Visualising Artworks: Translating the Invisible into Diagnostic Data for Identifying and Quantifying Paint Surfaces

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Abstract. The abstract should summarize the contents of the paper in short terms, i.e. 150–250 words. Multi-spectral imaging (MSI) is today a commonplace tool in the diagnosis of painted artworks. Instrumentation is becoming more accessible with a wide variety of custom and commercial equipment available. Obtained spectral data can be interpreted to provide information about pigments, painting practice, conservation history and condition of painted art works. Such data is typically analysed by the expert user (a scientist) and helps the way practitioners (conservators) visualise details presented by each unique artwork. Artificial intelligence (AI) is now being applied to the field of MSI. Machine learning enables the efficient comparison of spectral responses to pre-existing databases, providing automated interpretation of results. Clear mappings of selected pigments, damage patterns or condition phenomenon provide the conservator with a new means to visualise, diagnose and monitor artworks. An innovative technological system, provided by XpectralTEK (Portugal), was trialled at SRAL (Maastricht) in the spring of 2021. Multispectral images (360–1200 nm) were captured using the unique camera and acquisition platform. AI learning created overlays and mappings empowering the conservators by providing material-technical insights. This paper will report on case studies highlighting the functionality of the XpectralTEK's system. We will discuss how we familiarised ourselves with the new technology, adapted our working practice and how our knowledge of the paintings studied was enhanced. We will emphasise the training, interpretation and learning that our conservation team encountered, guided closely by the XpectralTEK support staff.

Keywords: Multi-spectral imaging · Pigment identification · XpectralTEK · Artificial intelligence (AI) · Pilot study · Beta testing

1   Introduction

Multi-spectral imaging (MSI) is a commonplace tool used by art professionals, (art) historians and (conservation) scientists in the diagnosis of painted art works. The instrumentation required is becoming more and more accessible, with a wide variety of custom and commercial equipment available.[1] When executing MSI, images are acquired at incremental, stepped wavelengths resulting in spectral data cubes. Each corresponding pixel from each image can be registered in the X and Y axes, and the Z dimension provides wavelength information for that specific pixel for each registered image taken.

The images and data can be interpreted to provide information about pigments, painting practice, conservation history and the condition of painted art works. Such data is typically interpreted by the expert user, a conservation scientist, and these interpretations are provided to the practitioner, an art conservator, to help visualise details presented by each unique artwork. Art conservation professionals are well-equipped, through their academic training backgrounds, to use technical photography, acquiring images of art works at different wavelengths, to investigate artworks. However, when it comes to utilising spectral data, many conservators will rely heavily on the interpretations made by the scientist. Of course, this statement sketches extremes and many conservators have a deep understanding of MSI and are fully capable of construing conclusions from acquisitions. Furthermore, conservators and scientists often forge deep collaborative partnerships, furthering the understanding of analytical results obtained using MSI. More importantly, the results obtained should be easy to convey to other art professionals, such as curators, and clients.

2   The XpectralTEK System

XpectralTEK is a company with a focus on imaging diagnostics, that creates tools to assist professionals in their daily work.[2] It offers quality proven solutions, with specialisation in spectral imaging. XpectralTEK has developed a system capable of high-resolution imaging in real time. The XpectralTEK technology consists of a multi-spectral, mono-chromatic camera (XpeCAM) with a complementary metal-oxide semiconductor (CMOS) sensor, autofocus capabilities, and a 35 mm C-mount lens. Narrow bandwidth filters eliminate unwanted wavelengths and are included internally within the camera housing. The hardware is connected, via a computer, to an acquisition platform (XpecEYE) which guides the conservator through a series of automated captures from 380 nm to 1000 nm. Manual settings extend the wavelength range captured from 350 nm to 1200 nm. In total, 30 bandwidths can be captured for each spectral cube. The camera is linked, via Bluetooth, to two custom light modules, named LAMPA, containing broadband visible, ultraviolet and infrared light sources, that are automatically driven by the system. All images are adjusted using acquisitions at each wavelength of a Direct Reflectance Target (DRT). Post processing of the captured images using the DRT captures increases accuracy of procurement eliminating reflectance anomalies. The system is completed with an appropriate wavelength selection system, which interprets

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[1] URL: https://chsopensource.org/multispectral-imaging-msi/ [accessed 13 January 2022].

