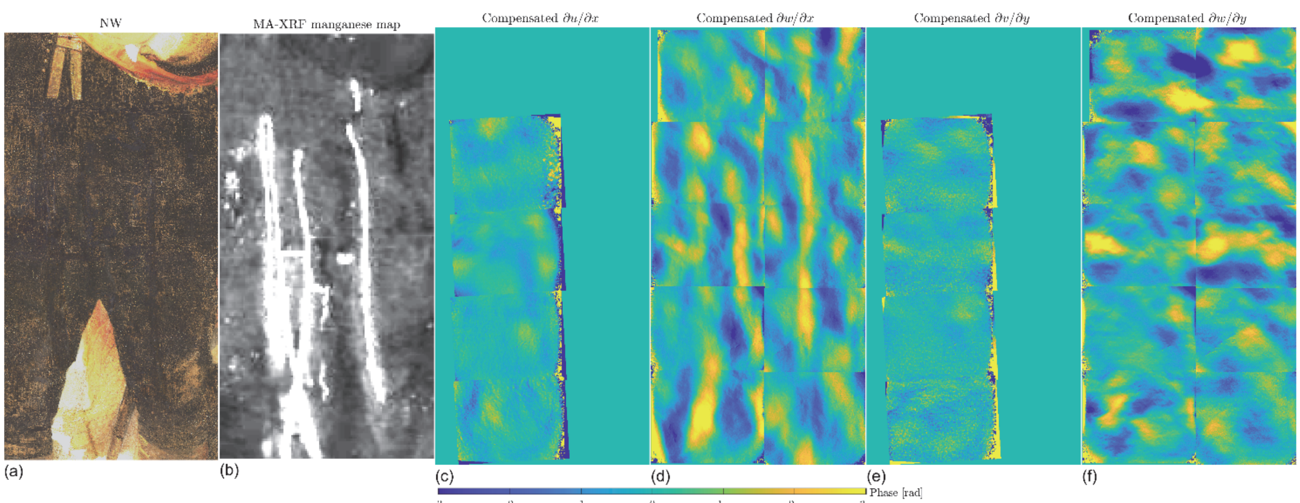

Figure 4. 3D shearography inspection results of the Captain Banninck Cocq's breeches area (445×909 mm). (a) white light image with corrected intensity levels, (b) manganese (Mn-K) map, macro X-ray fluorescence scanning spectroscopy (MA-XRF) associated with the pigment umber used for repairing the slashes during the 1975-76 restoration, (c) the in-plane phase $\partial u/\partial x$ and (d) the out-of-plane phase $\partial w/\partial x$ with the shear in the x-direction (horizontal), (e) the in-plane phase $\partial v/\partial y$ and (f) the out-of-plane phase $\partial w/\partial y$ with the shear in the y-direction (vertical).

The inspection results of both investigated areas (Figures 3 and 4) show that known structural features can be reliably identified and mapped (viz. the seam and the insert in the drum, Figure 3). The overall pattern of the repaired slashes in the breeches area can be traced in the out-of-plane phase map with the shear in the x-direction ($\partial w / \partial x$, Figure 4 (d)). However, both the in-plane (Figure 4 (c, e)) and out-of-plane phase maps (Figure 4 (d, f)) do not have clear and significant local variations as compared to the area around the drum insert (Figure 3 (e, f)). The localised strain around the drum insert can be explained by the lower quality of the patched canvas compared to the repaired slashes in the breeches of Banninck Cocq.

4. CONCLUSIONS

In this paper, 3D shearography with thermal loading was used to inspect two areas with restored damage in *The Night Watch*, specifically the Captain Banninck Cocq's breeches and the drum. The results of the inspection from the reverse of the painting showed that the out-of-plane strain in the Captain's breeches does not show significant deviation that would indicate weakness in the adhesion between the repaired slashes and the lining canvas. The other repair, the canvas patch in the drum showed higher in- and out-of-plane strain variations. This was explained by the lower quality of the patched canvas compared to the repaired slashes in the breeches of Banninck Cocq.

Overall, 3D shearography provided valuable inspection results for assurances regarding the structural integrity of the 1975 repairs and the wax-resin lining in *The Night Watch*, reducing the risks and providing the confidence to proceed with the planned retensioning of the canvas.

