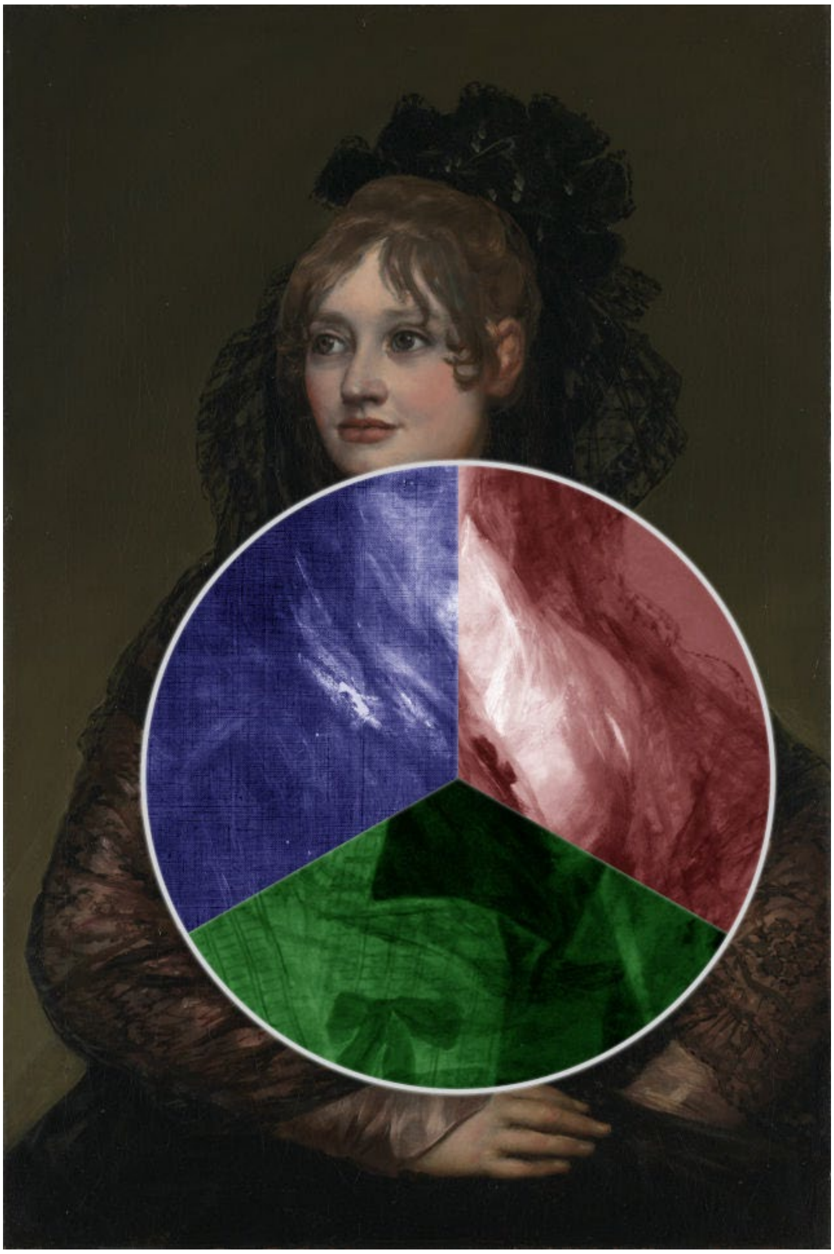

Book of Abstracts

Computational approaches for technical imaging in cultural heritage

(7th IP4AI meeting)

27–29 April 2022

THE NATIONAL GALLERY

Computational approaches for technical imaging in cultural heritage (7th IP4AI meeting)

27–29 April 2022

The conference has being organised as part of the EPSRC-funded *ARTICT | Art Through the ICT Lens: Big Data Processing Tools to Support the Technical Study, Preservation and Conservation of Old Master Paintings* project (a collaboration between the National Gallery, University College London and Imperial College London and in partnership with Duke University) and builds on the success of the Image processing for art investigation (IP4AI) workshops, first established in 2007. The aim of IP4AI is to support art scholarship with new computational tools that enable new findings, and this conference aims to expand the original IP4AI remit to include both image and signal processing approaches as applied to the investigation of artworks and other cultural heritage artefacts.

With the increasing use of a range of advanced technical imaging and spectroscopic imaging methods in the study and preservation of artworks and other cultural heritage artefacts, there is growing interest in - and need for - computational approaches to fully realise the potential in the data acquired, to automate aspects of the processing and interpretation of the data and be able to address research questions in a variety of disciplines. This is a rapidly growing field of research that is only possible through cross-disciplinary collaboration.

The aim of this conference is to provide a forum to bring together a multi-disciplinary group of researchers including:

- scientists and conservators working with various forms of technical imaging or spectroscopic imaging on paintings and other cultural heritage artefacts in museums, galleries and universities
- researchers working in computer science, data science, computational image processing, computer vision, machine learning and AI, mathematics, and statistics
- art historians, archaeologists and curators with an interest in the possibilities of technical imaging and/or those working in the digital humanities

to share their research and find fertile areas of collaboration and common inquiry.

Organizing committee:

- Catherine Higgitt, Nathan Daly and Ann Stephenson-Wright: National Gallery
- Miguel Rodrigues, Wei Pu and Chao Zhou: University College London
- Pier Luigi Dragotti, Junjie Huang, Su Yan and Maria Villafane: Imperial College London
- Ingrid Daubechies and Ashley Kwon: Duke University

Scientific committee:

- John K. Delaney, National Gallery of Art, Washington, DC
- Anya Hurlbert, University of Newcastle
- Koen Janssens, University of Antwerp
- Aggelos K. Katsaggelos, Northwestern University
- Juan José Murillo Fuentes, University of Seville
- Aleksandra Pizurica, University of Ghent

Engineering and Physical Sciences Research Council

Computational approaches for technical imaging in cultural heritage (7th IP4AI meeting) Programme

27-29th April, 2022

Wednesday, 27th April

Time, BST (UTC +1)	Speaker	Title
14:00-14:05	*Conference introduction*	
	Keynote 1	**Chair:** Catherine Higgitt, *National Gallery, London*
14:05-15:05	**Jill Dunkerton** *National Gallery, London*	**"Technical imaging and connoisseurship: investigating a collaboration between Botticelli and Filippino Lippi"**
15:05-15:10	*Short break*	
	Oral Presentation Session 1	**Chair:** Catherine Higgitt, *National Gallery, London*
15:10-15:30	**John K. Delaney** *National Gallery of Art, Washington DC*	**"An alternative approach to mapping pigments in paintings with hyperspectral reflectance image cubes using artificial intelligence"** Tania Kleynhans, John K. Delaney, Roxanne Radpour, Catherine M. Schmidt Patterson & Kathryn A. Dooley
15:30-15:50	**David Mills** *Queen Mary University of London*	**"Revealing the unreadable – digitisation without disruption"** David Mills
15:50-16:10	**Paolo Romano** *CNR-ISPC*	**"New developments on simultaneous MA-XRD/MA-XRF imaging: instrumental setup and computational approaches for pigment-specific mapping of paintings"** Francesco Paolo Romano, Costanza Miliani, Claudia Caliri, Claudia Fatuzzo, Danilo Pavone, Giulia Privitera, Dario Zappalà & Zdenek Preisler
16:10-16:30	**Juan José Murillo Fuentes** *University of Sevilla*	**"Crossings Segmentation in Plain Weaves for X-Rays of Canvases with Deep Learning"** Antonio D. Bejarano, Juan José Murillo-Fuentes & Laura Alba-Carcelén
	Poster & Demonstration Session 1	
16:30-17:30	*See list on p. 25*	

Computational approaches for technical imaging in cultural heritage (7th IP4AI meeting) Programme

27-29th April, 2022

Time, BST (UTC +1)	Speaker	Title
		Thursday, 28th April
	Panel Discussion	**Moderator:** Ingrid Daubechies, *Duke University*
14:00-14:55	**Jill Dunkerton** *National Gallery, London* **Ahmed Elgammal** *Rutgers University* **Robert G. Erdmann** *Rijksmuseum/ University of Amsterdam* **Haida Liang** *Nottingham Trent University* **Marc Walton** *M+ Museum, Hong Kong/ Northwestern University*	**The role of AI for art investigation** With the increasing use of a range of advanced technical imaging and spectroscopic imaging methods in the study and preservation of artworks and other cultural heritage artefacts and drives to digitise and share archives, collections and associated materials, there is growing interest in – and need for – computational approaches to exploit and explore this data. This conference includes many exciting uses of machine learning and AI approaches in the heritage/cultural sector and for art investigation for particular applications. However, the use of such approaches is not without problems and their critics. As we look to the future, is the heritage/cultural sector ready for AI / ML and are data scientists ready for the challenges in art investigation and art history? In this session we hope to explore and encourage an open discussion of some of the challenges and benefits of ML and AI for art investigation and how experts – from both the cultural and heritage sectors and data sciences – might interact with each other and with machines.
14:55-15:00	*Short break*	
	Keynote 2	**Chair:** Pier Luigi Dragotti, *Imperial College London*
15:00-16:00	**Haida Liang** *Nottingham Trent University*	**"AI for DIGILAB: A Heritage Materials Research Infrastructure for Multimodal Spectral Imaging Data Processing"**
	Oral Presentation Session 2	**Chair:** Pier Luigi Dragotti, *Imperial College London*
16:00-16:20	**Marta Melchiorre** *National Gallery, London* **Sotiria Kogou** *Nottingham Trent University*	**"Application of a novel neural network approach to investigate the painting materials and technique in *The Adoration of the Kings* by Sandro Botticelli and Filippino Lippi"** Marta Melchiorre Di Crescenzo, Sotiria Kogou, Luke Butler, Florence Liggins, Haida Liang & Catherine Higgitt
16:20-16:40	**Niranjan Thanikachalam** *Artmyn SA*	**"Multimodal image change analysis for artwork monitoring"** Niranjan Thanikachalam, Pierre-Antoine Héritier & Loïc Baboulaz
16:40-17:00	**Matthias Alfeld** *TU Delft*	**"DataHandlerP: An open access software package for the analysis of spectroscopic imaging data"** Matthias Alfeld & Luís Manuel de Almeida Nieto

Computational approaches for technical imaging in cultural heritage
(7th IP4AI meeting) Programme
27-29th April, 2022

Time, BST (UTC +1)	Speaker	Title
	Friday, 29th April	
	Poster & Demonstration Session 2	
13:30-14:30	*See list on p. 25*	
	Keynote 3	**Chair:** Miguel Rodrigues, *University College London*
14:30-15:30	**Marc Walton** *M+ Museum, Hong Kong/ Northwestern University*	**"Creating Images Worth More Than A Thousand Words: Computational Imaging for Cultural Heritage"**
15:30-15:35	*Short break*	
	Oral Presentation Session 3	**Chair:** Miguel Rodrigues, *University College London*
15:35-15:55	**Su Yan** *Imperial College London*	**"Automatic Algorithms for Deconvoluting Macro X-ray Fluorescence Data"** Su Yan, Jun-Jie Huang, Herman Verinaz-Jadan, Nathan Daly, Catherine Higgitt & Pier Luigi Dragotti
15:55-16:15	**Emeline Pouyet** *CNRS, Sorbonne University*	**"Artificial Intelligence for Pigment Classification Task in the Short-Wave Infrared Range"** Emeline Pouyet, Tsveta Miteva, Neda Rohani & Laurence de Viguerie
16:15-16:35	**Silvia Russo** *HE-Arc CR, Neuchâtel*	**"Monitoring metal soaps formation on painted metals: challenges in processing reflectance FTIR time-series chemical images in absence of sharp features"** Silvia Russo, Jean Baptiste Thomas, Laura Brambilla & Edith Joseph
16:35-16:55	**Patrice Abry** *ENS Lyon*	**"Multiscale anisotropic analysis for assessment of similarity between Arches papers in selected Matisse lithographs"** Patrice Abry, Stéphane Roux, Paul Messier, Margaret Holben Ellis & Stéphane Jaffard
16:55-17:00	*Conference closing remarks*	

WEDNESDAY 27th APRIL 2022

KEYNOTE 1

JILL DUNKERTON studied fine art at Winchester and Goldsmiths' Schools of Art, history of art (MA) at the Courtauld Institute, and paintings conservation at the Tate Gallery and Courtauld Institute. She has worked as a restorer at the National Gallery since 1980, specialising in particular on the restoration of paintings from the fourteenth to the sixteenth centuries. She has also written and lectured widely on the restoration and techniques of paintings of this period. Publications include co-authorship of *Art in the Making: Italian Painting before 1400* (1989), *Giotto to Dürer: Early Renaissance Painting in the National Gallery* (1991), *Making and Meaning: The Young Michelangelo* (1994), *Dürer to Veronese: Sixteenth-Century Painting in the National Gallery* (1999), *Art in the Making. Underdrawing in Renaissance Paintings* (2002), as well as contributions to catalogues of exhibitions at the National Gallery and in the United States and Italy, and articles in the *National Gallery Technical Bulletin*, *The Burlington Magazine*, *OPD Restauro* and other journals.

Technical imaging and connoisseurship: investigating a collaboration between Botticelli and Filippino Lippi

Jill Dunkerton, National Gallery, London

WEDNESDAY 27th APRIL 2022

Oral presentation Session 1

An alternative approach to mapping pigments in paintings with hyperspectral reflectance image cubes using artificial intelligence

*Tania Kleynhans,(1) **John K. Delaney**,(1,2) Roxanne Radpour,(2) Catherine M. Schmidt Patterson,(3) and Kathryn A. Dooley (2)*

(1) Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Lomb Memorial Drive, 14623 Rochester, NY, USA.
(2) National Gallery of Art, 6th and Constitution Avenue NW, 20565 Washington, DC, USA.
(3) Getty Conservation Institute, 1200 Getty Center Drive, 90049 Los Angeles, CA, USA.

Spectral imaging modalities, including reflectance and X-ray fluorescence, play an important role in conservation science. In reflectance hyperspectral imaging, the data are classified into areas having similar spectra and turned into labeled pigment maps using spectral features and fusing with other information. Direct classification and labeling remain challenging because many paints are intimate pigment mixtures that require a non-linear unmixing model for a robust solution. Neural networks have been successful in modeling non-linear mixtures in remote sensing with large training datasets. For paintings, however, existing spectral databases are small and do not encompass the diversity encountered. Given that painting practices are relatively consistent within schools of artistic practices, we tested the suitability of using reflectance spectra from a subgroup of well-characterized paintings to build a large database to train a one-dimensional (spectral) convolutional neural network. The labeled pigment maps produced were found to be robust within similar styles of paintings. Originally this algorithm was developed using visible to near reflectance image cubes (VNIR, 400 to 1000 nm) of illuminations from the Laudario of Sant'Agnese. In this talk we present new results of testing this approach to directly classifying pigments using this methodology on VNIR reflectance image cubes from thirteen illuminations attributed to the Master of the Cypresses working in Spain (c. 1440) as well how this approach can be generalized.