[2] URL: www.XpectralTEK.com [accessed 13 January 2022].

the incoming light as a function of wavelength. The images and data acquired are transferred to a cloud-based platform (XpeCAM Platform)[3], which provides integrated and collaborative visualisation of the visible and invisible.[4]

The innovations provided by the XpectralTEK system aim to make MSI more accessible and hands-on in daily practice to art professionals. The camera and lights while similar to other systems available function in tandem with each other and are operated through a unique, easy to function computer system. Once the MSI images are captured, the ground-breaking system uses artificial intelligence (AI) algorithms, applied to the MSI acquisitions, to provide clear analytical results empowering diagnostic capabilities by the user. Machine learning enables the comparison of spectral responses at specific wavelengths to existing databases, providing immediate interpretation of results. The visualisation of results, generated by AI algorithms, provides clear mapping of selected pigments, damage patterns or condition phenomenon allowing the conservator a new means to diagnose and monitor artworks.

An innovative technological MSI system using AI, developed and provided by XpectralTEK (Portugal), was trialled at SRAL (Maastricht) in the spring of 2021. The trial put the new instrumentation, user interface and analytical AI system through its paces, equipping the SRAL conservators with valuable insights into several artworks being treated in the conservation studio. This beta testing allowed the XpectralTEK developers to modify and improve the system and user experience. Multispectral images (350–1200 nm) were captured for each artwork, included in the trial, using the unique camera and acquisition platform. AI learning created overlays and maps empowering the conservators to identify more easily the effects of past conservation treatments, while providing material-technical insights. This mutually beneficial collaboration provided both parties with constructive feedback and has enhanced the AI potential of the system by increasing the capacity of the pigment database and the interpretation of acquired spectral data cubes.

3 Stichting Restauratie Atelier Limburg (SRAL), Maastricht

SRAL is a leading, not-for-profit, conservation institution situated in Maastricht (the Netherlands).[5] SRAL provides expertise in four conservation departments in areas relevant to our core business, which are Conservation-Restoration of painted artworks; Education & Training of conservators; Research & Development of conservation practice; Preventive Conservation and Advice. SRAL conservators offer expertise in the conservation of easel paintings, polychromed sculpture, historic interiors, which includes wall paintings, and modern and contemporary art. These conservation departments (Fig. 1) guide the essential activities of the institution. Each department is staffed with in-house experts who are recognised in their own fields regionally, nationally, and internationally. SRAL's expertise is transferred to the next generation through practical mentoring and training of students and emerging professionals. The institute offers several internships

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[3] URL: www.xpecamplatform.com [accessed 13 January 2022].

[4] Vassilis M. Papadakis and Jani dos Santos, XpeCAM: The Complete Solution for Artwork Documentation and Analysis. To be published in Heri-Tech Conference, May 2022.

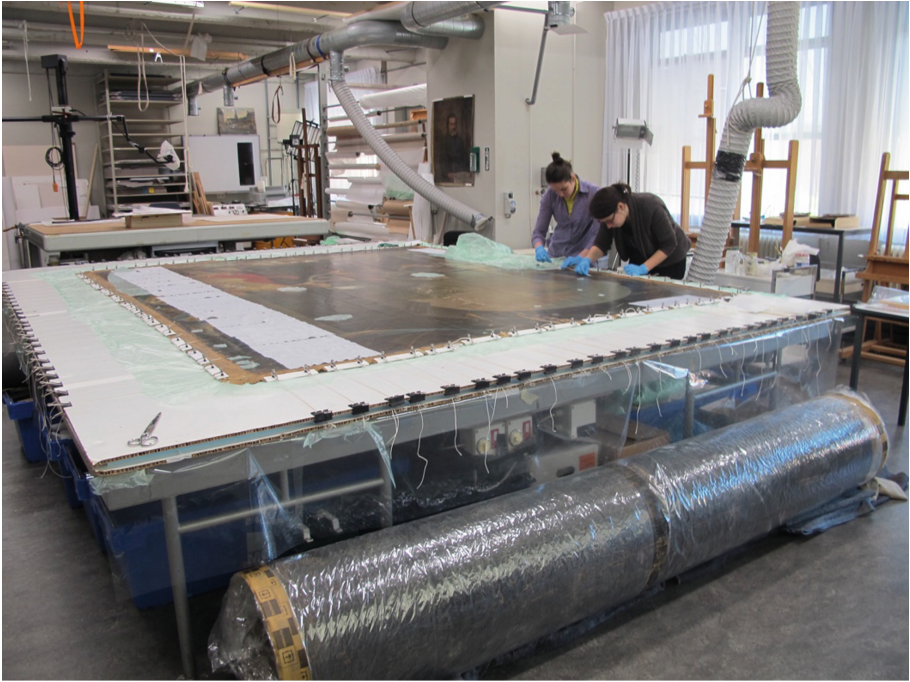[5] URL: www.SRAL.nl [accessed 13 January 2022].

Fig. 1. One of the conservation studios at SRAL. © SRAL

and fellowships annually and collaborates with the University of Amsterdam (UvA) in training Master students enrolled in the "Conservation and Restoration of Cultural Heritage".[6] The in-house team at SRAL, augmented by interns and fellows, participated in the XpectralTEK trial and their experiences with the system are discussed in this paper.

