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Using 3D scanning to support conservation treatments for paintings

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Abstract. Various imaging techniques are used to visualise issues regarding a painting's appearance before, during and after conservation treatments, i.e. visible light photography (VIS) raking light photography (RAK), ultraviolet fluorescence photography (UVF) and reflectance transformation imaging (RTI). However, these techniques cannot always visualise and/or quantify conservation issues. This paper presents a new approach: colour, gloss, topography imaging (CGT). CGT's applicability as a non-invasive tool for evaluating and documenting conservation treatments in comparison to VIS, UVF, RAK and RTI is discussed. Applying this to case studies with different conservation dilemmas illustrates the technique's potential and drawbacks. CGT can visualise issues such as gloss variations, resulting from (previous) cleaning tests, (partial) varnish removal, and possibly dirt and material degradation. Furthermore, CGT can elucidate topographical issues such as bulging, and losses, and also visualise high-frequency surface variations (e.g. canvas weave and crack pattern). This results in an improvement of documenting a painting's condition, and the evaluation of treatments and their effects on the visual appearance may be quantified. In conclusion, this research shows that CGT is able to better visualise texture, gloss and colour information than existing techniques like technical photography, facilitating a more precise documentation and localisation of previous and current conservation treatments.

1. Introduction

1.1 The appearance of a painted surface and its changes over time

The surface topography of a painting may be influenced by the inherent materials used by the artist in creating the artwork, and the natural or induced changes of these materials over time. The surface texture is, thus, a product of the type of support utilised, the thickness of the preparation layers, the type of binding material and pigment used to create the paint, as well as the artistic techniques and style used by the artist, such as brushstrokes and impastos. [1] The appearance of the artwork begins to change as soon as it leaves the artist's studio as the inherent materials alter affected by environmental conditions and any subsequent conservation-restoration interventions. Thus, the current appearance of the painting is influenced by the materials it is composed of and its condition. These complex surface characteristics can provide useful information for those involved in the cultural heritage sector; not only to those preserving and conserving paintings but also to those who study and authenticate these artworks. Recording and even replicating painted surfaces will therefore be of use to curators, conservators and researchers. [2]

1.2 Visualising surface topography and other aspects of appearance
Technical photography is typically used to visualise and document the condition and the conservation treatment of paintings. Visualising topographical irregularities is carried out using visible light (VIS), raking light (RAK), and more recently a more advanced method called reflectance transformation imaging (RTI). The presence of varnishes and retouches are typically identified and located using ultraviolet fluorescence (UVF). However, the calibration and standardisation of these systems is limited and, moreover does not offer quantitative, and thereby comparable, outcomes (i.e. specifically for RTI).

More recently, Elkhuizen et al. developed a three-dimensional (3D) scanning system which provides a new approach to capturing surface characteristics, including topography, colour and gloss of paintings. [3] Although this approach was originally designed for the purpose of replicating appearance - using advanced 3D printing technology - in recent work it was stated that this technique might also support documentation and potentially also conservation treatments of paintings. [4] This paper will explain the technological possibilities of this technique using a number of case studies to illustrate its capacities and, furthermore, it will show how results can be used by end-users. The canvas paintings in question are currently being treated at the Stichting Restauratie Atelier Limburg (SRAL) by post-master paintings conservation students from the University of Amsterdam (UvA). The case studies include two nineteenth-century portraits painted by a British artist Matthew William Peters (1742-1814), of which one is a self-portrait and the other is a sketch depicting his wife. The third case study is an early eighteenth-century canvas painting of St. Peter by a Belgian artist Seger Jacob van Helmont (1683-1726).

2. Method
The following techniques have been used to capture (several key areas of) the case study paintings. The result section will discuss the specific use of the images for the interpretation of the various conservation issues per case study.