WEDNESDAY 27th APRIL 2022

Revealing the unreadable – digitisation without disruption

David Mills

Lecturer in imaging and mineralised tissues, Queen Mary University London.

Damaged, sealed or otherwise unopenable manuscripts, letters and scrolls exist in collections around the world. In recent years, the x-ray microtomography group at Queen Mary University of London and other similar groups in the US and Italy have been using High dynamic range, high-contrast X-Ray Microtomography to image selected sealed or damaged items as a way to reveal their content without disrupting them by opening or other interventive actions.

The result of the tomography scanning process is a volumetric data file - effectively a 3D image. The volumetric data contains both the physical structure of the document as well as the text encoded in shades of grey in the data. The structure and the text can be recovered from the volumetric data with existing algorithms, or new software can be created to perform text extraction if existing software is unsuitable, once the scan has been performed. There is no need to scan the items again. Virtual item structure, like scrolls, can be used to inform any conservation efforts, highlighting internal holes, security locks or seals.

We show in this paper that content recovery and item structures from different collections illustrates how this form of digitisation is not a simple one-size-fits-all process. It can be a research activity in itself, involving many different disciplines and is a focus of genuinely interdisciplinary investigation. We use computational approaches to fully realise the potential from the scanned data, sometimes automating aspects of the processing and interpretation of the data and address research questions in a variety of disciplines including history, music, religion, cinematography and conservation.

We present results from sealed letters, water and fire damaged parchment rolls, sealed paper and parchment bundles and degraded cellulose acetate cine film.

Brief summary of the work: We have used high contrast, high definition time-delay integration x-ray microtomography to image a diverse range of heritage items and worked with computer scientists to reveal the hidden content of the items.

References:

1. Dambrogio, J. et al. ‘Unlocking history through automated virtual unfolding of sealed documents imaged by X-ray microtomography’. *Nat Commun* 12, 1184 (2021).
2. Rosin, P. L. et al. ‘Virtual Recovery of Content from X-Ray Micro-Tomography Scans of Damaged Historic Scrolls’. *Sci. Rep*. 8, 11901 (2018).
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WEDNESDAY 27th APRIL 2022

New developments on simultaneous MA-XRD/MA-XRF imaging: instrumental setup and computational approaches for pigment-specific mapping of paintings

Francesco Paolo Romano,*(1) Costanza Miliani,(1,2) Claudia Caliri,(1) Claudia Fatuzzo,(1) Danilo Pavone,(1) Giulia Privitera,(2,3) Dario Zappalà,(1) and Zdenek Preisler (1)*

(1) CNR-ISPC, Via Biblioteca 4, 95124 Catania, Italy
(2) University of Catania, Via Santa Sofia 64, 95123, Catania, Italy
(3) CNR-ISPC, Via Cardinale Sanfelice 8, 80134 Napoli, Italy

Pigments often present a polycrystalline nature and X-ray powder diffraction (XRPD) can be used for their direct identification even in the case of complex mixtures. The use of XRPD with imaging capabilities in macroscopic painted contexts is still an emerging research field. The impressive potential of the technique in painting investigation and conservation has been recently demonstrated by the advances of the MA-XRD device developed at the TU Antwerp [1].

This work presents a novel MA-XRD/MA-XRF system developed at the XRAYLab of ISPC-CNR in Catania. The main component of the device is a measurement-head consisting of a microfocus Cu-anode source coupled to a slightly focusing polycapillary and two X-ray detectors for recording both XRD patterns and XRF spectra simultaneously on the same irradiated spot. A mechatronic device moves the measurement-head in 1 mm steps along the XY directions. A total area of 50 x 50 cm^2 can be covered in one scan. A laser distance sensor controls an ancillary Z axis to keep the focus position pixel-by-pixel during the scanning allowing us to measure paintings even with an irregular morphology. The device operates XRD measurements in a parafocusing geometry. Diffraction patterns are collected in one-shot with a 1D microstrip single-photon-counting detector covering an angular range of 16-44 deg (2θ). Angular resolution in the diffraction patterns is about 0.25 deg and typical dwell-time per pixel is about 3 s. In parallel, a SDD detector collects the fluorescence spectra on the same irradiated spot allowing to combine XRF and XRD distribution maps during the analysis.

For one scanning session several tens of thousands of XRD patterns are recorded and misalignments caused by the sample morphology or by the layered structure of the pictorial composition are often observed. Given the number of patterns, a manual analysis of the full dataset (i.e., pixel-per-pixel theta-shift correction, pattern calibration and crystalline phase identification) is not feasible. Hence, we have modeled the measurement geometry with its characterizing parameters, and we have developed a custom-built minimization routine for the automatic pixel-per-pixel analysis including the search-match phase identification to create pigment-specific distribution maps of the painting under study. MA-XRF data are used to inform the analysis during the search-match procedure. In parallel, we have extended the methodology to determine the crystalline phases distribution maps using deep learning approaches. A preliminary training of the convolutional network is performed on synthetic data generated using tabulated diffraction lines of the commonly used pigments augmented to resemble our experimental measurement. A comparison of the conventional and AI/ML methodology is given and some results on compelling application in painting analysis are presented and discussed.

References

1. F. Vanmeert, et al., *Analytical Chemistry*, 2018, 90, 11, 6436-6444.

WEDNESDAY 27th APRIL 2022

Crossings Segmentation in Plain Weaves for X-Rays of Canvases with Deep Learning

Antonio D. Bejarano,(1) ***Juan José Murillo-Fuentes****,(1) and Laura Alba-Carcelén (2)*

(1) Dept. Teoría de la Señal y Comunicaciones, Univ. de Sevilla Spain, Email: murillo@us.es
(2) Dept. Restauracíon, Museo Nacional del Prado, Spain

MOTIVATION

The density of threads in plain weave fabrics of paintings has been widely studied to help in the forensic analysis of paintings. In the literature we find that the Fourier transform (FT) has been successfully applied to this problem [1,2], usually by means of X-plates. However, we found that the FT fails whenever threads are of different widths and for some fabrics where one direction, usually the warp, is predominant and the other is just perceived as a widening at the cross points.

To overcome this problem we can resort to thread counting in the spatial domain. In [3] the authors present a Bayesian tool to predict the position of the cross points between warp and weft. However, this approach quite depends on the labelling, i.e., it is needed to label some cross points in the canvas under study. In this scenario we propose to use other machine learning tools, namely deep learning, to perform a segmentation of the cross points. The pipeline of the solution is as follows.

PROPOSAL

Data Acquisition: We first selected 34 X-rays of paintings, from the Museo del Prado and more than 13 different painters. In this heterogeneous set we have plain wave of different densities from 6 to 23 threads per cm. They also present different resolutions ranging from 79 to 200 pixels per cm (ppc). We developed a library of functions to preprocess them and get some square crops, of 200 ppc and side 1,5 cm. A number of 219 crops were labeled. From every labeled crop 42 labeled instances of side 1 cm, i.e. 200 pixels, were generated as parts of the whole patch and then rotating and flipping them. This set, of 9198 samples, was partitioned into training, validation and test groups, where all instances from one painting were included in just one of them.

Model Design: Our goal is to detect the cross points between warp and weft. The segmentation approach was exploited and the Unet network was used with convolutional 5 layers with relu activation functions. The sigmoid was used in the last layer. The binary cross entropy was used as loss function and the Adam gradient descent approach was used to train the model along 30 epochs. This model was also modified to adopt the inception paradigm.

APLICATION TO THREAD COUNTING

A direct application of this cross point detection is to the estimation of the density of vertical and horizontal threads. However we need to translate the segmentation result into densities. We propose an approach where nearest points in the horizontal and vertical directions are found and average separation is used to derive the densities. This, applied to patches of 1 cm side along the whole X-ray plate provides the densities maps for the vertical and horizontal threads. We successfully applied this to a canvases by Manuel de Pret and Velázquez, with good results compared to the FT algorithm, see Figure 1.

WEDNESDAY 27th APRIL 2022

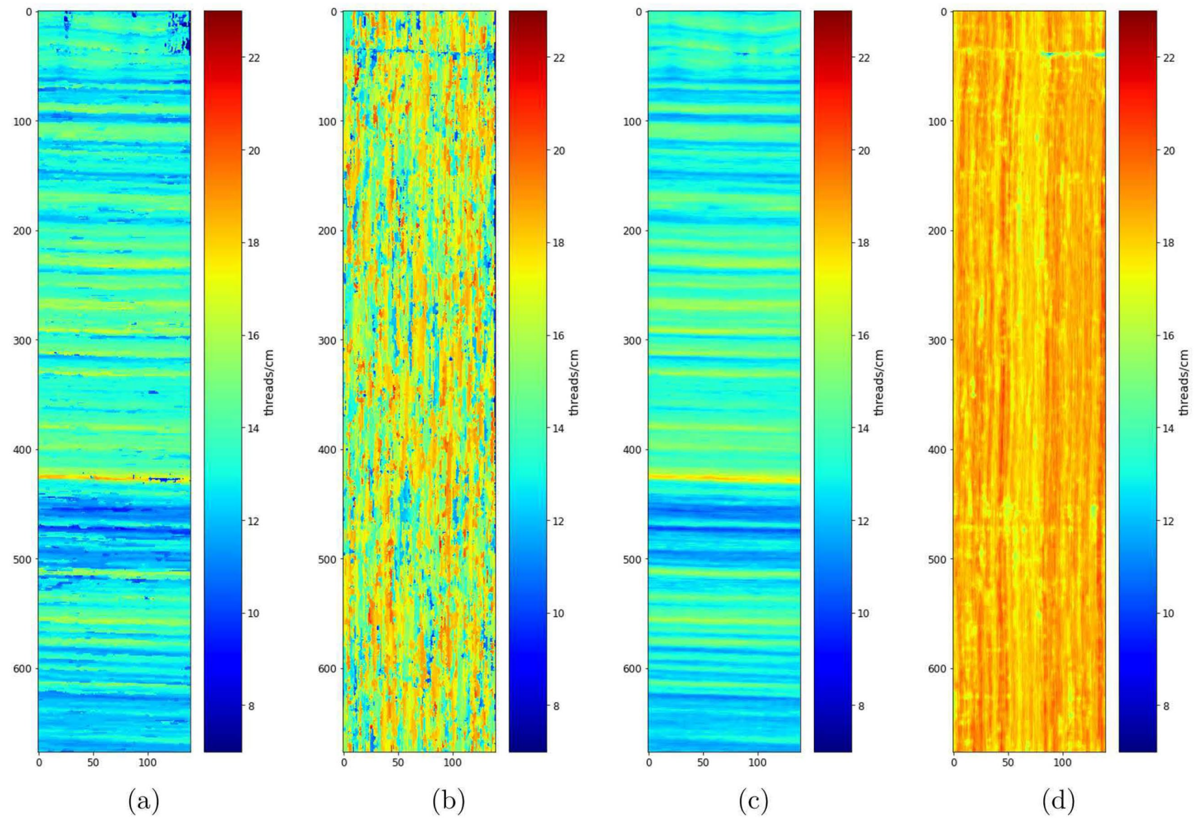

Figure 1: Horizontal and vertical threads density estimation for a region of the 'Prince Baltasar Carlos' by Velázquez with: (a)-(b) FT (c) -(d) DL segmentation with inception and spatial counting.

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1. D. H. Johnson, C. R. J. Jr., and R. G. Erdmann, "Weave analysis of paintings on canvas from radiographs", *Signal Processing*, vol. 93, pp. 527- 540, 2013.
2. F. J. Simois and J. J. Murillo-Fuentes, "On the power spectral density applied to the analysis of old canvases", *Signal Processing*, vol. 143, pp. 253 - 268, 2018. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0165168417302888
3. L. Maaten and R. G. Erdmann, "Automatic thread-level canvas analysis: A machine-learning approach to analyzing the canvas of paintings", *IEEE Signal Process. Mag.*, 2015.

Acknowledgments: Thanks to Consejería de Economía y Conocimiento, Junta de Andalucía and European Union in the framework of the Program FEDER Andalucía "Crecimiento inteligente: una economía basada en el conocimiento y la innovación" for funding this research under the ATENEA Project P20 01216.

THURSDAY 28th APRIL 2022

PANEL DISCUSSION

The role of AI for art investigation

Panel members:

Jill Dunkerton, *National Gallery, London*

Ahmed Elgammal, *Rutgers University*

Robert G. Erdmann, *Rijksmuseum/University of Amsterdam*

Haida Liang, *Nottingham Trent University*

Marc Walton, *M+ Museum, Hong Kong/Northwestern University*

Panel moderator:

Ingrid Daubechies, *Duke University*

With the increasing use of a range of advanced technical imaging and spectroscopic imaging methods in the study and preservation of artworks and other cultural heritage artefacts and drives to digitise and share archives, collections and associated materials, there is growing interest in – and need for – computational approaches to exploit and explore this data. This conference includes many exciting uses of machine learning and AI approaches in the heritage/cultural sector and for art investigation for particular applications. However, the use of such approaches is not without problems and their critics. As we look to the future, is the heritage/cultural sector ready for AI / ML and are data scientists ready for the challenges in art investigation and art history? In this session we hope to explore and encourage an open discussion of some of the challenges and benefits of ML and AI for art investigation and how experts – from both the cultural and heritage sectors and data sciences – might interact with each other and with machines.

THURSDAY 28th APRIL 2022

KEYNOTE 2

PROFESSOR HAIDA LIANG is Distinguished Professor at Nottingham Trent University, Department of Physics of Maths, Head of Imaging and Sensing for Archaeology, Art history and Conservation (ISAAC) Lab, and Director of Imaging, Materials and Engineering Centre (IMEC). She studied Physics at University of Sydney followed by a PhD in Astrophysics at Australian National University. She continued her research in astrophysics at CEA and IAS in France and at the University of Bristol before changing her research career to heritage science after a brief period at the National Gallery in London. ISAAC Lab is focussed on the development of non-invasive imaging, spectroscopy and remote sensing instruments and data science methods for cultural heritage research and practice, as well as interdisciplinary research in art conservation, history and archaeology, which led to the recent Queen's Anniversary Prize for Advancing Cultural Heritage Science. Her research interest also includes interdisciplinary research in historical global connections including both the terrestrial and maritime Silk Roads.