The XpeCAM project (SME Instrument, Phase 2, H2020) was trialled first at SRAL in June 2018 at a workshop introducing the XpeCAM X01 and XpecEYE to Dutch conservators and students. The workshop focused on the then current spectral imaging technology used in active and preventive art conservation. The basic principles of spectral imaging were discussed, and the available technological solutions explained. Potential applications for cultural heritage were presented using real case studies, and future perspectives were outlined. This included the development of the cloud-based AI platform (XpeCAM Platform) that would compare acquired data cubes to a pigment database and intuitively provide pigment identification and mapping. The collaboration between SRAL and XpectralTEK evolved in the interim period, which culminated in a three-month pilot study in the spring of 2021. The pilot study allowed SRAL conservators, fellows, and interns to put the system through its paces, using the results to better understand the material and technical characteristics of the observed artworks (Fig. 2). This enabled improved decision-making for conservation choices and enhanced the reporting provided by the conservator to the client.

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[6] URL: https://www.uva.nl/en/programmes/masters/conservation-and-restoration-of-cultural-heritage/conservation-and-restoration-of-cultural-heritage.html [accessed 13 January 2022].

Fig. 2. The SRAL team setting up the XPECAM system. © Kate Seymour

This paper will report on two of the numerous projects included in this trial, high-lighting the use of the XpectralTEK system to the conservator, scientist and curator of painted artworks. The authors will discuss how they familiarised themselves with the new technology, adapted their working practice and how their knowledge of the paintings studied was enhanced by the results obtained using the XpeCAM X02 and interpreted by the XpeCAM Platform. The projects studied cover a wide typology of art works ranging from medieval tempera panel paintings to oil paintings on plaster from historic interiors. As these are too many to do justice to within the confines of this publication, the authors will focus on the interpretation of image cubes acquired from an eighteenth-century, Dutch canvas painting, the Kapittel van Thorn (unknown artist), and a nineteenth century mural altar-frontal. The paper will also discuss the training, inter-pretation and learning that the team encountered, guided closely by the XpectralTEK support staff.

4   Technical Photography (TP)

Fig. 3. XPECAM and one LAMPA. © Kate Seymour

Technical photography (TP) consists of documenting and imaging a painting through photography using a variety of different illumination sources.[7] The surface's response to interaction with incident light is recorded and the images obtained, processed and analysed through observations and often remembered comparisons, making interpretations fallible. Modern technical photography is the acquisition of a collection of scientific images realised with a modified digital camera sensitive to the spectral range from ultraviolet to infrared. Each digitally acquired image records the specific reaction of the material to the influence of light falling on that surface. Light interacts with matter in a variety of ways - reflection, absorption, scattering or transmission. The ability of a surface to reflect, absorb, scatter, or transmit energy is specific to that material and depends on the wavelength. Some materials are translucent or semi-translucent to (higher) wavelengths and thus the light reflected may be from a lower substrate and the upper layers will not appear on the photographic image. The (digital) photographic image records an amount of reflected light specific to that surface. Thus, each capture at a set wavelength provides specific information on the material's chemical (and physical) characteristics. Taken together, an image cube which collects captures, taken at incremental steps, will provide spectral information that can be used to analyse the materiality of an object. However, the images alone provide only a visual record of the interaction of light with

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[7] Due to the more complex instrumentation required, x-radiography is often excluded from the acquired image cube.

the surface. Spectral data is difficult to extrapolate from these images. The response of the surface needs to be compared with standards to be able to interpret data and the images taken at different focal distances need to be correlated. Surface responses from narrower bandwidths, such as captured with the XpectralTEK system, are required to gain accurate material information. The cubes of images captured using the XpeCAM X02 (Fig. 3) are processed using AI algorithms on the XpeCAM Platform providing far more material information than photographs acquired by Technical Photography.

The simplicity or complexity of the technical imaging system will guide the quality and quantity of the spectral information gathered. Typically, at SRAL, artworks are photographed with a high-quality digital single-lens reflex (DSRL) camera, in a dedicated space with specialised lighting rigs emitting visible, ultra-violet, or infrared radiation.[8] SRAL staff also produces digital x-ray images (DX/XR) to provide supplementary information and examines objects using infrared reflectography (IRR). The SRAL Hamamastu Videcon IRR system is better at penetrating paints than the modified DSRL camera, although it still struggles with visualising the underdrawing present under blues and greens. Enhanced visible lighting conditions (raking or transmitted light) are also often used to record specific conditions. Initial images are taken to document the condition of the painting prior to treatment, and used to diagnose problems that will be treated in the conservation studio. Artworks are photographed to record the treatment process and the condition of the artwork before restoration is carried out. Finally, artworks are photographed as a testament to the condition that they are returned to the client and to provide evidence of the treatment. The set of images taken with broadband illumination provide a useful record of condition and treatment but have restricted potential for diagnostic or analytical means. For instance, UV radiation at around 365–385 nm can be used to detect the presence of organic surface layers such as varnishes and to tentatively identify some pigments like red lakes.[9] However, information at specific wavelengths cannot be captured, making identification of most pigments impossible. The image cubes acquired with the XpectralTEK system enhanced our ability to diagnose and identify the materials of the artworks studies without using destructive sampling methods.

