More than images: how Ma-XRF maps and hyperspectral images work together in the study of painting materials.

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In the present work, we consider MA-XRF as an imaging technique; in this approach, we were able to get a deep synergy with the other imaging techniques, in particular with hyperspectral images.
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1. Introduction

In the context of paintings characterization, X-Ray Fluorescence (XRF) combined with Fibre Optics Reflectance Spectroscopy (FORS) is a well-known methodology [1], [2], [3]. The latter allows to classify the pigments constituting the external layers (few microns) of the painting while the former provides the fingerprint of the main chemical elements present in almost all layers (tens of microns) of the sample.

The synergetic application of XRF and FORS is a key issue for non-invasive scientific analysis of works of art since it exhaustively describes the pigments employed by the masters and supplies a first insight into their distribution in the painting layers. In recent times, a step forward has been made with the extensive application of hyperspectral imaging (HIS) techniques and of XRF mapping (MA-XRF).

HIS captures image data in hundreds of narrow contiguous spectral bands, producing at each pixel a precise light reflectance information. Besides, recent instrumental developments enable MA-XRF analysis directly at the museum using mobile XRF scanners and allow for the elemental mapping of large surfaces. The huge amount of data acquired by both HIS and MA-XRF are typically studied with method based on statistical analysis. In the case of hyperspectral data, the analysis of spectra from many image pixels requires the use of multivariate statistical analysis.

In this scenario, XRF and hyperspectral mapping synergy promises to be a decisive tool to deepen the knowledge on painting materials. Due to the spatial information they contain, the maps not only provide a straightforward reference for comparing the data, but also allow treating the whole spectra as a collection of three-dimensional images. Taking advantage of computer vision methods, we present an innovative approach that exploits the features arising from the XRF data to improve the description of the hyperspectral ones and vice-versa. Moreover, looking at the spectra as stacks of images, this method consent to extend the analysis to other regions of the electromagnetic spectrum such as ultra-violet and infrared.

2. MA-XRF as an imaging technique

In the present paper we present how high resolution visible images, visible fluorescence induced by UV light, hyperspectral imaging in NIR and visible regions, NIR reflectography, IR false colour imaging, visible and IR trans-illumination, and MA-XRF could provide pivotal information on the complex structure of paintings. In particular, we present the case study of Chariot Race (oil on canvas, 42 x 295 cm) by Giorgio De Chirico. This unusual piece shows various pictorial layers and peculiar painting practices: the employed analytical techniques have been chosen to get synergetic and complementary information, starting from the consideration that the datasets refer to different depth layers. Indeed, we took advantage of the different penetration depths of electromagnetic radiation in different wavelength ranges. In general, penetration depth depends on the incident and the outgoing radiation wavelength as well as on the material investigated. Namely for visible and IR radiation, the penetration depth is linked to the refractive index and the absorption of different materials present in the pictorial layers, ranging from a few microns up to one or two hundred microns under the surface. On the contrary, X-rays can penetrate deep into the matter: in this specific case, incident X radiation can surely pass through the complete stratigraphy. Outgoing characteristic X fluorescence of medium-heavy elements can still pass the whole thickness, while relatively light elements (such as Ca and K) have a higher probability to be absorbed. Therefore, the information given by these very different techniques are surely complementary, but not always, and easily, correlated. The challenge of our approach is considering XRF maps as an imaging technique, permitting the synergic superimposition of various images and a more direct comparison with the other imaging results, giving a deeper knowledge of the creative process of such an artist.

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