AI for DIGILAB: A Heritage Materials Research Infrastructure for Multimodal Spectral Imaging Data Processing

Haida Liang, Nottingham Trent University

THURSDAY 28th APRIL 2022

Oral presentation Session 2

Application of a novel neural network approach to investigate the painting materials and technique in The Adoration of the Kings by Sandro Botticelli and Filippino Lippi

Marta Melchiorre Di Crescenzo,(1) Sotiria Kogou,(2) Luke Butler,(2) Florence Liggins,(2) Haida Liang,(2) and Catherine Higgitt (1)

(1) Scientific Department, National Gallery, London, UK
(2) School of Science and Technology, Nottingham Trent University, Nottingham, UK

The Adoration of the Kings (about 1472, NG592, National Gallery London), a masterpiece resulting from a collaboration between Sandro Botticelli and Filippino Lippi, has been recently the centre of a thorough investigation aimed at clarifying the likely sequence of events in the painting's execution [1] Within this study, the painting was investigated using macro-X-ray fluorescence scanning (MA-XRF) and short-wave infrared (SWIR) reflectance hyperspectral imaging.

The benefits of these two spectral imaging techniques on the analysis of easel paintings are well-acknowledged. However, the methods traditionally used for the post-processing and interpretation of the spectral imaging data often require the operator's input in many stages of the analysis, which may result in time-consuming data-processing procedures, with potentially biased and/or incomplete outcomes.

This presentation focuses on a novel processing approach, which uses a clustering method based on self-organising map (SOM), an unsupervised artificial neural network, to provide automatic and time-efficient interpretation of the various spectral imaging datasets [2, 3].

Building on previous research, the results of this new clustering approach are used to investigate the working relationship between Botticelli and Filippino even further, proving to be particularly useful to identify and map the use of different batches of green and blue copper mineral pigments available within their workshop.

This research was carried out within the AHRC UK-US project 'AI for Digilab: A new concept in digital infrastructure for heritage materials research', testing the potential of a completely remote data analysis laboratory for automated processing of complex multi-modal spectral imaging datasets.

References

1. J. Dunkerton, C. Higgitt, M. Melchiorre Di Crescenzo and R. Billinge, 'A Case of Collaboration: The Adoration of the Kings by Botticelli and Filippino Lippi. Part II: Investigating the collaboration', *National Gallery Technical Bulletin*, 41, 2021, pp. 27-59
2. S. Kogou, L. Lee, G. Shahtahmassebi and H. Liang, 'A new approach to the interpretation of XRF spectral imaging data using neural networks', *X-ray spectrometry*, 50, 2021, 310-19 (doi:10.1002/xrs.3188)
3. S. Kogou, G. Shahtahmassebi, A. Lucian, H. Liang, B. Shui, W. Zhang, B. Su and S. van Schaik, 'From remote sensing and machine learning to the history of the Silk Road: large scale material identification on wall paintings', *Scientific Reports* 10, 2020, 19312

THURSDAY 28th APRIL 2022

Multimodal image change analysis for artwork monitoring

Niranjan Thanikachalam, *Pierre-Antoine Héritier and Loïc Baboulaz*

Artmyn SA

From medical imaging to aerial remote sensing, capturing multimodal images over two instant in time allows monitoring changes of an observed subject. One challenge is to remove natural geometrical deformation and modality variances in order to detect only meaningful changes [Jia+21].

We present a framework for detecting changes in artworks over time. Previous works [Cor+13][Dul+19][Siz+20] focused on detecting damages from a single acquisition of an artwork. Our aim however is to monitor the condition of an artwork and identify critical changes from multi-temporal multimodal images. Some initial results were presented in [Hér+20].

The available multimodal data are high resolution images under visible light, near infrared light, and ultraviolet fluorescence from which artwork reflectance and surface geometry are computed. Given at least two temporal acquisitions, our methodology includes three stages: 1. Deformation correction, 2. Local feature extraction 3. Anomaly detection. The deformation map yields a model of global changes in the artwork while the predictions from the final step yields a model of local changes.

In the first step, we align and warp the two acquisitions to get pixel to pixel correspondence. After correction with affine transformation between the two acquisitions, we perform a customized optical-flow unwarping to correct for non-rigid deformations arising from sagging or other geometric deformations of the canvas due to different frame tightening. We then rotate normals and reflectances of the second acquisition relative to the first one as defined by the deformation map.

After geometrical correction, we assume that pixels in both images now correspond to the same physical points on the artwork. We can now define features that capture changes between the two acquisitions. From the visible, NIR and UV images, we obtain spatial features from steerable directional filters, multiscale morphological Top-Hat operators and a relative difference image. From reflectance, we compute a pixel-wise similarity metric. From surface topography, we calculate relative differences in geometric and mean curvatures, angles between normals as well as relative difference in the heightmap.

The final step is to detect meaningful changes. Due to the lack of quality labeled data in reasonable volumes at this stage, we propose using unsupervised learning techniques. We begin by pooling features from a random 10% subset of pixels from the original scans, which usually results in 4-9M data points. We then learn an anomaly detection model on this dataset using either Extended Isolation Forest [HKB21] or Copula-Based Outlier Detection [Li+20]. We then predict the probability that each pixel in the deformation-corrected painting is an anomaly.

We validate our framework by digitizing artworks before and after an art expert applied modifications to them. Those modifications were designed to simulate common changes from restoration or damages. Those blind experiments showed our framework can reliably detect 10 out of 11 classes of changes. In the future we envision our framework to be used by experts for quickly identifying damages and creating digital condition reports. We would also like to develop a supervised and semi-supervised anomaly detection model from a comprehensive labeled dataset of artwork damages.

THURSDAY 28th APRIL 2022

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[Dul+19] Tinsae Gebrechristos Dulecha et al. “Crack Detection in Single- and Multi-Light Images of Painted Surfaces using Convolutional Neural Networks”. In: *Eurographics Workshop on Graphics and Cultural Heritage*. The Eurographics Association, 2019. isbn: 978-3-03868- 082-6. doi: 10.2312/gch.20191347.

[Hér+20] Pierre-Antoine Héritier et al. “Monitoreo y detección de craquelado, grieta y falta de adhesión”. In: 21ª *Jornada de Conservación de Arte Contemporáneo*. 2020.

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THURSDAY 28th APRIL 2022

DataHandlerP: An open access software package for the analysis of spectroscopic imaging data

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In the investigation of cultural heritage objects by spectroscopic imaging one faces two challenges: The need for a rapid (if preliminary) evaluation of data and the lack of suitable algorithms for it. This data evaluation takes in general the form of data driven machine learning techniques, such as matrix factorization, highlighting correlations, reducing redundancies and de-noising the data.

Preliminary data evaluation is needed to verify the quality of the acquired data and guide the next steps during a measurement campaign. While this is possible by dedicated scripts written in, e.g., Python, these scripts miss, in general, an interactive character for the inspection of details and can only be modified by specialists. A Graphical User Interface (GUI) would be a suitable solution for this problem.

Cultural heritage objects are often more complex in shape, composition and stratigraphy than samples in other fields of science. Consequently, the algorithms developed for such "simple" cases can yield distorted or illegible results when applied in cultural heritage studies. In this case dedicated solutions must be found: the weights of the spectra need to be set on relevant features for matrix factorization techniques and data sets need to be cropped to avoid areas "off sample". These are solutions that can be implemented by directly programming them, but this is, again, not interactive and also limited to a few specialists.

In order to overcome these limitations we developed in the last years a number of interactive tools for the processing of complex hyperspectral data sets and collected them in a GUI based software package called "Data Handler P(aris)". It is available online as an open source project: https://sourceforge.net/projects/datahandlerp/

We would like to use the opportunity to draw attention to this user friendly and easily modifiable software and to demonstrate its capabilities. We have used it in the past in various studies, mainly for the treatment of Reflectance Imaging Spectroscopy (RIS) data in the visible and near Infrared range (VNIR, 400-1000 nm) and Macroscopic XRF imaging (MA-XRF): hard clustering of RIS of an illuminated manuscript by manual selection of endmembers [1], linear regression of reflectance spectra to visualize remnants of faded pigments on antique statues [2], the registration, alignment and fusion of multimodal data (XRF and RIS) acquired in the Theban Necropolis in Egypt and their hard clustering [3] and the automatic detection of endmembers in MA-XRF data of historical paintings [4].

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FRIDAY 29th APRIL 2022

KEYNOTE 3

MARC WALTON is currently the Head of Conservation and Research at the M+ Museum in Hong Kong. Before assuming this role, he was Co-Director of Northwestern University / Art Institute of Chicago Center for Scientific Studies in the Arts (NU-ACCESS) and a Research Professor of Materials Science and Engineering at Northwestern University (2013-2021). Marc earned a D.Phil. from the University of Oxford following an M.A. in art history and a diploma in the conservation of works of art from the Institute of Fine Arts, New York University. Following his doctorate, Marc worked as an Associate Scientist at the Los Angeles County Museum of Art for two years before joining the Getty Conservation Institute in 2005. There he established and ran an analytical laboratory dedicated to the analysis of ancient works of art and artifacts. Marc has since led multiple scientific research projects to investigate art objects in collaboration with cultural heritage institutions representing a broad spectrum of disciplines (from anthropology to contemporary art) and geographical reach (both U.S. and internationally). He has pioneered the development of computational imaging technologies bespoke for conservation science, resulting in over 100 peer-reviewed articles.

Creating Images Worth More Than A Thousand Words: Computational Imaging for Cultural Heritage

Marc Walton, M+ Museum, Hong Kong/Northwestern University

This contribution will discuss the aims and goals of the emerging field of computational imaging and how this research area has influenced the way we look at and study art objects. In recent years, there have been unprecedented advances in scientific imaging hardware engineered with end-to-end integration of image processing and data fusion methods, resulting in new ways to acquire and view images of artworks. Case studies collected from research conducted over the last eight years will be used to demonstrate how computer science and electrical engineering may be leveraged to undertake scientific imaging of artworks.

FRIDAY 29th APRIL 2022

Oral presentation Session 3

Automatic Algorithms for Deconvoluting Macro X-ray Fluorescence Data

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(3) Scientific Department, The National Gallery, London

Macro X-ray Fluorescence (MA-XRF) scanning is an increasingly widely used imaging techniques to non-invasively analyse old master paintings and other artworks. The collected MA-XRF datacube must be processed to produce maps showing the distribution of the chemical elements that are present in the painting, which is a task called MA-XRF deconvolution. Existing approaches for MA-XRF deconvolution require varying degrees of intervention from expert users, in particular to select a list of target elements against which to fit the data. However, the resulting element distribution maps can sometimes be completely different if the precise selection of elements changes, making the results inconsistent. As a result, the manual input form the users affects the accuracy of the final results. To address this problem, we have proposed two automatic methods that can deconvolute the MA-XRF datacube collected from oil paintings without the requirement of additional user intervention.

Our first method is based on Finite Rate of Innovation (FRI) sampling theory to estimate the locations of the spectral pulses corresponding to different chemical elements. The proposed approach consists of three parts: 1) pre-processing steps, 2) pulse detection and model order selection based on FRI theory and 3) chemical element estimation based on Cramér-Rao bounding techniques. The proposed method operates pixel by pixel and generates not only a quantity distribution map for each chemical element, but also a confidence distribution map showing the confidence that we have correctly allocated a pulse to that chemical element.

Our second method proposes to deconvolute the MA-XRF datacube automatically but also quickly. With the help of our FRI-based element pulse detection algorithm, we can model the MA-XRF datacube as a multiplication of the pulse shape matrix and the desired element quantity matrix, which contains the distribution maps for all chemical elements present in the painting. This enables us to convert MA-XRF deconvolution into a matrix factorisation inverse problem with additional constraints. To solve this inverse problem, we propose a fast optimisation approach inspired by the fast iterative shrinkage-thresholding algorithm (FISTA).

The performances of our two proposed methods are assessed using MA-XRF datacubes acquired from old master paintings in the collection of the National Gallery, London. First of all, the results show that both of our proposed methods are able to automatically deconvolute the MA-XRF datacubes and produce the distribution maps of the chemical elements that are present in the paintings, without the requirement of additional user intervention. The results from our FRI-based pixelwise method show the ability to detect elements with weak X-ray fluorescence intensity and from noisy XRF spectra, to separate overlapping elemental signals and, excitingly, to aid visualisation of hidden underdrawings in a masterpiece by Leonardo da Vinci. Moreover, the results from our FISTA-inspired fast method demonstrate that the processing time required for deconvolution can be significantly reduced.

FRIDAY 29th APRIL 2022

Artificial Intelligence for Pigment Classification Task in the Short-Wave Infrared Range

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Hyperspectral reflectance imaging in the short-wave infrared range (SWIR, "extended NIR", ca. 1000 to 2500 nm) has proven to provide enhanced characterization of paint materials. However, the interpretation of the results remains challenging due to the intrinsic complexity of the SWIR spectra, presenting both broad and narrow absorption features with possible overlaps.

To cope with the high dimensionality and spectral complexity of the datasets acquired in the SWIR domain, one data treatment approach inspired by innovative development in the cultural heritage field has been implemented: the use of a pigment spectral database (extracted from model and historical samples) combined with a deep neural network (DNN). This approach allows for multi-label pigment classification within each pixel of the data cube. The DNN model proposed in the study offers new possibilities in the SWIR range to identify and map pigments in complex materials either for unknown mixtures or multilayered systems. Conventional Spectral Angle Mapping (SAM) and DNN results obtained on both pigment reference samples and a Buddhist painting (thangka) will be compared. The DNN method, based on multiple inputs from mockup and historical paintings used as a training dataset, allows multi-labeling of the different zones and thus a more representative mapping of the pigments of interest.