Technical photography requires a significant practical and knowledge base of photography. The set up requires adjustment to ensure the images are faithful to the artwork being documented. Replicating the same set up at different moments of treatment is laborious. Frequently the images taken using different lighting conditions are difficult to correlate or register because the lighting set-up (distance and angle from the object)

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[8] SRAL currently uses a modified Sony A7RIV (61 MP) camera and a Sony FE 55 mm F/1.8 ZEISS Sonnar T* lens with interchangeable filters of Cosentino's Robertina set (v.2) for our Technical Photography needs. Photographs are typically taken using visible light, ultra-violet and infrared irradiation sources set at a 35°-degree angle to the artwork. Camera presets are used to ensure standardised photography in visible light (VIS), ultra-violet fluorescence (UVF) and infrared (IRP). Additionally, ultra-violet reflectance (UVR) images, infrared fluorescence (IRF) images and false colour infrared (IRFC) images can be made. The DSRL camera is tethered to a laptop which controls the camera through the Adobe Lightrooom software. An X-Rite ColorChecker Passport is used to calibrate visible images taken. The quality of these images is excellent and the colour accuracy is also optimal.

[9] See https://aiccm.org.au/national-news/summary-ultra-violet-fluorescent-materials-relevant-conservation.

is different. Focusing the camera in the different lighting conditions can be challenging as the focal point shifts with wavelength. For example, a UV image will typically record the induced visible fluorescence of the upper varnish layers, meaning that the focus on the paint layers will not be as clear. The quality of the images taken is determined by the equipment (and expertise) available. Shifting away from this traditional photographic set-up to a partly automated one utilising multi-spectral imaging (MSI) has the potential to enhance and expedite the acquisition of this essential documentation process and provide the conservator with more proficiency in analysing and diagnosing materials used by the artist, as well as distinguishing these from non-original additions. Degradation phenomena may also be identified and mapped and tracked over time if image capture conditions can be standardised using MSI or similar technologies. However, the system should be capable of taking images of large surfaces, at high resolution, without requiring stitching of composite acquisitions, to be considered a true replacement for traditional TP setup. XpeCAM X02 has an internal autofocus mechanism that corrects for the focusing when shifting from UV to VIS and NIR spectrum, resulting to sharp images across all the wavelength range. Furthermore, XpeCAM Platform is equipped with advanced co-registration algorithms that solve the stitching issues across the wavelength range, enabling the direct comparison between the multispectral images.

5 Multi-spectral Imaging (MSI)

Multi-spectral imaging (MSI) uses a mono-chromatic camera linked to a set of filters and lights. The filters block wavelengths, below and above a narrow bandwidth, arriving at the sensor. The same lighting rigs can be used as for technical photography. Images taken at incremental stepped wavelengths are calibrated and registered on the sensor. Once collected these images can be processed. The camera, lights, and object are not moved between captures. Filters can be placed, either externally or internally, on an automated wheel to minimise displacement. The resulting set of images needs to be correlated to ensure that the pixels from each image/wavelength can be overlaid, and sequential spectral information can be extrapolated from each pixel. Other systems utilise lights that emit in a narrow bandwidth to limit wavelength. The use of a higher number of discrete images relative to narrow bandwidths allows the shift in surface response to the incremental wavelengths to be highlighted and subsequently reference spectra obtained can be analysed.[10] Pigment distributions can be mapped and inconsistencies such overpaints visualised more clearly.

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[10] A reflectance spectrum shows for each wavelength the ratio between the intensity of the reflected light and the incident light, measured with respect to a standard white reference. This ratio is called reflectance and is given in percentage (%). Reflectance spectra can provide information useful for the identification of pigments since the light that is not reflected is absorbed or transmitted depending on the chemical composition of the material tested. The reflectance spectral features of materials in the UV/ vis range are attributed to electronic transitions while those in the near infrared (NIR) range to fundamental vibrational overtones and combination modes. Analysis by reflectance spectroscopy is based on building up an appropriate reference spectra database, in the case of art examination, a reflectance spectra database of historical pigments. Cosentino, Antonino. (2015). Multispectral imaging and the art expert. Spectroscopy Europe. 27. p. 6.