2.1 Technical photography
Visible light photography (VIS) is a commonly used documentation method, used by the conservation community to record the current state or condition of artworks.[5] This provides colour information which is used to record the appearance of paintings. From this initial illumination position, the two light sources are adjusted, in order to minimise disturbing reflections on the painting's surface. Ultraviolet fluorescence photography (UVF) uses a similar set up but replaces the two visible light sources with ultraviolet lamps. Induced fluorescence patterns emitted by photosensitive materials are recorded. The complete surface of every case study paintings was captured in a single overview image, using both types of illuminants.

Raking light photography (RAK) is also a commonly used technique for visualising topographical information. A photographic image is captured using a low angle light source almost parallel to the surface. While this light source can be moved around the object, conservators tend to capture only one or two images from the lateral vertical sides of the painting.[6] The result is typically a black & white image showing shadows cast by high textural points over the surface of the painting. RAK were also captured of all case study paintings, resulting in two overview images per painting (i.e. left and right illuminated). Due to a lack of standardization and documentation of exact parameters, the repeatability and comparability (within and between cases) of this technique is low.

2.2 Reflective transformation imaging (RTI)
To obtain a fuller set of data, multiple shots (36 images) at different angles and using different light directions were taken according to the visualisation in Figure 1 and 2.[7] These images were input in the RTI software, a computational photographic system, which then compiled the images into an RTI interactive image. An algorithm calculates the 'gaps' in the lighting set-up and replicates the shadows cast over the whole surface from the data derived from the set of images taken.[8]

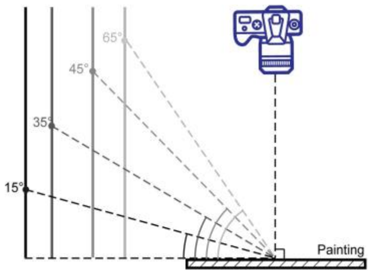

Figure 1. RTI side view

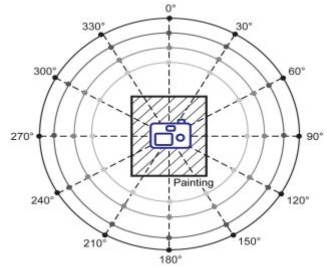

Figure 2. RTI top view

2.2. Colour, Gloss, Topography imaging (CGT)

The CGT imaging system consists of two integrated modules, one capturing the topography (and colour) and the other capturing spatially-varying gloss. The topographic scanning module uses two cameras, mounted at 40° angles (relative to the painting's surface normal), to triangulate the surface topography. The light source is a projector which illuminates the surface, positioned parallel to the painting's surface (Figures 3 and 4).[9] The scanner capturing the surface topography using a technique called 'fringe-encoded stereo imaging', originally developed by Zaman et al.[10] The technique relies on the projection of fringe patterns and stereo imaging, to triangulate the topography of a painting's surface. Surface reflections are filtered by the cross-polarised setup of the illuminant (projector) and cameras. The resulting heightmap is processed and can be visualised in two different ways; first the data can be plotted 'as-is', where the visualisation range is used to show complete height variation of the surface (i.e. the canvas bulging and losses). Secondly, the lowest frequency can be filtered out, so that the data visualisation range can be used to better visualise the high-frequency variations of the surface, which would otherwise not be or be less visible, due to the lack of contrast, locally in the image (i.e. showing the canvas weave and crack pattern).

The spatially-varying gloss is measured by utilizing the polarisation of reflectance, produced by illuminating a painted surface with a LED-array source placed at a 56° angle to the paintings surface normal. The surface gloss is recorded by a camera which has a polarisation filter fitted to the lens. This is mounted on the opposite side of a 56° angle. Pictures are then taken with and without reflection of the surface. Gloss maps are generated following the procedure described by Elkhuizen et al. and the obtained gloss maps are projected onto the topographical maps.[11] These gloss maps highlight the subtle differences in surface reflectance. These images are visualised in grayscale where, lighter regions signify higher glossiness. Both modules are mounted on a stage which can be moved along x- and y-axes. The cameras capture a surface area of 184mm x 91mm, so larger surfaces consist of multiple images mosaiced together. Overlaps are built into the positioning of the cameras.