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REFERENCES

[1] Gabrieli, F., Delaney, J. K., Erdmann, R. G., Gonzalez, V., van Loon, A., Smulders, P., Berkeveld, R., van Langh, R. and Keune, K., "Reflectance Imaging Spectroscopy (RIS) for Operation Night Watch: Challenges and Achievements of Imaging Rembrandt's Masterpiece in the Glass Chamber at the Rijksmuseum," Sensors **21**(20) (2021).

[2] Kuiper, L. and Hesterman, W., "Restauratieverslag van Rembrandts Nachtwacht / Report on the Restoration of Rembrandt's Night Watch," Bull. van het Rijksmus. **24**(1/2), 14–51 (1976).

[3] van Thiel, P. J. J., "Beschadiging en herstel van Rembrandts Nachtwacht / The Damaging and Restoration of Rembrandt's Night Watch," Bull. van het Rijksmus. **24**(1/2), 4–13 (1976).

[4] Rijksmuseum., "Operation Night Watch, https://www.rijksmuseum.nl/en" (2019).

[5] Steinchen, W. and Yang, L., [Digital shearography : theory and application of digital Speckle pattern shearing interferometry], SPIE Optical Engineering Press, Bellingham, Wash. (2002).

[6] Francis, D., Tatam, R. P. and Groves, R. M., "Shearography technology and applications: a review," Meas. Sci. Technol. **21**(10), 102001 (2010).

[7] Steinchen, W., Yang, L., Kupfer, G. and Mäckel, P., "Non-destructive testing of aerospace composite materials using digital shearography," Proc. Inst. Mech. Eng. Part G J. Aerosp. Eng. **212**(1), 21–30 (1998).

[8] Groves, R. M., Osten, W., Doulgeridis, M., Kouloumpi, E., Green, T., Hackney, S. and Tornari, V., "Shearography as part of a multi-functional sensor for the detection of signature features in movable cultural heritage," O3A Opt. Arts, Archit. Archaeol. **6618**, C. Fotakis, L. Pezzati, and R. Salimbeni, Eds., 661810, SPIE (2007).

[9] Groves, R. M., Pradarutti, B., Kouloumpi, E., Osten, W. and Notni, G., "Multi-sensor evaluation of a wooden panel painting using terahertz imaging and shearography," O3A Opt. Arts, Archit. Archaeol. II **7391**, L. Pezzati and R. Salimbeni, Eds., 73910E, SPIE (2009).

[10] Buchta, D., Hein, N., Pedrini, G., Krekel, C. and Osten, W., "Artwork Inspection by Shearography with Adapted

Loading," Exp. Mech. **55**(9), 1691–1704 (2015).
[11] Buchta, D., Heinemann, C., Pedrini, G., Krekel, C. and Osten, W., "Combination of FEM simulations and shearography for defect detection on artwork," Strain **54**(3), e12269 (2018).
[12] Gatto, V., Anisimov, A. G., Lettinga, W., Tao, N., Lantman, M., Crijns, B. and Groves, R. M., "Application of shearography and the percussion method for the structural inspection of wall paintings: a case study of St. Christopher in Maria Church, Nisse," Opt. Arts, Archit. Archaeol. VIII **11784**, H. Liang and R. Groves, Eds., 117840K, SPIE (2021).
[13] Anisimov, A. G., Serikova, M. G. and Groves, R. M., "3D shape shearography technique for surface strain measurement of free-form objects," Appl. Opt. **58**(3), 498–508 (2019).
[14] Anisimov, A. G., Müller, B., Sinke, J. and Groves, R. M., "Analysis of thermal strains and stresses in heated fibre metal laminates," Strain **54**(2), e12260 (2018).
[15] Tao, N., Anisimov, A. G. and Groves, R. M., "Shearography non-destructive testing of thick GFRP laminates: Numerical and experimental study on defect detection with thermal loading," Compos. Struct. **282**, 115008 (2022).
[16] Tao, N., Anisimov, A. G. and Groves, R. M., "FEM-assisted shearography with spatially modulated heating for non-destructive testing of thick composites with deep defects," Compos. Struct. **297**, 115980 (2022).