The collaboration with XpectralTEK allowed SRAL conservators to review how we undertake our technical photography and documentation. We wanted to streamline condition checking, diagnostic methodologies, and dissemination of results to clients, students and partners. Additionally, we wanted to extrapolate more from the images we take, and use the time invested in documentation and condition checking more efficiently to gather more information about the material-technical aspects of the paintings in our care. As part of a new Memorandum of Understanding (MOU), XpectralTEK provided SRAL with the XpeCAM X02, LAMPAs and access to the novel XpeCAM Platform for trial testing (Figs. 3 and 4). SRAL conservators and a team of young emerging professionals, led by Kate Seymour, put the system through its paces to discover the potential of this AI system.

Fig. 4. The XPECAM and LAMPAS. © Kate Seymour

XpectralTEK high resolution camera XpeCAM X02 allows for imaging in real time. The instrument's advantage over imaging systems is its potential to carry out on-site real-time analysis of materials imaged via a spectrometer function. Moreover, the quality of the lens results in sharp images across all the wavelength sensitivity range. This allows the camera to not only to image art objects between 350–1200 nm at good quality and resolution (6.5 MP), utilising a series of narrow band width filters (in increments of 10 nm in the UV, 25 nm in the VIS, and 50 nm in the NIR range), but also to carry out monitoring functions and characterisation of (surface) pigments, including mixtures. The camera can image and obtain millions of spectra from the surface at different spatial

points, plotting the information on a graph and image. Furthermore, post processing, such as false colour imaging, and mappings of paint classification, can be applied to digital photographs to make any alterations in underdrawing or as overpaint more easily visible.

6   Baseline Projects

Fig. 5. CHSOS Pigment Checker (2018). RGB generated image (left) and pigment classification XPECTRALTEK platform (right). © SRAL

After an initial, remote instruction session, the team began by acquiring image cubes from a number of baseline projects (Fig. 5). These baseline projects consisted of known paint-outs (pigments bound in a medium) that would provide additional capacity for the database of pigments used by the AI system to determine pigment identifications and mappings. The initial trials acquainted the SRAL team with the XpeCAM camera, setting up the LAMPAs (lights), working with the DRT and navigating the capture process. The team began by examining the CHSOS Pigment Checker (2018).[11] This has known pigments bound in gum Arabic applied to a watercolour paper. These are pure pigment systems, i.e. non-mixed pigments bound in the medium, which provide clear and distinctive spectral reflectance spectra. Paints consisting of mixtures of pigments are challenging for traditional MSI systems to identify. Additionally, the SRAL team were curious to see if the XpeCAM Platform could identify accurately mixtures. Thus,

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[11] URL: https://chsopensource.org/pigments-checker/ [accessed 13 January 2022].

the second baseline project studied was a copy of a 17th century panel paining made as part of the SRAL training programme in 2005. The pigments used and the application processes were known, which simplified the interpretation of the images acquired. As expected, the team observed the underdrawing emerging as the wavelengths increased. The response of the Lead White and Vermilion pigments were also as expected in the near IR region. The two baseline projects assured the team that the operating system was easy to use and intuitive.

7   Case Studies

1. An eighteenth-century Dutch canvas painting, the Kapittel van Thorn by an unknown artist, was brought to the SRAL conservation studios for treatment in early 2021.

This large oil painting, measuring 202 × 121 cm (height × width), dates from 1709. The painting belongs to the Abbey of Thorn and was requested for loan for the 2021–2022 exhibition "The forgotten Princesses of Thorn" at the Limburgs Museum, Venlo.[12] The painting shows the family crests of the various eighteenth-century princesses who lived at the Abbey in Thorn, depicted in an architectural setting, with a central portrait of the Princess-Abbess Kunigunde of Saxony, and a landscape showing the town of Thorn with the abbey (Fig. 6). The 2021–2022 Venlo exhibition examines the opulent daily lives of the German princesses, combining objects, letters, clothing, and jewellery with portraiture, illuminating the daily lives of these noblewoman. This painting is key to the didactic aspect of the exhibition, as it sets the scene for the environment in which the princesses lived and acts as a form of introduction to the women.

The painting was badly damaged in the past and has two wax-resin linings glued to the reverse, applied to provide additional support to the fragile original canvas and paint layers. Several layers of natural resin varnish had yellowed over time, reducing the clarity of the original paint colours. Overpaint was clearly visible across the painting, due to its poor colour-match and differing texture to the original in normal light. This had mostly been applied to disguise losses and wear to paint passages or to conceal tears to the canvas. The conservation and restoration treatment (undertaken by SRAL Conservation Fellow Alice Limb, with supervision from Luuk Hoogstede) focused primarily on removing these disturbing varnishes and overpaint campaigns and on improving the textual clarity of the worn inscriptions, allowing the painting to fulfil its didactic purpose of introducing these key Abbey figures and their familial allegiances once more.

