Documentation and analysis of some Picasso’s paintings by using hyperspectral imaging technique to support their conservation and stylistic matters

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Abstract. Imaging Spectroscopic techniques, also known as hyperspectral imaging, have been utilized in museums and conservation laboratories for documentation purposes and in support of restoration treatments on different types of artworks and archaeological objects. For more than a decade, several studies and research projects have been devoted to customize imaging spectroscopic instrumentation and methodologies to the specific needs of art conservation and applications in the museum context. Other issues arise such as the need to develop new image processing software, including the mosaicking of image-cubes, new pigment identification and mapping methods, visualization, and archiving of the results. The present communication reports the data obtained on two canvas paintings made by Picasso in 1917, presently in the permanent collection of the Museu Picasso in Barcelona. The hyperspectral data have been used to document his artistic technique and to define the chemical composition of the palette. In addition, these data supported the surface observations of the morphology and crack patterns of the paint layers in order to get a better understanding of the damage found. This study was carried out in the framework of an inter-institutional research project aimed to gain an insight into the failure mechanisms of modern and contemporary paintings.

1. Introduction

The present study was carried out in the framework of an inter-institutional research project “Study of the mechanical and dimensional properties of commercially manufactured paint films and their influence in the physical and chemical degradation of modern and contemporary paintings” (ProMeSA) whose aim was to gain an insight into the failure mechanisms of modern and contemporary paintings and to identify the role of artist’s materials in the degradation observed. [1]. Within the ProMeSA project, the study of the materials and techniques used by the artist, involved several different documentation and analytical methodologies. In particular, it was decided to focus on chromatic and
colorimetric analysis of Picasso’s (1881-1973) paintings belonging to the permanent collection of Museu Picasso in Barcelona (MPB).

Specifically, this project was focused on four paintings made by Picasso in 1917 during his stay in Barcelona. These cubist style canvas paintings, *Seated Man* (MPB110005), *Man with Fruit Bowl* (MPB110006), *Woman on an Armchair* (MPB110007) and *Blanquita Suárez* (MPB110013), were stored in Picasso’s family’s house until they were donated to the Museu Picasso in 1970 [1]. In this work the results obtained on two selected paintings among these four paintings, namely *Woman on an Armchair* (MPB110007) and *Blanquita Suárez* (MPB110013), are reported. The analysis were performed by using the hyperspectral imaging (HSI) technique covering the visible (Vis, 400-700 nm), near infrared (NIR, 700-1000nm) and part of the short wave infrared (SWIR, 1000-1700nm) range, and were addressed at documenting Picasso’s artistic technique and defining the chemical composition of the paintings’ palette. In addition, these data were intended to support the surface observations of the morphology and crack patterns of the paint layers in order to get a better understanding of the damage observed.

HSI is currently a well-established methodology for the non-invasive analysis of bi-dimensional polychrome objects for both documentation and analytical purposes. HSI devices acquire images in hundreds of narrow spectral bands, which allow the reconstruction of the spectra at each pixel in the imaged scene. Typically, hyper-spectral datasets contain millions of spectra and have a high redundancy, since many of them present similar spectral features. Thus, algorithms to reduce the dimensionality of data and extract the required information are needed to process these data. Typically, image-processing tools are based on multivariate techniques, including statistical methods, such as Principal Component Analysis (PCA), or automated classification methods, such as neural networks. When used to process the data acquired on painted surfaces, these methods allow the grouping and mapping of artists’ materials and alteration products according to their spectral similarities [2-4]. This provides elaborated images where the material’s distributions are mapped, thus enhancing aspects that are not detectable by visual inspection. The capability of visualizing hidden details is much improved when the HSI data cover the SWIR region. In this case, investigation of the painted surface is extended to the inner layers of paintings, thus highlighting the underdrawings, *pentimenti*, etc. [5]

2. Hyperspectral imaging technique

Hyperspectral imaging techniques combine the potentialities of spot reflectance spectroscopy with the advantages of digital imaging, by providing a high resolution reflectance spectrum for every pixel of the imaged surface. The set of hyperspectral data comprises a sequence of reflectographic images acquired on very narrow (less than 10nm bandwidth) and closely spaced spectral bands. The hyperspectral dataset is often referred to as file-cube, since each datum is univocally identified by two spatial coordinates (the x and y locating the pixel in the image) and one spectral coordinate (the wavelength \( \lambda \)). Thus, the file-cube includes in a unique set both the spatial and the spectral information on the imaged area.

A technical characteristic of hyperspectral devices is that usually the spectral selection is based on use of dispersive optical modules. The actual extent of the investigated spectral range depends on the type of detector: Si based CCD/CMOS (350-1000 nm), InGaAs (900-1700 nm), InSb, and MCT (1000-2500 nm) cameras are used. The entire spectral region of interest (400-2500 nm) cannot be inspected using a single detector, due to the limited sensitivity ranges of the available sensors. Consequently different aspects of the conservational problem can be tackled, depending on the device characteristics. The hyperspectral imagers may also have different optical characteristics in terms of field of view and spatial resolution. This affects the quality of the final images acquired.