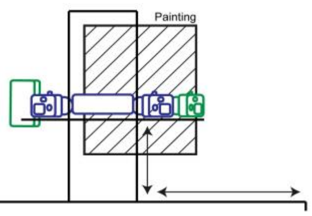

Figure 3. Schematic of CGT scanner front view with the x-axis and y-axis

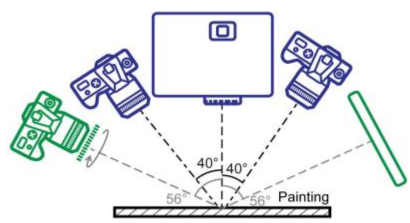

Figure 4. Schematic CGT scanner top view

3. Results

The three case studies illustrate how the results of these scans can be used by the conservator. The potential of the system will be defined by establishing limits and pushing technological boundaries, as well as interpretation of results. For this reason, it is essential to discuss not only successes but also the limitations of this new system for studying painted artworks. The case studies represent different typologies of painted surface in different conditions, state of conservation and problematics. This individuality aided in determining the potential and capacity of the CGT system. The paintings were scanned at different treatment stages. Captures and resulting maps were compared with traditional technical photography images.

3.1. Case Study 1: Self-Portrait by M. W. Peters

This portrait has a severely discoloured varnish layer and the surface is covered with an even layer of dirt deposits (Figure 5). A different craquelure pattern has developed in the paint layers where they are protected by the wooden stretcher bars. Furthermore, a rectangular deformation in the support, and overlying pictorial layers is easily identified in the upper section (Figure 5-I.a-f). This deformation results from the application of a label to the reverse of the canvas support. The glue used to adhere the label has caused the canvas to react differently to fluctuations in relative humidity resulting in the visual deformation, as well as the creation of a divergent crack pattern within the rigid ground and paint layers.

CGT was used to record the painting's extensive craquelure pattern, as well as to document topographical differences. The RTI captures lack accurate detail making it hard to disseminate differences in surface topography. Moreover, the high resolution CGT scans proved useful for extracting and visualizing both the detailed differences in craquelure patterns, as well as the defects in the global topography of the painting (Figure 5-I.a-e). The CGT height map clearly highlights the different topography of the area affected by the label (Figure 5.I.f).

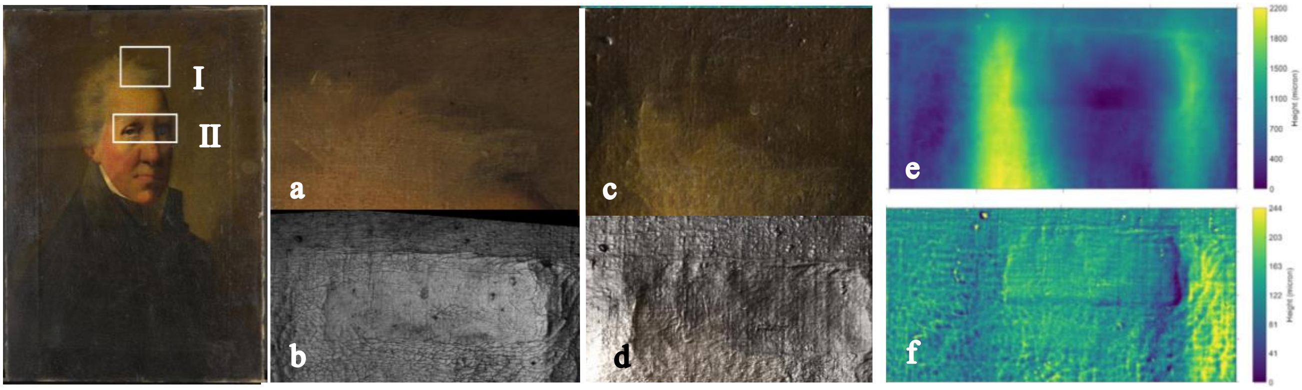

Figure 5. Matthew W. Peters, *Self-Portrait*, 1807. Oil on canvas, 46 x 61

Figure 5-I. (a) VIS, (b) CGT gloss map, (c) RTI, (d) RTI specular enhancement, (e) CGT false-coloured global height map, (f) CGT false-coloured detailed