As the extent and non-original nature of these overpaint campaigns was already known to SRAL conservators using conventional TP and visual methods, the Kapittel van Thorn was identified as a suitable trial project for the XpeCAM X02 and Xpec-CAM Platform. The hope was that the distribution of non-original material could be thoroughly mapped, with the resultant image cubes providing additional information - including information pertaining to the pigment composition of the various overpaints. Due to their familiarity with materials and methods of northern European painting of the

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Fig. 6. Kapittel van Thorn, 1709. Abbey of Thorn. 202 × 121 cm. After Treatment. Visible light. © SRAL

early eighteenth century, as well as their close examination of the original paint surface (including under microscopy), the conservators had a good idea of the likely pigment composition of the original. However, the pigment composition of the overpaints was largely unknown. Resolving these pigment questions would help to confirm the suspected dates of these restoration interventions. The team also hoped to confirm that the detailing in the quadrants of the coats of arms was authentic. Imaging with the XpeCAM X02 took place prior to and during varnish removal, meaning that some areas imaged were free of varnish, while others were still covered by a degraded layer of yellowed natural resin varnish.

Examination in UV light illustrated the distribution of the multiple overpaint campaigns present above and below the top layer of varnish, due to the quenching effect of overpaint on UV-induced autofluorescence (Fig. 7). TP (IR) images showed the extent of

Fig. 7. Kapittel van Thorn. Detail. Coat of Arms. Upper Left: TP (VIS) after treatment. Upper Right: TP (IR). Lower: False-colour generated from VIS and IR. © SRAL

overpaint and provided insight into the material beneath these non original layers. The false-colour image, created by substituting the red channel of the TP visible image with the TP infrared image, showed pigment distribution, but could not be used to elaborate on pigment identification as many blue pigments appear red in the FCIR imaging.

The AI spectral processing of the captured images successfully identified the 'whitish' overpaint present in many of the backgrounds of the Princesses' crests as containing Titanium white, a pigment that was not yet in use in 1709 (titanium white was first produced for artist's purposes during the 1920s).[13] This supported the existing interpretation that the overpaints were fairly recent, likely applied after the most recent structural intervention. This wax-resin lining was dated to 1938 by an inscription on the reverse of the second, outer lining canvas, further correlating to the known date range of titanium white usage.

In other areas of the Kapittel van Thorn, the AI spectral interpretations were less accurate (Fig. 8). The pigment Viridian was allocated to an area corresponding to the original paint of the blue sky by the AI algorithm. Viridian cannot be present in the original paint as this pigment was not in use in 1709 (it was developed in the mid-nineteenth century).[14] Manual comparison of the original blue's reflectance at a variety of known wavelengths in the IR region with the reflectance of reference paint samples at the same known wavelengths was undertaken using captures from the SRAL IR camera as well as XpeCAM captures, which were uploaded to and processed by the XpectralTEK system but not interpreted by the AI. These, coupled with microscopic examination of the paint surface, pointed to the original blue in the sky being azurite. Azurite is a copper-based blue pigment frequently used prior to 1724 (when even cheaper Prussian blue became widely available) by artists seeking to imitate the far more expensive natural ultramarine. In another area of the sky, examined prior to varnish removal, original blue passages with a layer of varnish were identified by the XpectralTEK system as containing the yellow pigment orpiment. While orpiment is possible in a painting of this date (the pigment has been used by artists since antiquity), it would be unusual to mix it into a blue area. Under the magnification provided by a stereo-microscope, the paint film appeared to contain lead white, blue particles thought to be azurite and some small black particles (probably vine or ivory black). The SRAL conservators were therefore surprised by the allocations suggested by the AI algorithms and notified the XpectralTEK team. It seems that the yellowed varnish residues on the surface of this uncleaned area gave a spectral response of this area similar to a reference spectrum that contained orpiment. However, where the yellowed varnish layers were removed, the AI algorithm accurately allocated azurite. This situation could be avoided by allowing the end-user (a conservator with knowledge of historical pigment usage) to confirm or deny suggested pigment allocations by the AI system.

This feedback was given to the XpectralTEK team and hopefully will be incorporated in updates to the system. While anomalies and unusual instances can occur outside of the accepted date ranges of historical pigment usage, basing the reference database used to

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[13] http://www.webexhibits.org/pigments/indiv/overview/titaniumwhite.html [accessed 13 January 2022].