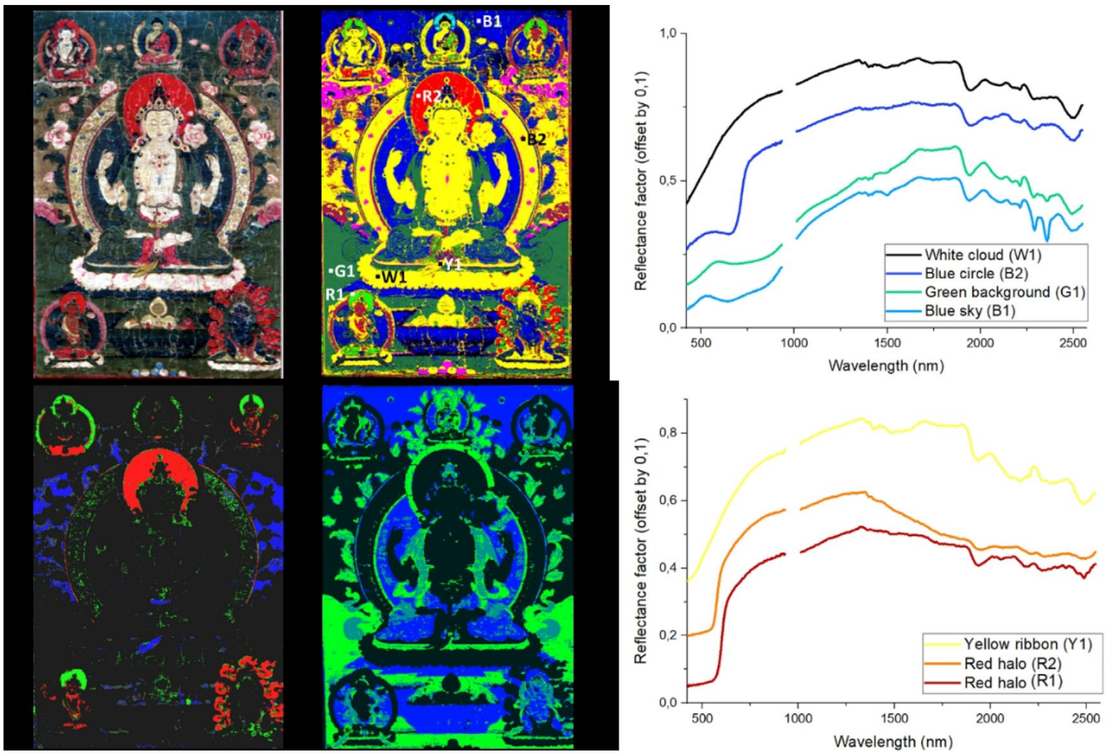

Figure a) Visible picture of the historical tangka analyzed; b) SAM classification of VIS-RIS dataset (red: minium, blue: azurite, light green: vermilion, dark green: malachite, pink: indigo, brown: organic lake - tolerance angle 0.15 rad) with analyzed sites and corresponding reflectance spectra presented in c) and f); DNN model results for d) minium, vermilion, orpiment (in red, green and blue, respectively) and e) azurite and malachite (in blue and green, respectively).

FRIDAY 29th APRIL 2022

Monitoring metal soaps formation on painted metals: challenges in processing reflectance FTIR time-series chemical images in absence of sharp features.

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(3) Norwegian University of Science and Technology (NTNU), Teknologiveien 22, NO-2815 Gjøvik (Norway)

2D chemical imaging in the infrared domain (Fourier transform infrared micro-spectroscopy, µ-FTIR) is a very versatile analytical technique that allows the collection of infrared spectra in an area of interests, providing spectral and spatial information simultaneously. It has been widely utilised in the study of metal soaps formation, a concerning degradation process in traditional oil-painted canvases, that is the product of the reaction between metal ions and free fatty acid in the oil layer [1][2].

In this study, µ-FTIR was utilised to monitor the early-stage formation of metal soaps on painted metals. Here, the metal substrate can act as a source of metal ions in the same way the mineral pigment would do on a painting on canvas [3]. The question of how such interfacial reaction occurs and progresses over time was the main interest of this research.

Model samples consisting on copper and zinc sheets coated with linseed oil were prepared, monitored for 30 days during artificially aging in a laboratory oven at 80°C and 80% relative humidity at first, and then for additional eight months during exposure to environmental conditions.

Some challenges arose in the processing of the collected chemical maps, related to the amount of data to process, handling and manipulation of the data in a controlled way, cropping and selection of regions of interest, alignment of consecutive time images and adaptation of mathematical operations to the shape of the curve (e.g., integration over a peak or band of interest).

A tailored script was developed for the scope of this work, largely built around existing Matlab routines. This programme, which is at its preliminary stage, currently allows for batch analyses of different areas reproducing processing steps in a chain (e.g., integration over multiple peaks of bands of interest, derivative analysis), with the aim of improving processing and results visualization time. Moreover, the problem of small shifting of peaks or bands of interest was taken into consideration and adjusted for in the computation of the area under the signal, a feature that is not present in proprietary software of common use for the processing of FTIR chemical maps. Additional considerations were made on the problem of the alignment of a time sequence of maps of the same area. Due to the repositioning of the sample on the machine stage, in fact, some shifting in the position of consecutive areas could be observed. This is a non-trivial issue, since the system is evolving over time, and only little features can be taken as reference points due to the physical and aesthetical characteristics of the samples. Using the dedicated script, the generated maps could first be aligned in a supervised way by identifying differing number of pixels, then automatically cropped to the minimum common area for better comparison.

Some examples of the application of such algorithms in the analysis of chemical maps acquired on the model samples are presented.

Possible implementations of the script would consist on allowing for multivariate analyses of the maps, and adapting registration algorithms for automatic alignment of chemical maps from raw data.

This research was carried out within the Marie Skłodowska-Curie Innovative Training Networks (ITN) CHANGE Programme (www.change-itn.eu, grant agreement no. 813789).

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FRIDAY 29th APRIL 2022

Multiscale anisotropic analysis for assessment of similarity between Arches papers in selected Matisse lithographs

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(2) Lens Media Lab, Institute for the Preservation of Cultural Heritage, Yale University, USA,
(3) Institute of Fine Arts, New York University, USA.
(4) Laboratoire d'Analyses Mathématiques et Applications, Université de Paris Est, Créteil, France.

This work aims to assess similarities between papers in a selected collection (215) of lithographs on Arches paper dating from 1925 to 1951 by Henri Matisse (31 December 1869 – 3 November 1954). The collection, held by The Pierre and Tana Matisse Foundation, was documented using the texturescope, a technology developed, by P. Messier and collaborators, to permit controlled and reproducible, high resolution, raking light images of paper. Four images (covering 1.0 x 1.5 cm) were made of each lithograph, with perpendicular light angles (vertical and horizontal) on both recto and verso. This dataset of images is augmented by metadata provided by the Foundation including the year of the print, dimensions, edition size, and impression number, as well as measurements of paper thickness made using a digital micrometer.

Using anisotropic multiscale representations (referred to as “the anisotropic wavelet transform”), features are computed from each sample, characterizing the texture across a continuum of scales ranging from tens of squared micrometers to one squared millimeter, with emphasis on anisotropy. These features enable distance computations among samples assessing similarities between pairs of samples. Several different similarity indices are constructed and compared. Figure 1 below illustrates the principle of the construction of these similarity indices.

Figure 1 shows three textures (top row) and the corresponding anisotropic features as functions of (the logarithm of) the scales. The texture anisotropy index is the sum across scales of the (squared) differences of the Horizontal (LH) and Vertical (HL) features. The anisotropy indices (reported above the texture images) show that the left most sample is very different from the two others, which are much more similar.

This work shows the potential of image-processing tools to enhance scholarly research into Matisse’s printmaking practices, both within editions and over time. For example:

- According to conventional practice, Matisse favored printing images on the “felt” side of the paper. This work provides insight into the consistency of this choice.
- The image processing methods quantify the paper texture variation and provide an understanding of paper manufacturer variability, especially after WWII.
- The comparison of paper thickness, another key variable in the manufacturing process, and estimated anisotropies of textures provide another index useful for creating a baseline characterization of the Arches paper used for Matisse’s lithographs.
- The potential of this baseline, and its associated methods, provides a means to understand Matisse’s paper selection process relative to the larger universe of papers available in the mid-20th century.

FRIDAY 29th APRIL 2022

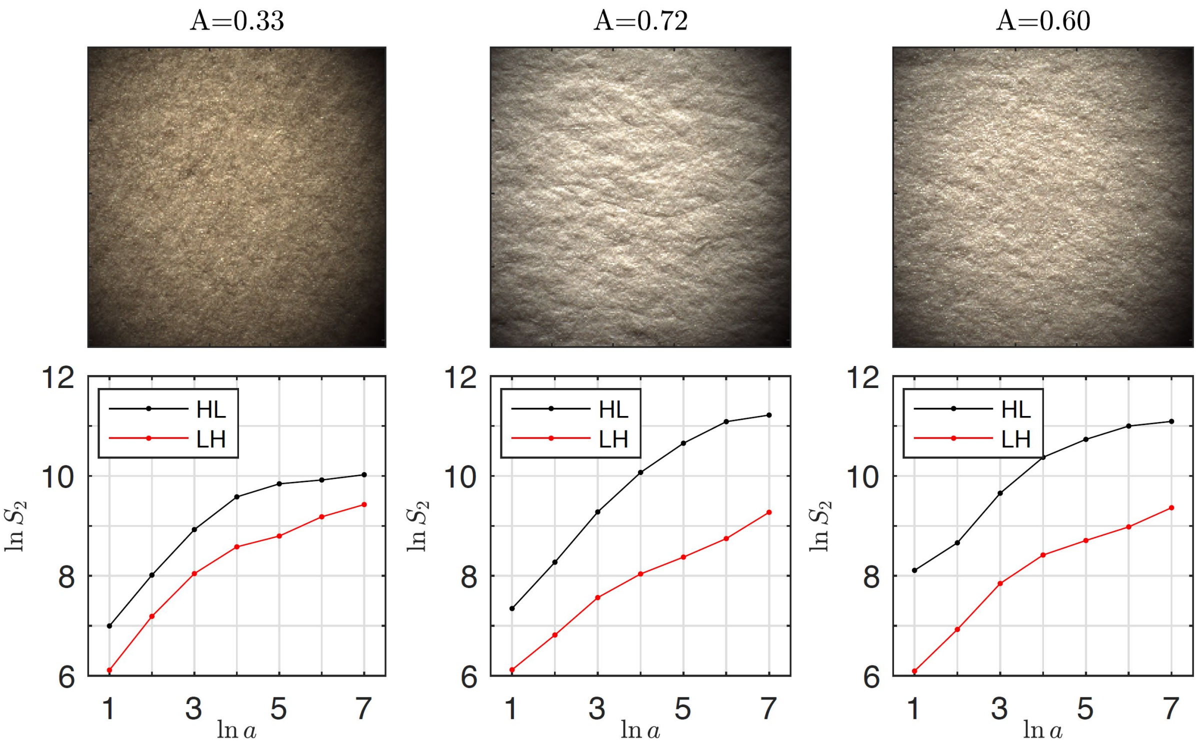

Figure 1. Top: Three different paper textures. Bottom: Anisotropic features as functions of (the logarithm of) the scales (from a few squared micrometers to a few squared millimeters). Computed from these features and reported on top of the texture images, anisotropy indices show that the two textures on the right are closely matched and dissimilar to the one on the left.).

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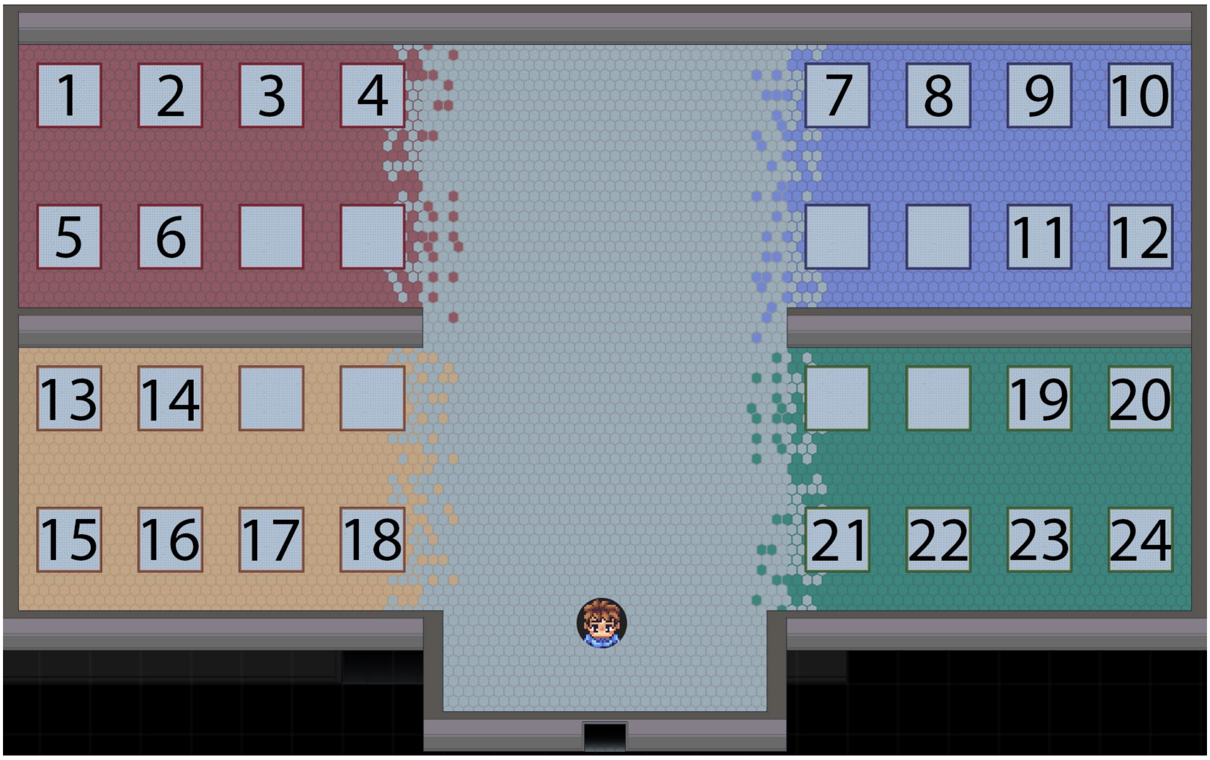
POSTERS

