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Original article

Review of several optical non-destructive analyses of an easel painting. Complementarity and crosschecking of the results

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ABSTRACT

Five optical analyses of a given work of art are presented, using multispectral imaging, optical coherence tomography, goniophotometry, UV-fluorescence emission spectroscopy and diffuse reflectance spectroscopy. All these methods are non-destructive, contactless, and implementable in situ. They all lead to results in quasi-real time. The multispectral camera allows imaging of the whole painting with very high definition and recording of 240 millions of spectra. Optical coherence tomography allows local 2D and 3D imaging with in-face and in depth stratigraphies inside the painting with a micrometric accuracy. It allows the evaluation of the pigment volume concentration inside a layer, the measurement of the thickness of one or two varnish layers, the detection and measurements of gaps inside the paint layer, the depth of varnish micro-cracks. Goniophotometry allows the measurement of the upper surface state of the painting in different locations, by quantifying the mean slope of the facets making up the surface. UV-fluorescence emission spectroscopy allows the identification of the resin, the binder and the ageing state of varnishes by use of databases of reference varnishes. Diffuse reflectance spectroscopy leads to pigment, pigment mixture and dye identifications again by use of databases. The three last methods are implemented with the same portable multi-function instrument. It allows time saving, locations on request in front of the artwork and easy use by non-scientists. Each instrument is described with its protocol and accuracy. The studied painting is a portrait of a lady painted by the Austrian artist Franz Strotszberg, chosen for its several restorations. The five kinds of results are successively detailed, analysed and compared between themselves. It is shown that the different results are complementary and their crosschecking brings thorough information. For example, the shape of the network of varnish micro-cracks detected on the surface with the multispectral camera is added to the measurement of their depth with optical coherence tomography. Another example allows connecting two different surface states of the upper varnished surface measured by goniophotometry with the identification of these varnish with UV-fluorescence and with their thicknesses measured with optical coherence tomography.

1. Research aims

In order to avoid chemical analyses that need long waiting time, little destruction of the artwork and modification of the samples during their preparation, optical analyses are now systematically preferred. The latter are non-destructive, contactless and implementable in situ. They lead to results in quasi-real time and are easy to use by non-scientists. The number of analyses can then seriously increase and the studied locations can be chosen in real time on request of the curator in front of the artwork. Moreover, the results obtained with different methods are often complementary and their crosschecking brings thorough information. The presented non-exhaustive review describes the analyses of a painting from F. Strotszberg deduced from five optical methods: a multispectral camera, an optical coherence tomograph, a goniophotometer, a UV-fluorescence spectrometer and a diffuse reflectance spectrometer. The three last techniques are implemented with the same portable instrument.

2. Introduction

Non-destructive and contactless analysis is an important goal for preservation of the uniqueness of works of art. Portable instruments developed for this purpose avoid moving the artworks from their exhibition places [1]. Results provided in real time in front of the artwork and in the presence of curators or conservators allow a significant saving of time and the possibility of studying numerous

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locations upon request and taking into account the previous results. Finally, if the same instrument allows different kinds of analysis, its transport and implementation are more practical. Optics is then the ideal domain for answering these goals.

Several optical ranges and phenomena have been recently used for increasing the knowledge of artworks and for helping restoration and conservation. They mainly call upon diffuse reflectance spectroscopy [2,3], UV-fluorescence emission spectroscopy [4,5], goniophotometry [6] and interferometry used in Optical Coherence Tomography (OCT) [7–10]. The following review of different optical techniques shows that the results are often complementary and that their crosschecking generates more thorough information. To our knowledge, such comparison between optical analyses cannot be found in the literature. Nevertheless, this review is non-exhaustive. Other optical methods such as Raman spectroscopy, optical profilometry, confocal microscopy, IR-spectroscopy, holography... have been neglected in order to keep things clear. Moreover, the main purpose of this review is to gather different information on the same material (varnish layer or paint layer) and not to validate one specific result, even if this task is necessary. For instance, information on a varnish layer deals with its nature (UV-fluorescence), its thickness (OCT) and its surface state (goniometry). Information of the degradation state of a varnish layer deals with the shape of the micro-cracks (spectral imaging) and with their depth (OCT). Information on a pigment layer deals with its composition (reflectance spectroscopy) and its concentration (OCT). The collected information can be separated in two domains: imaging and identification.