[14] The process for producing Viridan was patented in Paris in 1859. See http://www.webexhibits.org/pigments/indiv/overview/viridian.html [accessed 13 January 2022].
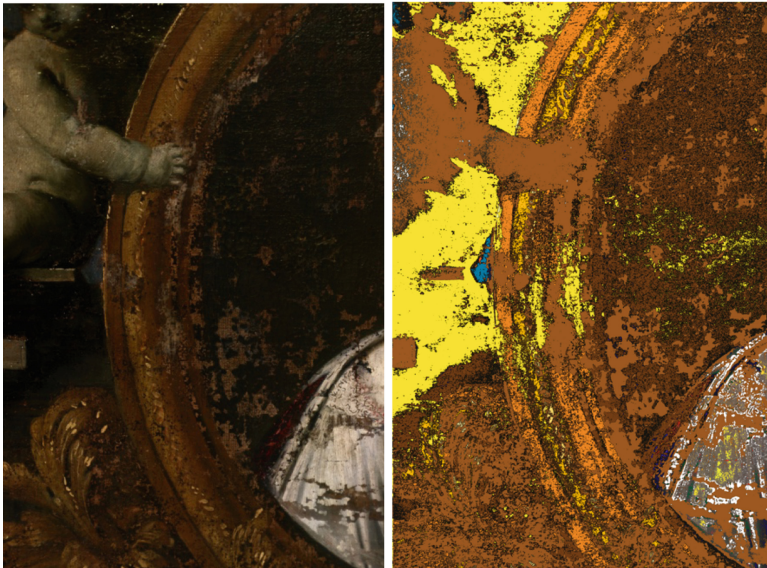
Fig. 8. Kapittel van Thorn. Detail. Putti and portrait of Princess-Abbess Kunigunde. Right: TP (VIS) after treatment. Middle: Detail X02 RGB. Left: Detail. AI pigment classification. © SRAL

inform the AI spectral allocations on existing evidence in conjunction with the known or suspected date of the painting under examination would result in more reliable inferences by the AI system.

The large size of this painting brought other factors under consideration when implementing MSI. The relatively small pixel counts of the CMOS sensor (6.5 MP), relative to the high resolution of the TP camera (61 MP), means that the camera does not provide enough resolution for the spectral imaging of the entire artwork in one capture. The maximum distance that the camera can be placed, when coupled with the 35 mm objective lens, from the artwork is 2 m; this gives a field of view of approximately 50×50 cm. It is therefore necessary to acquire a large number of captures, should one wish to image the entire surface. The details can be mosaiced together in order to achieve an image of the whole surface. These larger images are often very MB heavy and need computers with considerable processing power to view and manipulate. As yet, although the XpeCAM Platform has the cloud processing resources available to perform analysis of very heavy datasets, it does not provide mosaic possibilities, but this option is being planned and will greatly improve the ability to map pigments across large surfaces. When working with glossy or varnished paint surfaces glare from lighting was also found to be an issue, necessitating changing the angle or position of the LAMPAS. This in turn can affect the quality of the spectral data acquired as well as the ability to replicate imaging conditions, so basic geometric photographic principles must be applied.

2. Nineteenth Century Mural Painting, Altar frontal, the chapel of the Holy Appearance, St. Servaas Basilica, Maastricht. (1893–1894). Pierre Cuypers' studio.

The Chapel of the Holy Appearance (1893–1894) is an iconographic rarity. Two carved angels stand on top of the altar holding up the venerated painted veil of Veronica above the frontal depicting the prostrate, enshrouded (painted) body of Christ entombed within a stone niche (Fig. 9). The free-standing altar is placed within the chapel with walls either side set with votive stones that match the decoration scheme in shape and colour. The ensemble, a tromp d'oeil masterpiece, was created by the studio of Pierre Cuypers, in a typical Neo-Gothic style. The painted surfaces were constructed in two phases 1858–1865 and 1886–1899.

The altar frontal requires conservation treatment. Successive and ongoing salt damage has caused paint layers to flake. There is evidence of previous consolidation and overpaint, as well as considerable fresh losses in the white areas and blue background. These retouches are discoloured and becoming visually evident. There is also a discoloured, greenish, coating that is disturbing. This seems to be applied solely to the blue zone. There is also evidence of additional overpainting in the stone area. It is likely that different phases of conservation treatment exist.

The research carried out as part of the XpectralTEK trail aided SRAL conservators in identifying areas of original paint and distinguishing these from later applied overpaint. While the overpaints in some areas had discoloured, in other paint passages it was very difficult to determine the retouches. The blue background was especially problematic as the 'yellowed' coating masked the edges of the applied overpaint. The AI mapping function was applied and differences in the spectral response in the white

and blue paint passages could be interpreted. This overview indicated the extent of the previously applied overpaint. The information provided an easy manner in which to quantify the extent of the overpaint and estimate the time-scale required to treat the art work. Cleaning tests were carried out to reduce the yellowed coating. The mapping compilation guided the conservators to test in areas where the overpaint was not present and provided assurance that any pigment removed where the overpaint was present was not original.