#	**Poster Title**, live presenter, co-authors	**Abstract page**	**Live session(s)** Wed. 27/4, 16:30-17:30 BST (UTC+1)	**Live session(s)** Fri. 29/4, 13:30-14:30 BST (UTC+1)
1	**"DEEP LEARNING MODELS FOR MA-XRF IMAGING SPECTROSCOPY OF PAINTINGS"** Zdenek Preisler, Andrea Busacca, Rosario Andolina, Claudia Caliri, Claudia Fatuzzo, Christine Kimbriel, Giulia Privitera, Costanza Miliani & Francesco Paolo Romano	p. 27	✓	✓
2	**"Multimodal Image Registration of Old Masters Paintings"** Maria Eugenia Villafañe, Su Yan, Junjie Huang, Nathan Daly, Catherine Higgitt & Pier Luigi Dragotti	p. 28 - 29	✓	✓
3	**"The PISTACHIO imager: testing and validation of a new hyperspectral imaging system in the MID-IR"** C.R.T. Young, M. Botticelli, V. Risdonne, M.J. Smith, T. Visser, J.M. Charsley, M. Rutkauskas, Y. Altmann & D.T. Reid	p. 30 - 31	✓	✓
4	**"Conservation and Preservation process of an Islamic jurisprudence Manuscript Includes High Acidity Papers Back to 17th Century"** Ahmed Adel ZWAIN & Simona INSERRA	p. 32	✓	✓
5	**"Investigations into photogrammetry as an accessible 3D measuring tool for monitoring the structural condition of panel paintings"** Christina Cachia	p. 33	✓	X
6	**"Discovering Connections! Analysis of black ink sketches with Uniform Manifold Approximation and Projection"** Rita Wai-tung LIU, Ethel Yi-man LOWE, Gordon King-wai CHIU & May Chui-in LONG	p. 34	X	✓
7	**"Reconstruction of colors from macroscopic X-ray fluorescence for investigation of artworks"** Michal Bartoš, Jan Blažek, Steven De Meyer & Koen Janssens	p. 35 - 37	✓	✓
8	**"Complex Twill Fabrics Pattern Recognition in Canvases"** María del Mar Velasco Montero, Juan José Murillo-Fuentes & Laura Alba-Carcelén	p. 38 - 39	✓	✓
9	**"The Use of Short Wave InfraRed Reflectance Imaging Spectroscopy for Pigment specific mapping"** Luís Manuel de Almeida Nieto, Francesca Gabrieli, Annelies van Loon, Victor Gonzalez, Joris Dik, Matthias Alfeld & Raf Van de Plas	p. 40	✓	✓
10	**"Computed Tomography for cultural heritage: Tailoring X-ray imaging techniques for dendrochronology of large wooden objects"** Francien G. Bossema, Marta Domínguez-Delmás, Willem Jan Palenstijn, Alexander Kostenko, Jan Dorscheid, Sophia Bethany Coban, Erma Hermens & K. Joost Batenburg	p. 41 - 42	✓	✓
11	**"Neural network-based classification of X-ray fluorescence spectra of artists' pigments: an approach leveraging a synthetic dataset created using the fundamental parameters method"** Nathan S. Daly, Cerys Jones, Catherine Higgitt & Miguel R.D. Rodrigues	p. 43	✓	✓
12	**"Mapping the Distribution of Pigments in Paintings Using Macro XRF Element Maps and the Least Squares Method"** Hojung (Ashley) Kwon, Barak Sober & Ingrid Daubechies	p. 44 - 45	✓	✓
13	**"Enhancing Underdrawing Visualization using Adaptive and Localized Image Analysis of Reflectance Hyperspectral Imaging Data from a 15th Century Painting"** Wallace Peaslee, Marta Melchiorre Di Crescenzo, Nathan Daly, Ingrid Daubechies, Shira Faigenbaum-Golovin, Catherine Higgitt & Barak Sober	p. 46 - 48	✓	✓
14	**"Modelling the wet cleaning of museum textiles using FTIR and Principal Component Analysis"** Christopher Foster, Simon Collinson, Alex Forsey & Frances Hartog	p. 49	✓	✓
15	**"Automated mapping of bronze disease in ancient bronze using non-invasive hyperspectral imaging solutions"** Florence Liggins, Alessandra Vichi, Wei Liu, Alex Hogg, Sotiria Kogou, Jianli Chen & Haida Liang	p. 50	✓	✓
16	**"Virtual restoration of the bio-deteriorated image: applied on the gelatin photographs back to 1950s"** Youssef Elreweny, Rasha Shaheen, Abdelrahman M. Elserogy, Shaaban Abd Elaa & Mona Ali	p. 51	✓	✓
17	**"Modelling decay in stone heritage using Machine Learning"** Jonathan Kemp, Kourosh Khoshelham & Zihao Sun	p. 52 - 53	X	X
18	**"Recognizing physical damages from historical documents using a computational model"** Tan Lu & Ann Dooms	p. 54 - 55	✓	X
19	**"Crossings Segmentation in Plain Weaves for X-Rays of Canvases with Deep Learning: Technical Details"** Antonio D. Bejarano, Juan José Murillo-Fuentes & Laura Alba-Carcelén	refer to p. 10 - 11	✓	✓
20	**"Application of scanning microscopy for craquelure analysis"** Sergii Antropov & Łukasz Bratasz	p. 56 - 57	✓	✓
21	**"Automatic Algorithms for Deconvoluting Macro X-ray Fluorescence Data – Software Demonstration"** Su Yan, Frederick McCallum, Jun-Jie Huang, Herman Verinaz-Jadan, Nathan Daly, Catherine Higgitt & Pier Luigi Dragotti	refer to p. 19	✓	✓
22	**"GUISI: Open access data visualisation tool for spectral imaging"** Luke Butler	refer to p. 13 - 14	✓	✓

POSTERS

Poster Room map:



DEEP LEARNING MODELS FOR MA-XRF IMAGING SPECTROSCOPY OF PAINTINGS

Zdenek Preisler(1), Andrea Busacca(1), Rosario Andolina(1), Claudia Caliri(1), Claudia Fatuzzo(1), Christine Kimbriel(2), Giulia Privitera(1,3), Costanza Miliani(1), Francesco Paolo Romano(1)

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The current advancements of non-invasive imaging methods applied for the study and conservation of cultural heritage have driven a rapid development of novel computational methods. MA-XRF is nowadays well-established and often used for the investigation of paintings in museums and conservation studios. However, MA-XRF scanning generates large datasets that can be challenging and time-consuming to analyze. In the following, we employ machine learning approaches as they allow for identification of non-trivial dependencies and classification across the high dimensional data hence promising a more comprehensive interrogation.

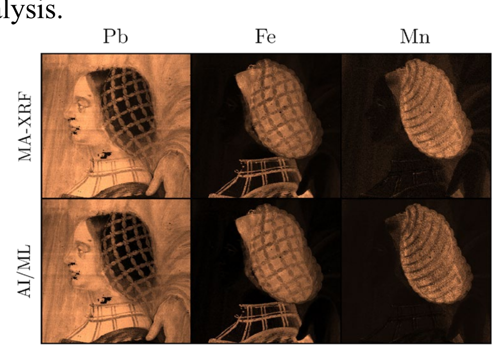
We have developed a novel deep learning model for the MA-XRF imaging spectroscopy. The new proposed methodology is based on standard CNN and ResNet type networks and takes advantage of both synthetic as well as experimental data. In this work, the synthetic data are used for training while the experimental ones are used for testing, evaluation, and as a reference.

The experimental data are taken from previous MA-XRF in-situ investigations of XRAYLab of ISPC- CNR of Catania performed on artworks painted across a range of art periods to include different typologies of pigment materials, and pictorial techniques [1].

The experimental data are used as a guideline to build a consistent synthetic dataset representing XRF spectra of pigments and their mixtures in real artworks. The synthetic XRF spectra are generated by Monte Carlo simulations based on a Fundamental Parameters approach and tuned for the geometry and X-ray source of our MA-XRF setup [2]. Moreover, simulations can be easily generalized for different experimental conditions. The simulations were run with a two-layers painting model representing a preparation layer and mixtures of pigments at the surface. The use of the synthetic data is important because the training is no longer dependent on the classical deconvolution of experimental XRF spectra and allows us to extend the models to work for various measurement settings (i.e., X-ray source parameters, anode material, acquisition time, measurement geometry).

We have optimized the network architecture and their hyperparameters to maximize the performance in terms of speed and accuracy but also to limit the size of the network to make the evaluation possible with conventional GPU-based workstations.

Finally, we show a comparison of the conventional and AI/ML methodology and present current applications in painting analysis.



A comparison of AI/ML results with the ones obtained by the conventional deconvolution of MA-XRF data

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Multimodal Image Registration of Old Masters Paintings

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**The National Gallery London
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In this research, jointly conducted by Imperial College London and The National Gallery London, a method based on mutual information for registration of multimodal technical images of Old Master Paintings is presented. In particular, this work looks at the registration of elemental distribution maps resulting from macro X-Ray Fluorescence (MA-XRF) scanning of paintings, to the visible image of the same artwork, as illustrated in Fig.1. These maps are 2D matrices representing the quantity of a given chemical element detected at each pixel in the MA-XRF datacube.

One common way of addressing image registration is to select tie points in both moving and target images to calculate the transformations to apply to the moving images (here XRF maps), and to obtain, in turn, the correct registration to the target (visible) image of the painting. Most feature matching algorithms in computer vision are designed to find tie points in images of similar levels of brightness and illumination. However, multimodal images may have dissimilar levels of brightness, different image resolutions and different features may also be apparent in the different modalities. Hence, these feature-based algorithms may struggle when validating tie point matches and in providing successful registrations when working with multimodal images. For this reason, instead of relying on detection of individual features, the new approach presented here makes use of metrics that rely on the overall pictorial composition of the working images, and is based on methods utilised in the medical imaging sector designed to allow multimodal image registration based on mutual information.

The method presented here is designed to work with a stack of XRF chemical element distribution maps derived from a full MA-XRF scanning datacube as the moving image and to register the slices of this stack to the visible image of the painting (the target image). The method is based on 4 consecutive “searches”, as illustrated in Fig.2. At each search stage, all transformations within a prescribed range of parameter values are explored. The transformation (similarity, affine or non-rigid) that provides the highest average mutual information across all slices is kept to serve as the starting point for the following search. This allows the best transformations with consensus among all slices to be identified. Each search is more detailed than the previous one, looking at transformations parameters that are progressively more refined. Thus, initially the “distortions” to be applied to the moving image that are being evaluated are quite significant, but become more subtle at each consecutive search. The result is an optimised transformation that can be applied to the moving image to obtain the best alignment between the two images when overlapped. It is important to note that, during the registration process, although each slice is individually assessed to find a best transformation to register that slice to the visible image, the final transformation will be the same for all slices, since they have been acquired simultaneously and are therefore aligned by construction.

The method is currently designed to work with the set of 95 element maps that are the output from the automatic algorithm for chemical element extraction from MA-XRF data recently developed by Imperial College London and The National Gallery London [1]. In particular, it allows for a painting-specific user selection of which element maps (slices) should be considered during the searches and in the identification of the optimal transformation that is then applied to all slices.

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Fig.1 – Moving images (elemental distribution maps derived from six different MA-XRF datacubes) and target image (visible image of the artwork – here Titian's *The Death of Actaeon* (NG6420, image © The National Gallery). Boxes in white indicate the approximate location of each datacube within the target image.

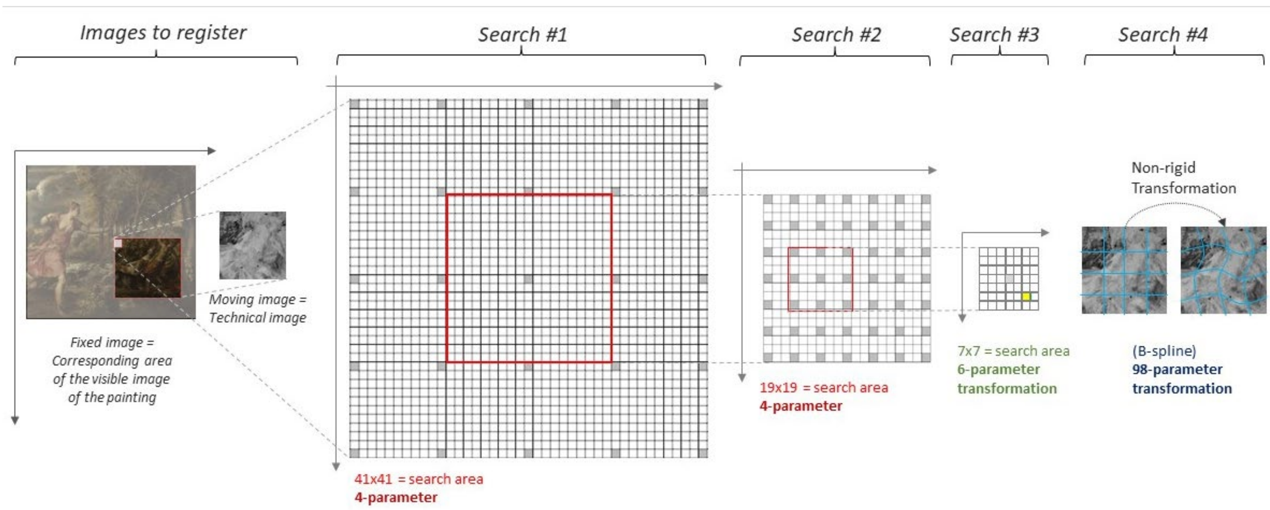

Fig.2 – This sequence illustrates the overall method here presented. The initial working images to register (fixed and moving images) and the 4 searches of progressively increased resolution. Through these searches, the best transformation for registration of each MA-XRF datacube is found.

The PISTACHIO imager: testing and validation of a new hyperspectral imaging system in the MID-IR

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Abstract

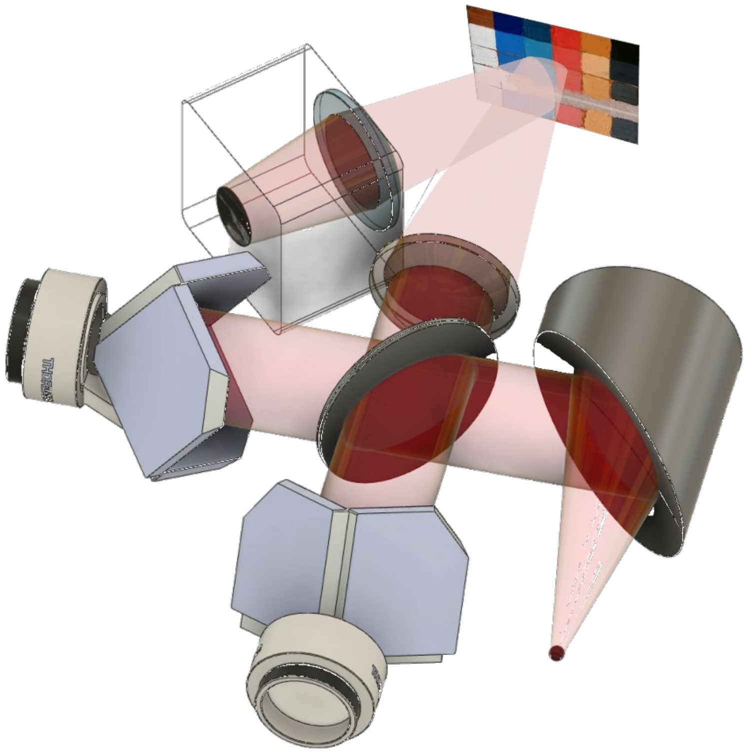
The simultaneous spectral and spatial collection of information from an object using hyperspectral imaging (HSI)[1] has supported interpretation of materials and techniques within Technical Art History and Conservation over the last fifteen years, since it was first introduced to the community. The wavelength range (typically from the visible[2] to the mid-infrared[3]), spatial resolution and field of view mainly depend on the type of detector. Due to the broadness of hyperspectral datasets, data-processing algorithms of varying degrees of complexity are a key-factor in the acquisition and computation time for HSI.

The *Photonic Imaging Strategies for Technical Art History and Conservation* (PISTACHIO) project is a collaboration between Heriot-Watt University and the Kelvin Centre for Conservation and Cultural Heritage Research, Glasgow University. A mid-infrared hyperspectral imager developed in the project[4] has been applied to Cultural Heritage analysis in reflection mode and achieves spectroscopic imaging in the 800–1400-cm^{-1} band with minimal heating of the painted surface, confirmed by monitoring the painting temperature by using a thermal camera (the absorption being pigment specific). Other features of the imager include ease of alignment of the optics and positioning of the object on a motion stage, offering a wide field of view, and the integration of fast acquisition/processing algorithms into a single graphical user interface (GUI).