The HSI system used in this work was designed and assembled at IFAC-CNR, as an upgraded version of a first prototype developed in 2002. It is based on push-broom systems that use prism-grating-prism (PGP) line-spectrographs connected to high-sensitivity CCD and InGaAs cameras, which operate in the 400-900 nm and 900-1700 nm ranges, respectively (Fig. 1). The two interchangeable spectrographic heads are fixed with the illumination module, which consists of a broad-band light source connected to
a couple of fiber-optic line-lights illuminators. These illuminators symmetrically project their beams at angles of 45° with respect to the normal direction on the imaged surface. This configuration guarantees that reflectance spectra are acquired in accordance with the 2x45°/0° illumination/observation geometry recommended by CIE for color measurements. The latter is an important pre-requisite for providing high-quality RGB calibrated images.

The optical module and the illumination system are fixed together and can be moved along two orthogonal, high-precision motor-driven linear stages. These permit movements along both the vertical and horizontal axes on the plane parallel to the surface of the painting. This structure is tailored to acquisitions on large paintings. The scanning is performed by acquiring adjacent vertical strips measuring about 7 cm in width, slightly overlapped at the edges. The present scanner covers an area of 100 cm x 100 cm without moving the structure.

3. Results and discussion

Blanquita Suárez is one of the works that Picasso painted in Barcelona in 1917, and is one of the most meticulous paintings he produced (Fig. 2). In this period Picasso performed new plastic resources developed after his Italian experience in the world of scenography, which led him to oscillate between cubism and realism.

The hyperspectral imaging study of Blanquita Suárez has provided new information about its creative process. More specifically, the study of IR data-images revealed a thorough preparatory drawing and evidenced that the composition is structured through the intersection of lines and planes where the figure of the dancer stands out. Picasso applied the color following this preparatory drawing as a pattern, covering the different planes evenly and without nuances. However, some modifications not visible to
the naked eye are present: namely, the curl on the top of the head - which he will later hide with what seems to be a green comb - and some of the leaves of the fan (Fig. 3).

![Fig. 3 – Detail of the sRGB image of the painting Blanquita Suárez (left); SWIR image at 1350nm extracted from the HSI cube-file (right).](image)

Blanquita Suárez was painted in June, coinciding with the dancer’s performance at the Tivoli Theater in Barcelona. The plastic parallelism between the postcards of the time and the plastic procedure of the painting is remarkable: Picasso used the lightest colors accurately for the figure, leaving the darker areas for the background in a similar way to the postcards - made from very realistic photographs- where the figure stands out from the dark background. In our opinion, it is the most scenographic painting of the whole set. The artist filled in each area with flat and opaque colors. By using light through color contrast, he was able to transmit some plastic dynamism while coding and categorizing colors, light and shadows.

Among the pigments used by Picasso, it was found the green pigment viridian, hydrated chromium oxide Cr$_2$O$_3$ • 2H$_2$O or Cr$_2$O(OH)$_4$, which presents a typical spectral shape in the 400-900 nm range, similar to the chrome green, chromium oxide Cr$_2$O$_3$, but with the absorption bands and its reflectance maxima shifted of approximately 20 nm to lower wavelengths than Cr$_2$O$_3$. In figure 4 the reflectance spectrum of the green right sleeve of Blanquita is reported together with the reference spectra of viridian and chromium oxide. The spectrum of viridian, as well as the chromium oxide pigment, is characterized by a strong absorption band in the ultraviolet spectral region (outside the sensitivity range of the present HSI setup), which is due to a ligand-to-metal charge transfer transition between the oxygen anion and the chromium, and by a double absorption band with two absorption maxima at approximately 430 nm and 620 nm due to the d-d electronic transitions, typical of chromium (III) in an octahedral coordination (Fig. 4). Viridian can also be recognized by its reflectance maximum at about 515 nm. Chromium oxide, on the other hand, shows similar spectral features shifted at 460 nm and 600 nm, respectively, while its reflectance maxima are positioned at approximately 410 nm and 535 nm. [6]
Fig. 4 – Green sleeve of Blanquita reflectance spectrum extracted from the HSI data (black) together to the reference spectra of viridian (blue) and reference chromium oxide (red) mockups.

In order to define the homogeneity and distribution of the above identified pigments, it was decided to use the spectral classification Spectral Angle Mapping (SAM) algorithm, which is one of the most applied methods for visualizing the areal distribution of selected compounds. SAM can be performed by using either reference spectra available in external databases or selected spectra belonging to the investigated scene. In this case, it was used as reference a spectrum from the analyzed painting (Fig. 4). The distribution of the viridian pigment, which was obtained by applying the SAM algorithm using the spectrum in figure 4 as reference, is reported in figure 5. The SAM distribution map was calculated with an angular threshold of 0.120. The pixels that are constituted by reflectance spectra similar to the reference one are visualized as light grey. From the results obtained it is evident that all the green areas of the painting were made with viridian.