The pigment distribution maps provided by the AI algorithms clearly show the difference between original pigment paint passages and retouches (Fig. 10). Azurite pigment was used to make the paint in blue background. The pigment distribution map clearly shows the extent of loss due to flaking paint caused by salt efflorescence in this area. The 'voids' in the azurite map match the map of losses. The gilded halo had been retouched in the past with paints containing cadmium yellow. The sporadic distribution of this pigment in the corresponding map clearly shows that this was applied in a non-uniform manner and thus relates to a later addition. Additional maps plot the distribution of other pigments used by Cuypers' studio and later overpaints. The distribution maps provide a quantitative value to the amount of overpaint and losses present, information that was of considerable use to the SRAL conservation team when making condition reports and treatment plans for this artwork.

The examination of this altar frontal took place on-site in the chapel. This project allowed the SRAL team trialling the XpectralTEK system to experience fully the portability of the system. The lightweight, cube-formed camera fits neatly and securely into its own carry case and the two LAMPAs, and connecting cables, into a second. Two tripods, the DRT target and the laptop complete the equipment. The compact system is easy to set up on-site and meant that new operators quickly picked up the functionality of the system.

The XpectralTEK system is not without is teething problems. The collaboration provided a unique opportunity to work with the design and development team at XpectralTEK, providing feedback and commentary. The team at SRAL immediately were taken with the automated system. The unique manner in which the Bluetooth system provides connection between the lights and the camera is smart and useful, eliminating excessive cabling between the parts of the system and ensures minimal irradiation towards the artwork. Minor logistical improvements would include providing a longer cable connecting the LAMPAs. The length provided was same as the optimal distance that the light positioning required, but this optimal positioning proved difficult to maintain when working on-site, or with larger paintings. The automated switching between light sources housed within the LAMPAs was useful and user friendly. The team appreciated greatly the ability of the system to change the mode of wavelength by itself, depending on the light that is selected. This enhanced the operator experience and ensured a high level of safety. Once the lights and camera was set up the operator did not have to move away from the laptop to operate the entire system during an entire cube capture. Uploading the captured images to the platform was quite challenging due to hardware, network and server security issues, but the constant help provided by the XpectralTEK team helped overcome all issues.

Fig. 9. Altar Frontal. Chapel of the Holy Appearance, St. Servaas Basilica. Mural Paintings. TP (VIS). © SRAL

Overall, the SRAL team was impressed with the system - the hardware, the software and the usability. While, the AI processing also requires some adjustment, particularly when dealing with varnished paint surfaces, we are confident it will improve as the reference databases used to train the AI algorithms become more extensive. We believe

Fig. 10. Chapel of the Holy Appearance, St. Servaas Basilica. Detail. Head of Christ. Upper left: AI RGB. Upper Middle TP (UV). Upper Right. AI Mapping Losses. Lower Left: AI Mapping. Cadmium Yellow. Lower Right. AI Mapping Azurite. © SRAL.

that this system will indeed develop to become a powerful tool for researching and diagnosing artworks in preparation for conservation treatments and other related tasks.

We hope that in the future the system can be also tested to research microscopes to enable the study of cross-sections. Cross-sections are small sections of paint that are removed from the painting, mounted and prepared for stratigraphic and pigment studies. Using the MSI pigment mapping on these cross-sections could give a clear and accurate identification of individual crystals. Spectral data obtained can be directly compared to reference spectra without the problems that we encountered with pigment mixtures of painted surfaces or miss-attributions due to influence of non-original layers such as varnish coatings. Each grain of pigment can be mapped within the cross-section and the imaging of lower layers can also take place. We hope that this system can be adapted for these purposes in the future.

8   Conclusion

While this spectral analysis of pigment data still requires interpretation and confirmation by the end-user, the hardware and growing reference database associated with the software have the potential to be powerful tools for the conservation field. The camera comes with a C-mount lens which could easily be fitted to a research microscope and thus the system has the potential to image and analyse cross-sections. The XpectraTEK system further empowers the conservator with an affordable tool that will aid the quality of the conservation process and document treatment carried out. It will provide a collaborative spectral imaging platform, pooling resources and making interpretations more accurate, through the online cloud-based system the storage of raw data acquired by the XpeCAM X02 will be facilitated and can be used as a reference allowing for powerful analytics and accurate scientific correlations. This system is very user friendly and has high

potential for the analysis of artistic materials. Taken as a whole, these data sets represent a practical and successful, non-destructive methodology to study artworks. Combined with other filters available on the XpeCAM Platform and other features provided within the platform the XpectralTEK system will enhance and expedite the conservators' job.

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