Imaging can be separated in two parts. First, the reproduction of the superficial layer of the painting initiated by classical photography is now developed by use of a multispectral camera [11–13]. The latter produces images with very high definition (hundred millions of pixels) and the spectrum associated to each pixel opens new developments such as pigment identification, virtual varnish removing and quantified accurate colours. Second, in-face axial images inside the paint layers but also transversal stratigraphies in 2D or 3D can now be obtained by OCT without any sampling and without contact [10]. The spatial accuracy stands around the micrometer and is enough for imaging individual pigments in stratified pictorial layers or for measuring the thickness of a varnish. Both techniques are often complementary. For example, the network of micro-cracks in a varnish can be imaged and quantified by a multispectral camera and the depth of each crack by OCT with a micrometric accuracy.

In association with the previous imaging, the quantification of the surface state of a painting is also an important goal for restoration and preservation of works of art. The upper surface is often subjected to changes due to ageing, humidity, temperature, transport, lighting, varnishing or varnish removing. OCT can provide stratigraphies in order to follow such alteration in the case of strong changes [14], but goniophotometry in back-scattering configuration [6] is the perfect method to quantify such modifications, without contact and whatever the extent of the changes. Once again, the results can be crosschecked with OCT images for deeper understanding [15].

Finally, the identification of the materials (pigments, dyes and varnishes) is necessary for a better knowledge of the artworks and of the artists and is a useful tool for restorers and curators. It can be easily provided by optical spectroscopy with portable instruments. The results are obtained in real time, without contact, thanks to the comparison with spectral database. For pigment and dye identification, diffuse reflectance spectroscopy is used [2,3]. For varnish identification, UV-fluorescence emission spectroscopy is implemented [4,5]. Both recognitions lead to the most probable material, using mathematical and graphic comparisons but never to an unambiguous result, just as with other non-destructive analyses.

Fig. 1. The portrait of a lady, Franz Strotszberg (1811–1889) recorded with the multispectral camera of Lumiere Technology–illuminant D65.

Nevertheless, they have already been validated by other methods on several artworks for a long time [3,5]. Different recognized varnishes in a given painting can then be compared with the corresponding surface states measured by goniophotometry and with OCT images giving the varnish thickness.

The previous methods are developed in the following sections where the instrument is briefly presented with its accuracy. The protocol is explained in details. Examples on the same painting are presented and the results obtained by different techniques are crosschecked. Sections 2 and 3 are devoted to imaging, first with a multispectral camera, second with OCT. It must be noticed that OCT images with such a micrometric accuracy on a painting has never been obtained before today. Sections 4, 5 and 6 call upon the same instrument: a multi-function and portable goniophotospectrometer in back-scattering configuration. The quantification of surface states is first presented. Identifications of pigments, dyes and varnishes finish the review and the crosschecking of the different results is always pursued.

All these sections present the analyses of the same painting, a portrait of a young lady painted by the Austrian painter Franz Schrotzberg (Vienna 1811–1889, Graz) recorded with the multispectral camera and shown on Fig. 1. The artist is well-known for his numerous woman portraits of the royal court and high aristocracy and was a member of the academy in Vienna. The studied painting could be the portrait of the Countess Kinsky de Wchinitz of Lichtenstein and now belongs to a private collection. It suffered several questionable restorations that explain some surprising images recorded with OCT. Moreover, classical UV-imaging shows two homogeneous varnished areas and a repaint on the right part of the bottom of the nose.

3. Multispectral camera

The multispectral camera [13] developed by Lumiere Technology, shown on Fig. 2 is based on a CCD sensor array of 12,000 pixels moving along 20,000 vertical lines, that is an overall number of pixels around 240 millions. The size of each pixel lies between 25 and 70 μm^2 depending on the size of the artwork. For the studied portrait (316 × 387 mm) each pixel stands for 50 μm^2. Thirteen filters