Here we show results from the first experiments conducted with the PISTACHIO imager on a reconstruction on boxwood with a range of pigments in oil, both representative of the technique of the Glasgow Boy painter D. Y. Cameron (1865-1945), whose paintings form part of The Hunterian collection (Glasgow University) and are currently the focus of PhD research. A comparison of technical and experimental details from the imager and a conventional micro-FTIR system operating in reflection mode is also provided, highlighting

the performance of the system. The validation of the imager clustering analysis by comparison between single spectra from the PISTACHIO imager and the micro-FTIR system is presented.

Results show that the PISTACHIO imager is fast and particularly efficient in the detection of pigments such as ivory black or lead white. When the acquisition is combined with an effective clustering tool in the GUI, the performance enables the discrimination of single components, i.e., one pigment in one binder, or more complex systems, with mixtures of pigments in the same binder.



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Conservation and Preservation process of an Islamic jurisprudence Manuscript Includes High Acidity Papers Back to 17th Century.

Ahmed Adel ZWAIN[1], Dr. Simona INSERRA[2].

Abstract

Egypt is the richest country in Africa and the Middle East for heritage manuscripts dating back to long periods of time. It is well known for its extensive library collections, for a large part in public institutions such as the National Library, Egyptian Bookshop, Bibliotheca Alexandria, university libraries, museums etc. Public and private collections of manuscripts and books in Egypt are in rapid deterioration due to environmental factors.

By addressing many significant topics in paper heritage conservation. The main focus of this research was the conservation of an Islamic paper manuscript dating back to the 17th century which found in a very poor condition. The uniqueness of this case study is due to its state of preservation as it contains several papers that appear burnt and are extremely acidic and thus brittle. This condition made handling of the manuscript is a challenge.
Two problems have been faced. The first one is the weak structure of this group of paper because of its very high acidity condition. The second problem is the burning and dark appearance of this group of paper which leads to block the written text.

Our Conservation process began by how can we able to both chemically stabilize the condition of the case study as well as reveal the hidden texts within the burnt papers by multispectral imaging. In addition to prepared a customized preservation box that would ensure the preservation of both the burnt paper and manuscript. Replaced the deteriorated paper with a digitized and printable version for scholars. We utilized different methods to study the selected object such as pH value measurement, ATR-FTIR spectroscopy, X-ray fluorescence, and as mentioned earlier multispectral imaging.

Keywords

Islamic manuscript conservation, Weak structure, Hidden text, Burnet appearance, high acidity , Conservation, stabilization, ATR-FTIR spectroscopy, Multi spectral imaging, X- ray fluorescence , Housing, Customized box.

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Investigations into photogrammetry as an accessible 3D measuring tool for monitoring the structural condition of panel paintings

Christina Cachia - Easel Paintings Conservator

It has been outlined in the NWO's Research Agenda that panel painting conservation practice is looking to improve the accessibility to the conservation community, portability, and speed of methods to capture accurate 3D measurements, and to monitor panel deformations[1]. Being able to measure and monitor the movements of panels can aid in structural treatment proposals, improve preventive conservation methods, condition reporting, framing and more. Photogrammetry, which is defined as the art and science of extracting 3D information through the use of 2D photographs, has the advantages of being portable, economical, simple, as well as fast. This research thus aims to investigate photogrammetry as an accessible, efficient, and reliable method for conservators to monitor and document movement in panel paintings.

Most studies which monitor the mechanical behaviour of panel paintings using photogrammetry were conducted prior to the most recent Structure from Motion developments, whereas affordable options mostly based on Free Open-Source Software (FOSS) have focused on built heritage and archaeological specializations and sectors. No such investigations had yet been carried out on the structural monitoring and documentation of panel paintings.

Through the creation of a mock-up panel painting exposed to extreme fluctuating RH changes, photogrammetry was used to capture and document the paintings movement. Tools and features were explored on both commercial photogrammetry (Agisoft Metashape, 3DF Zephyr Free), and FOSS (Regard 3D, Meshlab, CloudCompare) to determine what they can show us. Commercial and FOSS options were then compared to establish whether cheaper software tools are in fact also reliable options.

Final results demonstrated that commercial software tends to have a user-friendly design and a range of products including digital elevation models and elevation profiles, that can be very beneficial for accurate out-of-plane and in-plane monitoring and documentation of panel painting form and movement. It is shown however, that FOSS can also provide reliable data on form and movement. Although not as quick and perhaps not as accurate, free alternatives prove to be useful and can still achieve results such as elevation profiles. This study thus demonstrates the potential of photogrammetry as an accessible and portable non-invasive monitoring and documenting tool for the structural analysis of paintings on panel supports.

This study forms part of the authors MA thesis presented at Northumbria University, Newcastle-Upon-Tyne, October 2021.

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Discovering Connections!
Analysis of black ink sketches with Uniform Manifold Approximation and Projection

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Abstract

Black ink has long been used as a typical artist sketching medium, with observation alone it is difficult if not impossible to discern or identify the types of inks used in an artwork. Modern black ink formulations may be formulated with black pigment, dye or a combination of both, pigment formulations are more resistant to deterioration and with good light- fastness, whilst dye based inks are prone to fading and sensitive to humidity. Material identification is fundamental in the decision of the most appropriate preservation plans for an artwork. Currently in the field of cultural heritage most publications have focused on the identification and properties of historical inks including carbon black, iron gall and sepia, few have engaged in the study of twentieth century black inks, especially in the form of black markers.

The use of hyperspectral imaging (HSI) a non-invasive chemical analysis technique has emerged as a material identification tool in the field of cultural heritage, especially in the identification of pigments and colourants. The advantage of the technique is its capability of generating reflectance spectra at the rate of scanning, thus producing a reflectance image with the associated reflectance spectra at each pixel. Consequently the generated dataset is composed of millions of spectra, such large amounts of data have led itself to be an analytical and computational challenge, various machine learning models have been researched to provide an effective data reduction and visualization, capable of identifying trends and clustering data.

In this study a selection of black ink sketches from the Wu Guanzhong collection of the Hong Kong Museum of Art, were scanned with HSI, their datasets were processed within one Uniform Manifold Approximation and Projection (UMAP) model, to analysis the black ink media used in these artworks. The result from UMAP has demonstrated the ability to discern the different ink types, the generated endmember spectra have provided characteristics features to differentiate between pigment and dye based black colourant inks, and a comparison of the artwork with the endmember maps has provided further insight into the artistic process. Moreover, with an established black ink reference library, there is potential for material identification. Unsupervised learning of the HSI datasets has proved to be an effective method to draw the connection between the individual black ink sketches and the potential to develop into a chronological study.

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Reconstruction of colors from macroscopic X-ray fluorescence for investigation of artworks

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Introduction

Modern investigation of artwork paintings is based on non-invasive scanning techniques. This includes macroscopic X-ray fluorescence (MA-XRF), where a set of images describing the spatial distribution of selected chemical elements in the artwork is obtained. However, processing of the collected multi-channel data is complicated and requires a time-consuming visual comparison of each grayscale image in the MA-XRF set with the rest and with a color photograph of the artwork. This is usually done in a general software for manipulating photos as used by graphical artists.

To simplify this process, we present a new concept of visualization of the datasets that assigns a color to each measured MA-XRF intensity map. The channels are then linearly mixed to create a color reconstruction of the artwork solely based on the MA-XRF data.

Model

Our linear forward model (mapping MA-XRF intensity onto the natural color) is based on the implicit assumption that each channel (one MA-XRF image per element) has its own conversion function to the color domain. The pixel intensities represent the contributions to the particular color. We also assume that the final color image is a linear combination of all transformed channels.

The important part of the proposed concept is the estimation of the color for each MA-XRF channel. This is done by the means of linear least squares. The inputs are the color photograph of the painting and the MA-XRF images that are spatially registered to the photograph and masked beforehand.

The estimated mapping for each channel can be further modified to suit user needs. A usual modification is complete exclusion of the channel, multi plication by a constant to change the contribution of the channel or change of the color associated with the channel/chemical element. The above-mentioned procedures are controlled by our developed software inspired by audio mixing consoles (Fig. 1).

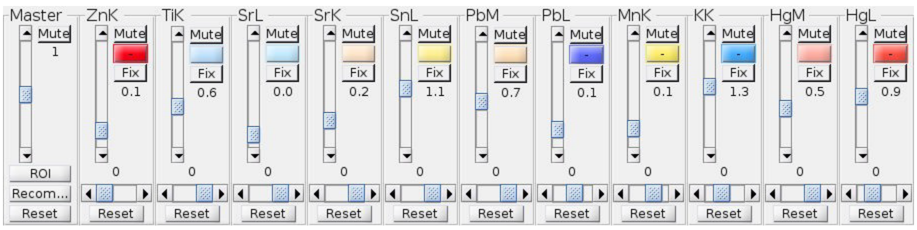

Figure 1: Main control panel of proposed software for color reconstruction from MA-XRF data. The panel is related to Fig. 2 but it is cropped to first 12 elements from 19 for visualization. The low values under the color buttons indicate low importance of respective channel.

Use case

The proposed method is demonstrated using MA-XRF data obtained from the *Knights of Christ* panel of Van Eyck's Ghent Altarpiece. The measured MA- XRF dataset contains 19 channels, all of which were used to reconstruct the color image (Fig. 2). Some advanced possibilities of our software to enhance interesting features are shown in Fig. 3.

Discussions and Conclusions

The goal of our concept is to simplify visualization of the MA-XRF (or similar) datasets. Since human eye is sensitive to colors, a representation of MA-XRF channels by colors together with their fusion into one color image seems to be an attractive way. Further analysis of the dataset (toggling and enhancing channels, modifying their colors) can reveal interesting features hidden in paintings. However, the presented method is based on simplified assumptions; thus the estimated colors of each MA-XRF image can be far from human understanding of colors and real pigment mixtures. It is clear that the conclusions always need an expert knowledge of element–pigment–color relationship. Additionally, the MA-XRF is not able to provide information on all pigments used in a painting, e.g. carbon black, so the available color palette also limits the quality of reconstruction. In modern paintings, that contain more organic dyes to which MA-XRF is largely insensitive, this may pose a larger limitation than in old master paintings. However, despite the limitations, we believe our tool can help in discovering secrets of ancient artworks.

Figure 2: Photograph of Van Eyck's *Knights of Christ* (left) and its color reconstruction from MA-XRF data (right).

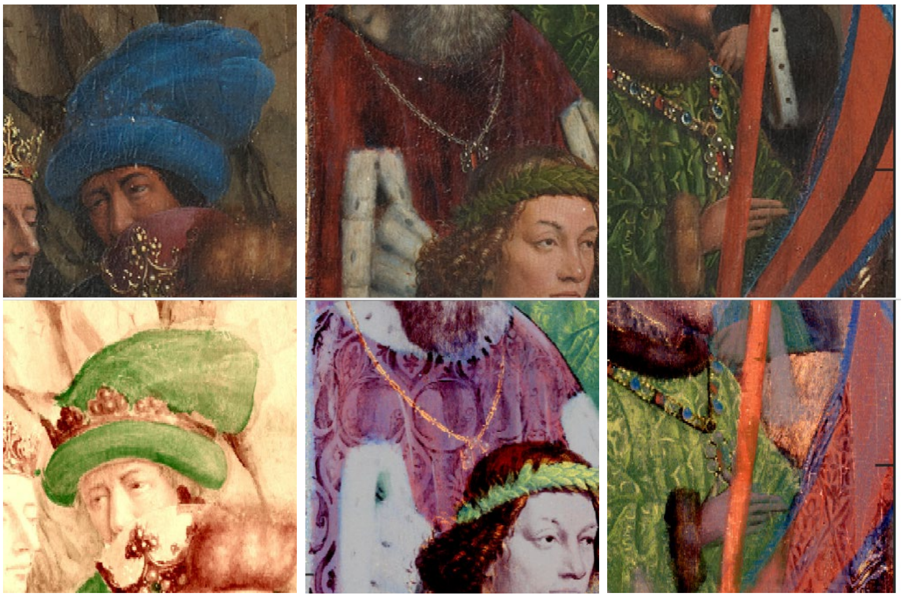

Figure 3: Interesting hidden features of Fig. 2 in closeups: top - color photographs, bottom - respective reconstructions after enhancements using proposed method. Left - hat with different shape and color, crown; middle - coat with texture; right - neck of horse and texture beneath the flag.

Complex Twill Fabrics Pattern Recognition in Canvases

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MOTIVATION & SCOPE

The density of threads in plain weave and simple twill fabrics have been widely studied to help in the forensic analysis of paintings [1,2]. However, there is no previous works focusing on complex twills such as those found in paintings by Murillo, El Greco, Velázquez or Zurbarán, among others, see, e.g., Fig 1.a.

The Fourier transform, quite useful in simpler fabrics, cannot be applied in many cases here, as the pattern is quite big and power spectrum estimations, based on averaging repetitions of the pattern, are quite noisy. Here we propose to use some key ideas along with spatial image processing to extract these patterns. Besides, we provide some guidelines to characterize them based on the analysis of underlining basic structures.

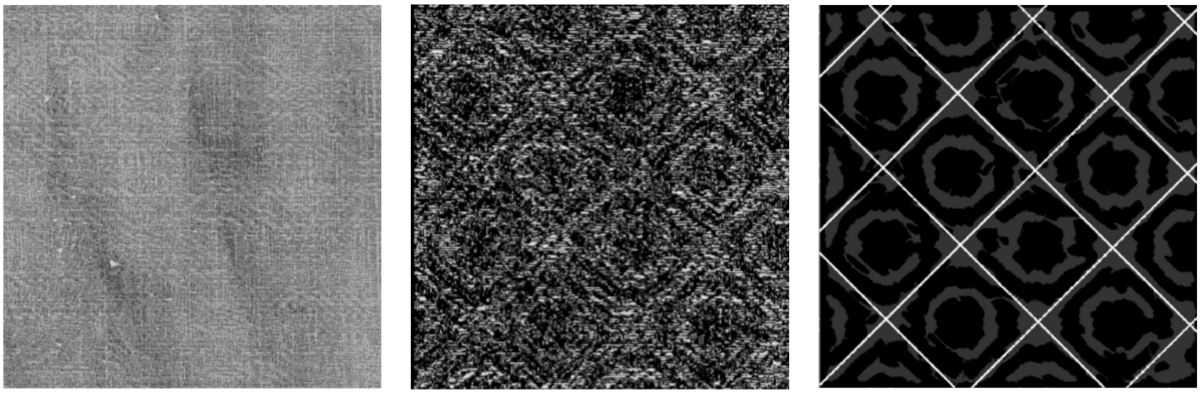
PROPOSAL

The main challenges when analyzing these fabrics are twofold. On the one hand, noise makes it difficult to observe the underline structure of the fabric. On the other, the pattern is build upon a configuration of threads usually organized vertically and horizontally, hence simple image processing tools to enhance the pattern fail here. See Fig.1.a for an example. In this scenario, our key idea is to exploit any off-the-shelf tool to identify these threads and their orientation. We selected the fingerprint image enhacement algorithm by Hong et al [3]. This algorithm applied to our problem identifies threads as fingerprint ridges, indicating also their orientation. The algorithm proceeds by first normalizing, then identifying regions with ridges in the image, it identifies areas in the image where fingerprint ridges are detected, estimate their local orientation, their frequency and finally applies a filtering. In the latest steps, Gabor filters are used. The result for Fig.1.a is included in Fig. 1.b.