Furthermore, CGT images uncovered that RTI does not show comparable potential for accurate visualisation of actual surface gloss. This became evident when scanning the face of the Figure. While the CGT gloss map detected matte paint in the pupils of the man (Figure 5-II.a-f), the RTI spectral enhancement capture showed no such indication (Figure 5-II.f). The mattness of the paint in this area has not been suggested by any other technical photography technique used. This can be explained by the fact that the RTI captures images at the specular reflection direction, and is thereby unable to detect these variations in gloss, which are particularly distinct with the specular peak reflection. The cause of the matteness of the eye regions cannot be determined based on these visualisations and

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requires further investigation. Repeating the scan after varnish removal is expected to assist in understanding this material behaviour.

Figure 5-II. (a) RAK (front), (b) RAK (left), (c) VIS, (d) CGT gloss map, (e) CGT false-coloured height map, (f) RTI specular image

3.2. Case Study 2: Female Portrait by M. W. Peters

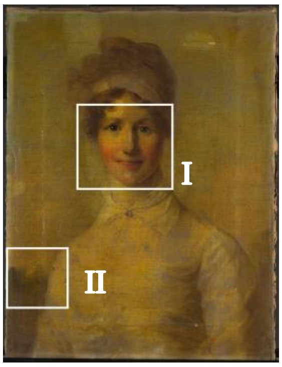

Figure 6a. Matthew W. Peters, *Female Portrait* ca. 1810. Oil on canvas, 46 x 61 cm.

Figure 6b. *Female Portrait* photographed with a 45° angle

This painting appears to have been designed as a sketch and as such has a different layer build-up than the accompanying self-portrait (Figure 6a & b). There is no evidence of a ground layer and the paint is applied thinly and loosely, leaving parts of the canvas exposed. The original surface was later obscured by multiple layers of a now-discoloured varnish. A relatively thick layer of surface dirt covers the surface. Signs of previous cleaning tests in this layer are present. The resulting surface has an irregular appearance and an uneven surface gloss, which is visualised with an additional photograph of the painting, under specular reflection direction imaging (Figure 6b & 6-I.a). Furthermore, observations using UVF indicated a section, to the left side of the woman, where the surface dirt was removed in the past (Figure 6-I.c). The strongly fluorescent varnish layer is easily identifiable using this standard technical photography method, but not when observing the surface in VIS (Figure 6-I.b). Whereas the RTI specular enhancement image shows no sign of gloss differences on the surface, CGT can detect and visualise gloss deviations (Figure 6-I.d). Therefore, the results show that RTI cannot be used to illustrate surface reflectance of paintings. The spatially-varying gloss differences that are visualised by the CGT, correspond to what can be seen visually (also see Figure 8b), but do not seem to correspond to the areas where the dirt was removed earlier, thereby showing the fluorescing varnish. As of now, the cause of the differences between these two modalities - UVF and gloss - remain unknown.

Figure 6-I. (a) RTI, (b) VIS, (c) UVF, (d) CGT gloss map of the face of the sitter. CGT gloss map indicates glossier surface in areas that appear lighter in the image.

Comparison of the results obtained from CGT and RTI indicate that the RTI specular enhanced image could be easily misinterpreted. The lower left section of the background depicted behind the sitter shows a rough outline of vegetation (Figure 6-II.a-e). The form of trees is insinuated by the artist rather than painted with natural precision. This area is difficult to 'read' in the RTI specular enhanced image as it appears dark and has little distinguishing gloss nuances (Figure 6-II.b). Without knowledge of the actual painting, it could be interpreted as some exceptional material behavior. However, the CGT maps clearly show that variations in both the gloss and surface texture are detectable, suggesting an interplay of different materials (Figure 6-II.d &e).