Fig. 5 – reconstructed sRGB image of the painting Blanquita Suárez from the HSI data (left); SAM distribution map of the viridian pigment (right).
In *Woman in an armchair*, Picasso also worked by areas (Fig. 6). A look at the drawings preserved in the artist’s notebooks reveals that Picasso must had studied the composition in detail, as it appears outlined in graphite pencil, on various sheets. Picasso had probably brought to France the three drawing notebooks he used in Barcelona. His detailed sketches show the evolution of the works under discussion. In the notebooks, the drawings do not present a chronological order and repetitions as well as thematic connections can be found in all of them, oscillating between cubism and naturalism as previously explained. Picasso unfolds the shapes and reduces them to elementary planes by means of the intersection of lines in the drawings of *Woman in an armchair*. This painting could have been produced between June and November in 1917. It is also structured in areas, although the application of color is less uniform than in *Blanquita*, which could suggest Picasso’s evolution towards a “more pictorial” process by applying more fluid and dark colors in the background and lighter and more material in the foregrounds. The area at the bottom representing the newspaper with small parallel strokes simulating the black text over the white sheet does not seem to follow any pattern.

Here, HSI analysis has revealed the extensive presence of lead white pigment, which was used alone or in combination with other colors. Lead white has a typical absorption band around 1450 nm due to the first overtone of the hydroxide stretching fundamental vibrational mode. Even in this case, the SAM algorithm was applied to evidence the pigment distribution over the painting (Fig. 7). It is interesting to note that in the SAM map most of the red areas were rendered with the same gray scale level than the white ones, indicating the extensive use of lead white in these areas. On the other hand, in the medium-dark gray areas, even if they were made mixing a black pigment with lead white (XRF data), HSI data did not reveal its presence due to the strong absorption of the black pigment in the entire Vis, NIR and SWIR regions.
As indicated above, the approach to this study is mostly intended to understand how slight changes in the choice of the materials used by Picasso might lead to different damage patterns, considering that the paintings had a similar history in the last century having been kept in similar conditions.

The paintings under discussion preserve the original stretcher. Previous visual observation and chemical analysis, which were made by ARTE_LAB (Madrid) in 2016, showed that Picasso used mercerized cotton fabrics in both paintings. The seal of Casa Texidor (Barcelona, Spain) on the back of Blanquita Suarez reveals the supplier of materials during Picasso’s stay in Barcelona. In this research it was observed that both the density and weave geometry of the canvases, as well as the composition of the grounds and oil paint films together with the thickness of each layer, may have play a significant role in the extent of damage observed on the surface of each of the paintings studied. In this context, HSI data elaboration was addressed to help the analysis and observation of damage and allowed a more detailed view of the different crack patterns.

Woman on an Armchair presented some paint flaking in coincidence with the marks of the edges of the stretcher bars, as well as a random network of large superficial cracks in the central brown areas. Damage observed in Blanquita Suárez, however, differs in that the painted surface presents a regular network of small superficial fissures in the areas that are not coincident with the stretcher bars being local deep cracks at the top and the bottom of the painting - probably as a result of some unexpected mechanical impact- the most prominent ones (Fig. 3).

As reported above, HSI in the SWIR region has evidenced some differences in composition and materials. These differences were also stressed by the application of PCA to the SWIR HSI data of Woman on an armchair (Fig. 8). In this case, PC2 highlights the paint brushes and the homogeneity of the painted areas. Thanks to the satisfactory spatial resolution of the SWIR data-cube it was possible to enhance details of the brush strokes in order to visualize the execution technique with which Picasso created the painting (Fig. 8left). PC3, instead, highlights the presence of differences in areas depicted with same color, such as in the case of the white areas (Fig. 8right), even if these differences are not determined by the presence of diverse white pigments, as previously discussed. Furthermore, in PC3 the brown area in the lower right part of the painting disappears giving the impression that it was painted later.

Fig. 8 - PC2 SWIR: highlights paint brushes and homogeneity of painted areas (left); PC3 SWIR: the four white areas present different behaviors (right).
4. Conclusions

From the reported HSI data it is evident that this technique is mature for being used at the same time as a documenting and analytical tool to support conservators, curators and scientists in their decision making during surveys and conservation treatments.

5. Acknowledgments

The authors acknowledge the Ministerio de Economía, Industria y Competitividad (MICINN/FEDER) – Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia, Subprograma Estatal de Generación del Conocimiento for having financially supported part of this research within the ProMeSA Project.

The Programa para la Promoción de la Investigación Científica, el Desarrollo Tecnológi­co y la Innovación en la Comunitat Valenciana of the Conselleria de Educación, Investigación, Cultura y Deporte for having financially supported part of this research within the AICO/2019/231 Project (Estudio multianalítico de los mecanismos de degradación física, química y mecánica de pintura sobre lienzo) is also acknowledged.

Sonia Berrocal and Anna Velez at MPB are thanked for their assistance during the measurements at the Museu Picasso.

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