After the application of the fingerprint detection we separate vertical and horizontal ridges (threads) into two images. Then apply morphological methods to erode them and select the one with largest area. A dilation and filtering is applied to join the threads into shapes, that describe the structure. In Fig1.c, as background of the thin white lines you can observe the result for Fig1.a. At this point we have the estimation of the underlying pattern.

Finally, we estimate the principal directions of the pattern of the fabric by means of the Hough transform (HT). From the results obtained the two longest lines with an angle separation large enough are selected. To find a grid describing the pattern, other parallel lines previously obtained with the HT are used. Angles at the corners of the resulting paralleloids (usually diamonds) are measured as features of the pattern. Also, by exploiting the BLOB (binary large object) concept, the size of the diamonds are also estimated. With the dimensions and angles a grid is estimated and superimposed on top of the image or the retrieved pattern, see white lines in Fig.1.c.

Five canvases of four different authors were successfully processed with this approach to retrieve both a sketch of the pattern and a grid describing it.



(a) (b) (c)

Figure 1: Pattern recognition in 'The Nun Jerónima de la Fuentes' by Velázquez: (a) a crop, (b) the result of the fingerprint approach, and (c) the pattern highlighted with the basic diamond structure of the fabric.

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The Use of Short Wave InfraRed Reflectance Imaging Spectroscopy for Pigment specific mapping

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In the last few years, reflectance imaging spectroscopy (RIS) has become an important tool in the analysis of cultural heritage objects for both conservation and art historical research purposes, particularly in the identification and mapping of pigments in paintings. RIS data is most often analyzed using methods like spectral angle mapping (cosine distance), which are limited to qualitative analysis, or by integrating over specific spectral channels, which present issues when pigments present overlapping absorption features. This work seeks to address these shortcomings by fitting gaussian profiles to pigment-specific absorption features in the short-wave infrared range (SWIR, 1000-2500nm), to provide quantitative pigment mapping. Two pigments are considered in this work, lead white and blue verditer, which are fit using the first overtone of -OH stretching of their primary compounds, hydrocerussite ($2PbCO_3 \cdot Pb(OH)_2$) and azurite ($Cu_3(CO_3)_2(OH)_2$), at 1447 nm and 1498 nm, respectively.

The methods are evaluated using a set of specially prepared paint samples, as well as a 17th century painting. Results are compared to those achievable by macroscopic X-ray fluorescence imaging spectroscopy (MA-XRF), another method often used for pigment analysis and mapping, but which only provides elemental information. The achieved results on the paint samples show the potential of this method for the identification, mapping, and quantitative analysis of the considered pigments. The results achieved on the painting show the methods value for distinction of pigments with similar elemental footprints which cannot be differentiated using MA-XRF.

The greater information depth of RIS in the spectral range considered when compared to MA-XRF results, also shows potential for the non-invasive analysis of paint layer stratigraphy.

Computed Tomography for cultural heritage: Tailoring X-ray imaging techniques for dendrochronology of large wooden objects

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Topics: Computational Imaging, X-ray Imaging, Computed Tomography, Dendrochronology, Cultural Heritage, Conservation, Art History

Abstract:

Computed Tomography has increasingly been applied to cultural heritage objects over the last decades. This X-ray absorption technique allows for the investigation of the interior of objects in a non-invasive way. The digital 3D object can be sliced to reveal its inner structure. This is of interest to conservators and researchers, for example to determine the current state of the object and possible conservation treatments, or for authentication purposes and dating.

To determine the date and provenance of historical wooden art objects, dendrochronology is an important tool. It is based on the investigation of the width of the tree rings in the wood. The tree rings are however not always accessible on the outside of the object. X-ray computed tomography (CT) has successfully been applied to visualise the tree rings within an object in a non-invasive way. For large objects such as chests or cabinets, it is however often impossible or impractical to rotate fully within the scanner as is necessary for CT. As a solution to this challenge, we developed a line trajectory X-ray tomography technique, in which the object is moved only sideways. We show that this method, although not yielding a full 3D image, is particularly well suited to reveal tree rings. Using this easily implementable scanning trajectory, sharp reconstruction images of the tree rings can be obtained for dendrochronological purposes. This result is of importance to the fields of both imaging and dendrochronology and opens up a wide variety of objects of which the internal tree ring pattern can now be investigated using X-ray imaging. The method is illustrated by a case study conducted at the Rijksmuseum Amsterdam, investigating a large wooden chest, known as the Hugo de Groot chest. The Dutch jurist and writer Hugo de Groot was imprisoned in Castle Loevenstein, from which he escaped in 1621 by hiding in a bookchest. The question that we aimed to answer is whether the chest in the museum collection could have been the one in which he escaped, by determining the age of the wood using tree ring measurements.

In this presentation, we will discuss the state of the art of CT for cultural heritage research, continuing with our novel method for visualising tree rings in large wooden objects. We will use case studies from the Rijksmuseum collection to illustrate our work.

Related manuscripts:

F.G. Bossema, S.B. Coban, A. Kostenko, P. van Duin, J. Dorscheid, I. Garachon, E. Hermens, R. van Liere, K.J. Batenburg, Integrating expert feedback on the spot in a time-efficient explorative CT scanning workflow for cultural heritage objects, Journal of Cultural Heritage, Vol. 49, p38-27 (2021)

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Neural network-based classification of X-ray fluorescence spectra of artists' pigments: an approach leveraging a synthetic dataset created using the fundamental parameters method

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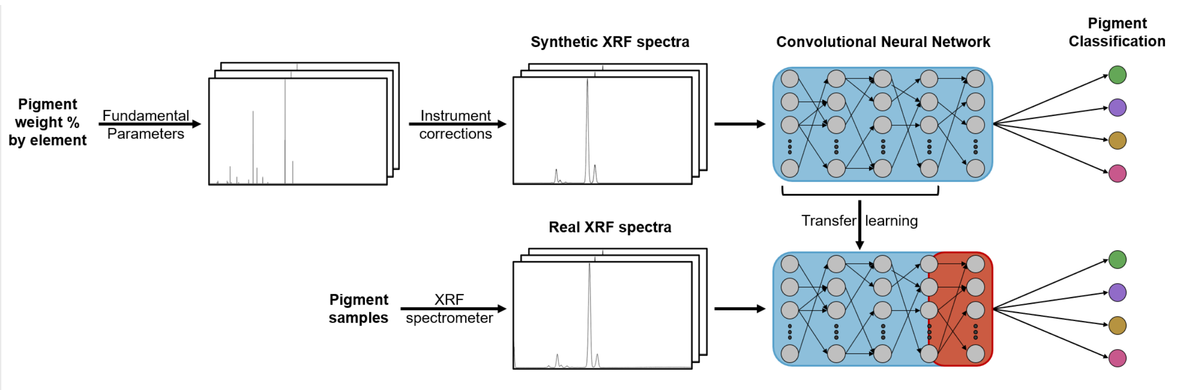
X-ray fluorescence (XRF) spectroscopy is an analytical technique used to identify chemical elements that has found widespread use in the cultural heritage sector to characterise artists' materials including the pigments in paintings. It generates a spectrum with characteristic emission lines relating to the elements present, which is interpreted by an expert to understand the materials therein. Convolutional neural networks (CNNs) are an effective method for automating such classification tasks – an increasingly important feature as XRF datasets continue to grow in size – but they require large libraries that capture the natural variation of each class for training. As an alternative to having to acquire such a large library of XRF spectra of artists' materials a physical model, the Fundamental Parameters (FP) method, was used to generate a synthetic dataset of XRF spectra representative of pigments typically encountered in Renaissance paintings that could then be used to train a neural network. To account for the varied elemental compositions of pigments in historical paintings, at least to some extent, data for the 15 pigment classes studied was sourced from quantitative studies of the elemental composition of historical pigment samples where it was available. The synthetic spectra generated – modelled as single layers of individual pigments – had characteristic element lines closely matching those found in real XRF spectra. However, as the method did not incorporate effects from the X-ray source, the synthetic spectra lacked the continuum and Rayleigh and Compton scatter peaks. Nevertheless, the network trained on the synthetic dataset achieved 100% accuracy when tested on synthetic XRF data. Whilst this initial network only attained 55% accuracy when tested on real XRF spectra obtained from reference materials of known composition, applying transfer learning using a small quantity of such real XRF spectra increased the accuracy to 96%. Due to these promising results, the network was also tested on select data acquired during macro XRF (MA-XRF) scanning of a painting to challenge the model with noisier spectra Although only tested on spectra from relatively simple paint passages, the results obtained suggest that the FP method can be used to create accurate synthetic XRF spectra of individual artists' pigments, free from X-ray tube effects, on which a classification model could be trained for application to real XRF data and that the method has potential to be extended to deal with more complex paint mixtures and stratigraphies.



Mapping the Distribution of Pigments in Paintings Using Macro XRF Element Maps and the Least Squares Method

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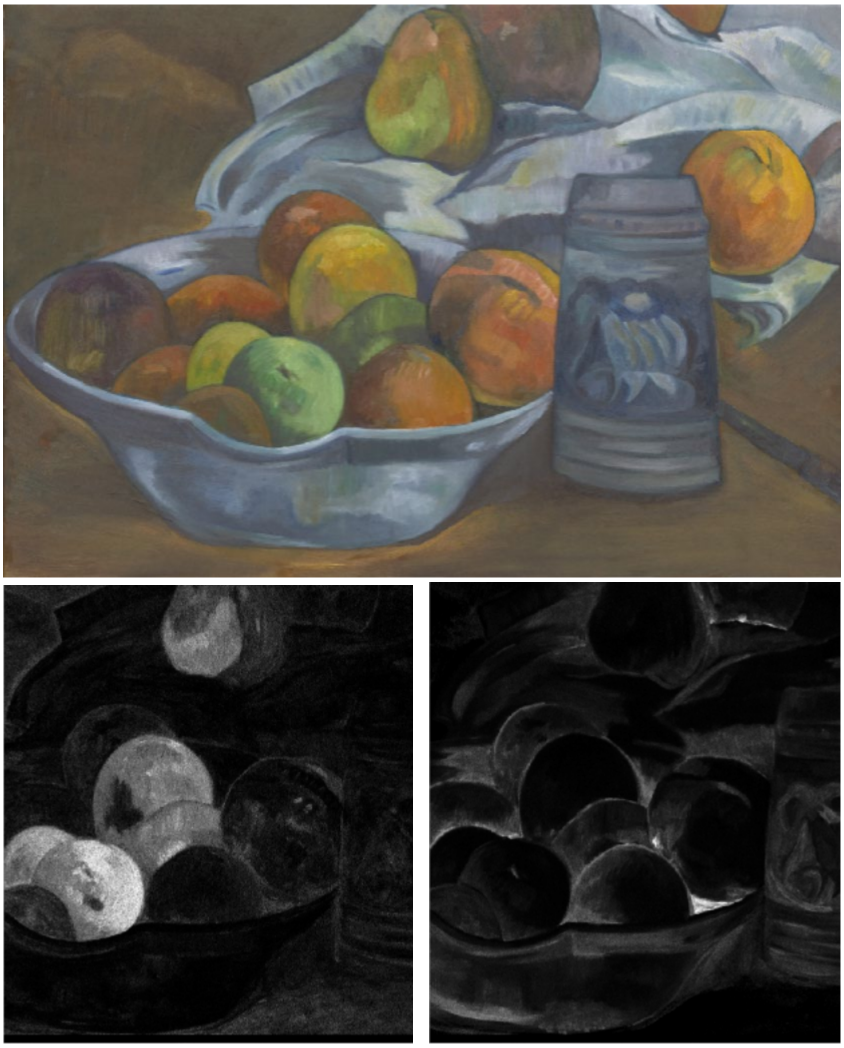

Figure 1: The RGB image at the top shows a sample painting made at the National Gallery, London. The two element maps at the bottom indicate with brighter colored pixels areas where different chemical elements are present in the painting. The image at the bottom left shows areas where barium is present, while the image at the bottom right shows areas where cobalt is present

A painting's pigments change colors and sometimes fall off from the painting as they interact with the painting's environment over time. Art restorers retouch areas where pigments were lost or discolored often with their contemporary pigments that are different from those that the artist originally used in the painting. Therefore, being able to identify where specific pigments were used in a painting helps art restorers and investigators uncover the painting's conservation history and provenance [1]. Because pigments are composed of chemical elements, once we know where certain chemical elements are present in a painting, we can derive areas where different pigments were used.

In recent years there has been a growing use of non-invasive imaging techniques for the purpose of art investigation [2][3]. One of such commonly used techniques is macro X-ray fluorescence (MA-XRF) scanning, which uses X-ray radiation to excite the chemical elements present in both surface and underlying layers of a painting and then records the fluorescent light which is emitted from the elements. This emission recording process generates images mapping the distribution of elements across the entire artwork (i.e., "element maps") as can be seen in Fig. 1 [4][5]. However, the number and size of images generated with MA-XRF makes the entirely manual assessment of the element maps to determine the composition and location of pigments used in the painting cumbersome and almost intractable. Therefore, creating a tool to automatically generate pigment maps based upon the element maps would be of great importance for the cultural heritage field.

We present in our poster a model that uses MA-XRF element maps and known proportions of chemical elements in selected pigments to reconstruct the pigment maps and can even adapt to reconstruct some missing pigment compositions. To obtain pigment maps based on input information, we create a mathematical model and solve a least-squares problem involving element maps and the element proportion information.

