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Color and gloss measurements in cultural heritage conservation science : recent advances in France

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Abstract

The Ministry of Culture in France has its own center dedicated to the conservation of works of art from its 1200 national museums, called Center of research and restoration for French museums. It works on all types of artworks: jewelry, painting, furniture, bronze statues… The research department has several instruments, optical or chemical, dedicated to analyse the artwork's materiality before restoration or for art history purpose. Except color that has been studied since the opening of the laboratory in 1931, other apparence attributes were not included in analysis workflow. Recent advances in color and gloss measurements and their application to cultural heritage analysis and restoration are presented in this article.

Introduction

The Ministry of Culture in France has a center dedicated to the conservation of works of art from its 1200 national museums, called Center of research and restoration for French museums (Centre de recherche et de restauration des musées de France - C2RMF [1]). Created in 1931 and located at the Louvre Museum, it works on all artwork types : jewelry, painting, furniture, bronze statues…

It is currently organized into four departments: research, restoration, documentation and preventive conservation. The research department has a wide range of optical and chemical analysis instruments, mobilized according to the question to solve. It could be the analysis of materials before restoration or before purchasing by a museum, knowledge about an author, a period or even authentication. This department is made up of five groups, a group dedicated to objects, one dedicated to paintings and three analytical groups, one on dating, one on imaging and one on ion beam analysis with a particle accelerator.

The Imaging group takes care of producing the images to analyze the works of art with non-invasive and contactless techniques. Various radiations are used, X-rays, ultraviolet, visible light and infrared radiation. It also captures shapes in 3D scanning, at macro or micro level. The purpose of these images is to record the visual state of the work at a given time and also to understand the constituent materials, their internal structure and the manufacturing processes. Around 400 artworks per year are processed.

The appearance of a work of art is a major information in the knowledge of the object. In the main attributes of appearance, color, gloss, translucency and texture, color has been a subject of attention since the creation of the laboratory. However, historically, measurements of other appearance attributes were little developed for the analysis of works of art. This comes from the fact that vision models and light-measuring instruments were until recently not sufficiently developed or not easily accessible. With recent advances in these two fields, conservation science begins to consider appearance attributes as interesting data for understanding works of art. This article aims to review recent color and gloss protocols for the analysis and conservation of works of art in French museums.

Register color of artworks

History

The measurement of color was established in 1931 by the CIE, with the development of a reference observer. This model of human vision was the missing link to the already known physical measurements of light. Color is the best known and used appearance attribute, although the colorimetric values are only valid under well-defined conditions and do not yet take into account all the cognitive phenomena of colored appearance. Research on the subject continues but the CIE 1931, 1976 or CIECAM models are good enough to be used by industry.

In the field of cultural heritage, recording the colors of paintings has been a concern of the center since its creation. Indeed, in 1934 Dr. Fernando Perez, one of the two founders of the laboratory, noted the colors of a Velasquez painting using the color classification created by F.W. Ostwald in 1916. On a black and white photograph, the colors of the painting were compared to the classification and the corresponding number was noted (Figure 1). Press article indicated that this method will finally allow an accurate registration of colors, which shows the importance of this information for the field of application.