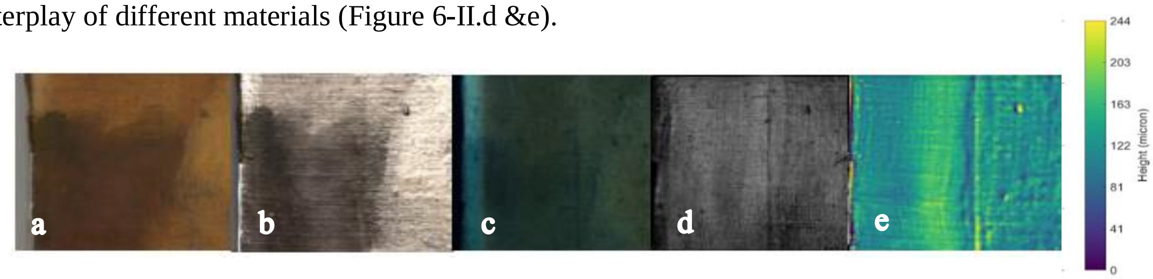

Figure 6-II. (a) VIS, (b) RTI specular enhancement, (c) UVF, (d) CGT gloss map, (e) CGT false-coloured height map of the background near bottom left corner.

3.3. Case study 3: St. Peter, S.J. van Helmont

Figure 7. Seger Jacob van Helmont. *St. Peter*. ca. 1720-1726. Oil on canvas. 164.5 x 128.5 cm.

This case study gave the researchers the opportunity to see if CGT could be used to record and establish the effectiveness of the removal of varnish and non-original layers. The painting's original paint surface was obscured by thick yellowed varnish layers, which are in the process of being removed as part of the ongoing treatment (Figure 7). The varnish removal involves two steps: first the removal of the bulk of the varnish using the compress gel-tissue technique developed at SRAL and then using a more refined cleaning system to remove the residues of an older varnish.[13] Sections at different stages of varnish removal are present on the surface and were studied and compared using CGT and traditional technical photography techniques. The conservators hoped that the different materials present on the surface would reflect differently so that minute or non-visible residues could be detected. Furthermore, the paint surface is disturbed by the presence of overpaints situated on top of fillings to reconstruct paint losses. The structure and texture of the overpaints differ from the original paint layers, especially where they were applied over filling material. CGT was tested to assess its ability to document and situate overpaints on the surface of the painting based on subtle differences in surface texture and gloss. While the overpaints on *St. Peter* had discoloured and were thus easily identifiable visually, the scans could potentially be used in other projects where the overpaints blend more closely in colour to the original. Identifying these non-original materials using differences in gloss or height would expedite the conservation process.

The gloss-maps proved to be a good method for documenting the different stages of varnish removal. There is a clear decrease in gloss from the varnished surface compared to the surface cleaned from the bulk of the varnish (Figure 7-I.a-c). Again, a decrease in gloss is detected when the surface is cleaned from the older varnish residues (Figure 7-II.a-f). Visualizing areas with a higher glossiness - indicating an incomplete removal of the varnish – helped in identifying the locations and size of areas that required further treatment. In this case, the gloss maps proved to be more suitable for this purpose than the UV photographs, commonly used by conservators for this end (Figure 7-II.c). Due to the limited thickness of the varnish layers they cannot be detected in the topography scan. Furthermore we might assume that with partial varnish removal - leaving varnish residues on the surface - would likely not lead to very sharp height steps but rather smooth transitions which can therefore not be identified specifically as varnish-induced height variations. (Figure 7-II.d,e,f). The structure of the fillings in the paint layer can to some extent be recognised in the height maps due to subtle discontinuity of the canvas weave. However, this recognition still relied strongly on a direct comparison with the paint surface to confirm that the discontinuity in the height maps were caused by fillings. Thus, the height maps do not expedite the conservation process at present concerning this aspect. In contrast, the gloss maps were more useful in capturing the different texture and gloss of the overpaints compared to the original paint (Figure 7-II.a).