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Abstract: Enhancing Underdrawing Visualization using Adaptive and Localized Image Analysis of Reflectance Hyperspectral Imaging Data from a 15th Century Painting

Wallace Peaslee, Marta Melchiorre Di Crescenzo, Nathan Daly, Ingrid Daubechies, Shira Faigenbaum-Golovin, Catherine Higgit, Barak Sober

Reflectance hyperspectral imaging (or reflectance imaging spectroscopy), in different spectral domains, is becoming a routine non-invasive spectral imaging technique to identify and map the composition of materials in works of art. Infrared hyperspectral imaging in particular can be used on paintings as a tool to unveil underdrawings, preliminary sketches made by an artist prior to painting. However, the high dimensionality of the hyperspectral data and the spatial heterogeneity of paintings pose a challenge for underdrawing visualization. In particular, different parts of the underdrawing may be more or less legible in certain wavelength ranges, in relation to the material used for the underdrawing and the pigments in the overlying paint.

We propose several global and local methods that process hyperspectral data to enhance visualization of the lines of the underdrawing and make them more interpretable for art historians. First, we apply Principal Component Analysis (PCA), a global dimension-reduction method, and find a lower-dimensional space that will be beneficial for underdrawing enhancement. Next, we apply the Maximum Noise Fraction transform (MNF), a method that also performs dimension reduction while maximizing the signal-to-noise ratio. Later, we consider *local* versions of PCA [1,2] and MNF, taking into account the heterogeneity of the painting and utilizing spatial information.

As a case study, we utilized reflectance hyperspectral imaging data from a portion of the *Adoration of the Kings,* a panel painted by Sandro Botticelli and the young Filippino Lippi in the 15th century. The hyperspectral datacube includes over 500 bands from shortwave infrared wavelengths (SWIR) ranging from 1000 nm to 2500 nm. We demonstrate the effectiveness of our methods on a central portion of this artwork, which contains underdrawing that cannot be seen in the visible image (Figure 1). We apply global PCA (Figure 2) and local PCA (figure 3), as well as global MNF and local MNF.

We find that all these methods may be useful for automatically enhancing underdrawing visualization. In addition, we see that using local spatial information can be beneficial for the PCA method, increasing underdrawing line legibility under paint passages containing pigments with different compositions. This initial study shows that a number of statistical methods could be used to enhance the visualization of underdrawing using infrared reflectance hyperspectral imaging data and to better understand the painter's materials and techniques.

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Figure 1: A color image showing a detail from *The Adoration of the Kings* (NG592. Tempera on wood, about 1472) by Sandro Botticelli and Filippino Lippi with concealed underdrawing.

Figure 2: A global PCA result, using SWIR hyperspectral data between 1000 nm and 2500 nm. The hyperspectral data is projected onto the first principal component.

Figure 3: A spatially-localized PCA result, using SWIR hyperspectral data between 1000 nm and 2500 nm. Each pixel of the hyperspectral datacube is projected onto its first local principal component.

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Modelling the wet cleaning of museum textiles using FTIR and Principal Components Analysis.

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Textile conservators and curators may decide that a textile object should be washed for a variety of reasons. Often this is done to remove unwanted soiling and to preserve the object's longevity. Surfactants aid this wet cleaning process due to their amphiphilic nature. Although these surfactants make excellent cleaning aids, questions have arisen concerning their potential adsorption on the surface of textiles. Due to the irreversible nature of washing, any potential surfactant adsorption must be investigated. Current literature on this topic is limited and little work has been done to understand chemical changes that occur during this wet cleaning process. Likewise, computational methods such as chemometrics have scarcely been used in the field of textile conservation. This research aims to bridge the gap between textile conservation and multivariate analysis. PCA analysis will be used to investigate chemical changes that occur during the wet cleaning process.

In order to reach these aims, this study will focus on the combined power of ATR-FTIR and principal components analysis. This combined approach allows the construction of a non-destructive model that can group samples based on their spectral similarities. Samples were washed according to a protocol, provided by the Victoria and Albert Museum, using the surfactants Hostapon TPHC and Dehypon LS54. FTIR spectra were recorded for all samples, these spectra were then transformed into their second derivative spectra and pre-processing methods were then applied. A PCA model was constructed. This model was further improved by the use of a Random Forest Classifier in order to remove effects of random noise.

Modelling of the dataset showed that washing with high surfactant concentrations lead to surfactant being present on the surface. On the other hand, samples washed with low surfactant concentrations showed spectral similarity to samples which had been washed in water alone. This is most likely due to water absorption or adsorption of a biocide which was found to be present in the Ramer© sponges used for the wet cleaning.

In conclusion, it was found that surfactant adsorption can be detected by ATR-FTIR using PCA, when high levels of surfactant are present. Furthermore, there were slight differences within the spectra of samples which had been washed compared to those which hadn't. Without the use of a multivariate method, these differences would most likely have been disregarded. This work reveals the benefits of using chemometrics for the cultural heritage sector.

Automated mapping of bronze disease in ancient bronze using non-invasive hyperspectral imaging solutions

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The colour and form of ancient bronze can largely tell us a story about the environmental conditions in which it has been surrounded for the duration of its existence. It is subject to complex degradation which is determined by a chemical interaction of the bronze alloy with the reactive species present in the surrounding environment. The bronze degradation products considered to be most dangerous are the copper chlorides which, when combined with moisture and oxygen, can induce a cyclic and self-sustaining degradation process commonly referred to as 'bronze disease'. If left unattended, bronze disease can ultimately lead to bronze death through deterioration into a blue-green powder. Identifying bronze disease through the detection of its indicators (in particular the copper trihydroxychlorides) is therefore necessary in guiding conservation.

The identification of bronze disease is typically done using invasive techniques which require sampling an area of interest for analysis or by non-invasive techniques which involve analysis of a localised area. The complexity of bronze patination and the sparsely distributed nature of copper alloy corrosion, mean that it is preferable, particularly in a museum setting where collections of numerous large objects are stored, to develop a method which allows a rapid mapping of material distribution [i].

We present a high spatial/spectral resolution short wave infrared (SWIR) imaging solution for mapping unstable corrosion products (copper trihydroxychlorides) associated with bronze disease, combining hyperspectral imaging data with an in-house developed unsupervised machine learning algorithm for automated spectral clustering. Using the same clustering algorithm, we also test the suitability of a visible to near-infrared (VNIR) hyperspectral imaging system as a more accessible solution for mapping copper trihydroxychlorides associated with bronze disease.

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Virtual restoration of the bio-deteriorated image: applied on the gelatin photographs back to 1950s

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The collections of historical photographs in Egyptian libraries and museums are exposed to many factors that threaten the survival of the image, given the climate change in Egypt and the high rate of humidity that allows the growth of organisms that cause the deterioration of image.

In this paper, a virtual restoration was made of a biologically infected black-white gelatin photograph dating back to the 1950s. This image carries the characteristics and features of the Egyptian society where it documents the clothes and fashion in Egypt at that time. The image is documented in color and gray scales. The image has been digitized. A virtual Photoshop restoration was made of affected areas of the image that had faded and disappeared due to microbiological damage. Negative image has been created. The image has been reprinted using a developer and fixer, keeping the original image unchanged. The mountain was made for the image to be presented in a scientific way.

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Modelling decay in stone heritage using Machine Learning

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Background

Both natural weathering and anthropogenic pollution exert a range of pressures that trigger the decay of stone. These can be thought of as the physical effects of climate, particularly related to water and temperature and attack by an atmosphere loaded with complexes of chemical pollutants. Conservation surveys to understand stone decay have traditionally been carried out using methods that are often expensive and difficult to execute because of site access, urban disruption and risk. Conventionally such survey snapshots are executed either from the ground, scaffolds, or mobile platforms, all of which are limited in terms of the holistic understanding of the stone heritage and its decay patterns. Advances in Unmanned Aerial Vehicles (UAVs) provide a platform from which to obtain data rapidly using sensor technologies. We will report on a proof-of-concept study that explores the application of UAV photogrammetry and machine learning for automated detection and 3D visualisation of stone decay on a heritage building. We outline some of the workflows including 3D reconstruction and Machine Learning implementations we have completed to date. We will conclude by outlining the project's next steps and quantify some of the computational scaling required.

Project Aims and Methods

The project is aimed at developing bespoke machine learning and 3D visualisation technologies for the mobile detection, visualisation, and analysis of stone decay found on buildings and first people’s sites of significance across Victoria, Australia. It is aimed delivering a holistic survey tool accessible to a range of custodians and stakeholders involved in the care of Australia’s stone heritage (and beyond).

We will:

1. Build an enduring digital record of vulnerable heritage sites in the region to assist in heritage documentation, research, advocacy, management and conservation.

2. Create an innovative 3D visualisation and research environment for potential development through professional- and community-led research.

3. Compare site location and environmental context to map the geographic/metrological/locational aspect and extent of the detected patterns of stone decay.

We will report on the workflow to help achieve these aims:

a) Image capture and annotated labelling of defined types of stone decay.

b) Use of the annotated images as training data for machine learning modelling.

c) Testing the modelling on selected sites

d) Criteria for establishing the success of the approach is determined by measuring the consistency of stone decay estimates made by the machine learning model with ground truth established through expert input. This will be done by computing classification/regression accuracy metrics on a sample test dataset.

We will report on the success of the proof-of-concept stage through the implementation of a deep convolutional network for image segmentation and classification of stone decay on the images.

We will conclude by discussing details of how we will develop the work:

e) Testing airborne sensor array on sites inaccessible from the ground but accessible to data collection through UAV survey.

f) Phased development of non-ocular decay pattern quantification using sensor technologies including thermal imaging.

g) Providing legacy open-source software and development of low-cost hardware.

Recognizing physical damages from historical documents using a computational model

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Abstract

Physical damages (such as torn-offs and scratches) are commonly seen in historical documents such as collections in the cultural heritage sector. Recognition of such damages is currently absent in digitization-and-information-extraction (DIE) systems but crucial for automatic document comprehension and exploitation. In particular, the presence of these damages tends to upset downstream algorithms such as document image segmentation and optical character recognition (OCR). This in its turn affects DIE systems and disturbs the process of extracting meaningful information from document images. In this case, damage recognition can be included as a pre-processing step such that the operation of these algorithms is automatically supervised to avoid confusion on damaged regions. Furthermore, the recognition of such damages can also benefit document image quality assessment, where existing quality prediction models rely on global quality metrics such as OCR accuracy. However, the OCR accuracy of a document containing physical damages may be comparable to that of a document without such damages. While existing quality prediction models operating on OCR accuracy would mark these two documents as having similar quality, an advanced model may further distinguish these documents and alert a DIE system of the damaged zones. Such advanced models can be developed only if damages (contained in document images) can be automatically recognized.

Despite its necessity, little efforts has been devoted to the recognition of physical damages in document images. This may be attributed to the fact that these damages tend to have arbitrary size and shape, and may appear at random locations in a document. This makes damage recognition fundamentally different from our former work in crack detection in paintings, where cracks tend to have a more global and homogeneous distribution over large areas of the paintings (therefore present a different set of challenges for recognition). The added complexity of document damages, together with other difficulties (e.g. faded print and versatile text formats) seen especially in historical documents, hinders the application of knowledge-based document recognition frameworks which are often formulated heuristically.

We propose a computational method for damage recognition based on a joint global and local modeling of the text homogeneity (TH) pattern exhibited in document images. More specifically, a connected component (CC) based formulation is developed as a global homogeneity measure, where TH is characterized using a probabilistic graph model for a coarse recognition of damaged regions. A multi-resolution analysis of TH is further developed for a granular within-CC recognition of damage pixels, where the disparity between damage and text pixels is characterized by exploiting neighborhood transitions. This enables the formulation of a local homogeneity measure, where the neighborhood transition around an individual pixel is modeled using the propagation of the

approximation coefficients of a stationary wavelet transform. The proposed global and local homogeneity measures are integrated as a joint likelihood in a Bayesian model with a Markov random field prior, where damage recognition is formulated as a maximum a posterior inference which is then addressed using Markov Chain Monte Carlo (MCMC) sampling. The resulting algorithm is tested on a set of real-life historical newspaper images containing damages of varying size and shape, where test results demonstrate the promising potential of the proposed method.

Author Information

Tan Lu is a researcher in the KBR data science lab (https://www.kbr.be/en/projects/data-science-lab/), where his work mainly focuses on image modeling and deep learning for analyzing and extracting information from cultural heritage materials. He has previously worked on the auditing digitization outputs in the cultural heritage sector (ADOCHS) project which was established to investigate image quality in digitization workflows in the cultural heritage sector. He is also an assistant professor in the digital mathematics (DIMA) research group in the department of mathematics and data science of Vrije Universteit Brussel.

Ann Dooms is a professor in the department of mathematics and data science, where she is currently leading the research group digital mathematics (https://we.vub.ac.be/en/dima-digital-mathematics). She has rich experiences in applying mathematical modeling for image processing and understanding especially in the cultural heritage sector. She has previously worked together with Ingrid Daubechies and Aleksandra Pizurica on the crack modeling and detection in paintings. Their work was highlighted in different venues including the previous IP4AI series, where Ann hosted the 4th edition in Brussels in 2011.

Application of scanning microscopy for craquelure analysis

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Looking at paintings one sees colours, shapes and brushwork…but also craquelures, which give painted surfaces a historic appearance and enrich a viewer's perception. Craquelure patterns on paintings, various craquelure patterns can be recognized andrelated to art-historical categories of paintings. However, the mechanisms which generatethe mechanical stress fields and dissipate them through crack formations in a specific painting are understood only in basic terms. More importantly, there is no quantitative understanding of the ways in which pre-existing craquelures, as well as conservation treatments, influence the current and on-going vulnerability of paintings to changes in temperature and RH in their environments. As presented above, it is only generally understood that the cracks 'saturate' with time and that the crack saturation significantly reduces vulnerability of paintings to climate variations. Limited information on the mechanisms of 3D crack formation and growth, historic material properties, as well as the effect of accumulated cracks in paintings on their susceptibility to environmental variations have been perceived as major deficiencies of the research. The project „CRAQUELURE" aims to develop a 3D physical model of paintings with existingcraquelure patterns and through this decisively contribute to the development of evidence-based environmental specifications for paintings which are frequently the most precious and vulnerable heritage asset in museums and historic buildings worldwide. Development of 3D physical model requires identification of a topology of cracks for the chosen paintings.

The goal of the talk is to present capabilities of HIROX microscopic scanner to provide data regarding craquelure characteristics. The first studied painting is Madonna and Child (XIV-XV c.) by unknown author. It is tempera painting from the collection of St. Mary's Basilica in Krakow. 45 000 images (approx. 200 Gb) has been taken during the scanning procedure and has been processed allowing multizoom analysis of the picture. Initial analysis highlights two distinct networks of cracks: network of anisotropic cracks in the tempera layer and isotropic cracks in the gesso layer that are perpendicular to the wood grains. Timeline of the appearance of these cracks is restored: the first to appear had been cracks in tempera layer, only after that the cracks in the gesso layer had started to appear.

Long term goal of this research is to create cheap and affordable tools for painting authentication.

Our results are presented at http://hirox.ikifp.edu.pl.