Figure 7-I. (a) VIS, (b) UVF, (c) Gloss Scan
Left: After removal of the bulk of the varnish. Right: before varnish removal)

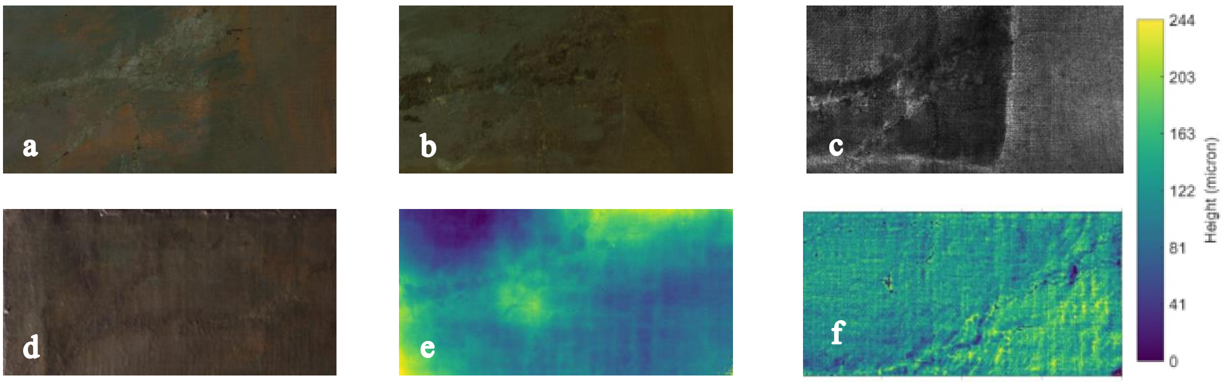

Figure 7-II. (a) VIS, (b) UV, (c) Gloss scan, (d) RAK left, (e) Height map (low frequency), (f) Height map high frequency) Left: after removal of varnish residues, right: after removal of bulk of varnish and before removal of varnish residues.

Conclusion

In this paper, we presented CGT as a method for documenting and quantifying visual material behavior using three different case studies. The case studies demonstrated that CGT's capacity to register gloss, topography, and colour provided more accurate data concerning the material behaviour and its effects on the aesthetics of paintings than more commonly used methods for photographic documentation. The gloss maps for instance, can provide conservators with a method of evaluating the efficacy of varnish removal by capturing gloss variations across the surface. The performance of the gloss scans to detect remnants of varnish exceeds that of UV photography. Overall, the CGT scans produce more detailed images with much higher resolution. Compared to RTI, CGT was found to be able to accurately document variations in gloss and topography where the RTI was revealed to be misleading in some cases, on these aspects. Moreover, the CGT is able to generate a quantified measurement, compared to the other visualisation techniques.

However, CGT also has several limitations. Firstly, it is not precise enough to be able to determine topographic differences smaller that the theoretical resolution boundary of roughly 30 µm. Furthermore, the set-up, calibration and processing of the images takes time, making it a more complex procedure in comparison to other techniques, albeit more repeatable. Moreover, the technique is limited by its depth-of-view, whereby paintings with large fluctuations in canvas shape (i.e. extensive warping) or overhangs cannot be measured. Despite these limitations, future technological developments for CGT show great potential when adapted for the field of art conservation. The results of the scanning might be used to 3D print specific areas of the paintings, which might in turn be used for topographical reconstructions of the flattened surfaces present on the self-portrait by M.W. Peters, for instance. Furthermore, when using these scans as zero-measurements and repeating the scanning process over time, this technology allows for consistent monitoring of the efficacy of conservation-restoration interventions. Additionally, at present the identification of fillings in the paint layer from the subtle discontinuities in the height maps is a time-consuming process, due to a need for continual comparison to the paint surface. Future research may focus on developing methods for an automatic recognition of divergent patterns in the height maps to clearly point out areas of interest to the conservator.

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