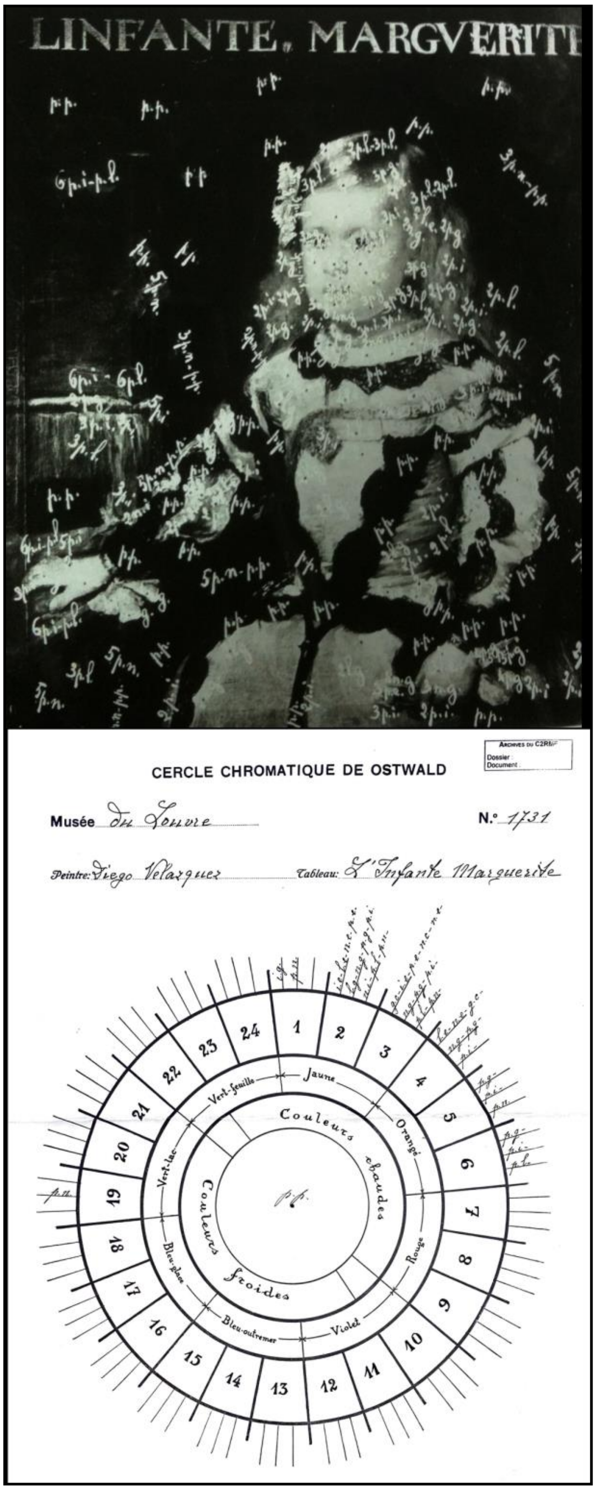

***Figure 1**. Color statement of painting of Velasquez using Ostwald color system in 1935.*

Long carried out by comparison with atlases or with descriptions in words, it was necessary to wait for the establishment of color photography in 1962 for a more precise recording entering the condition report file.

Since 2004, color photography has been completely digital. Colors are recorded in RGB and L*a*b* through chart calibration with an average accuracy of 2,1 delta E (45/0 geometry, Gretag charts, camera profile and reproduction mode of Phocus Hasselblad software). This rapid technique is used on almost all the artworks studied in the laboratory.

Few years ago, multispectral photography by calculating the spectral responses of the three photosensitive sites of the sensor by artificial intelligence has been put into production [2], which is a breakthrough in efficiency. If multispectral cameras have been used for cultural heritage since 2000 [3], the process with several filtered acquisition was very long. Now, a 35-point reflectance curve is thus obtained with only 4 filtered shots. This rapid acquisition is particularly used when the spatial spectral response is useful for material recognition.

For fast color measurements with maximum accuracy and reproducibility, point fiber optic spectrophotometers are used, in reflection or in transmission for transparent objects. In the 1990s, a device was even specially developed by the center to measure at a safe distance from the artworks (7,5 cm) [4]. Spectrophotometers have several nm resolution and range of wavelengths from ultraviolet to infrared ; spectral reflexion curves are mainly used to identify pigments by features comparison with known pigment spectral database [5]. In the visible domain, the CIE color calculation and the variations in delta E are finely controlled to evaluate safety of an exposure or a restoration treatment

Combination of photography and spectrocolorimetry has now evolved to hyperspectral cameras with acquisition precision of 1 nm. The spectral curve of reflectance is recorded in each pixel of the image, with 3 or 1nm of precision. Stable and spatialized color measurements are now possible. This technique is not yet used routinely for only color measurement, because it takes a very long time to produce. The spatially recorded spectral curves are used to map identical pigments on artworks, or to identify directly the material by comparison with spectral database. Identification often needs other techniques like XRF or Raman to confirm the hypothesis [6]. Research on hyperspectral pigment identification actually focuses on accuracy of classification algorithms for complex cases (non flat objects, mixed pigments…) [7, 8].

Applications

Measuring the colors of cultural heritage objects has several applications in the field of conservation science. The more obvious is the registration of colors as a condition report, in order to be able to compare them if a doubt arises about conservation issues. It could be redone when the artwork will be studied again in several years. It could also be done to check that no alteration has taken place after exposure or even to help to choose the adequate restoration protocol. Color could also be the main part of a research protocol, here we give two examples.

The first example comes from early color photography. The analysis of works by the inventor of color photography Louis Ducos du Hauron (1837-1920) aimed to identify the production techniques and constituent materials to help in their restoration [9]. Production techniques could be gelatin photo print (heliochromie), mechanical gelatin print (photoglyptie) or mechanical press print with oily ink (collotype). All are made with three colored images superimposed, yellow, blue and red. The 50 prints were analyzed by non-contact, optical (imaging UV to IR) and chemical methods (XRF). More than half were not identified or dated. By results comparison, unknown prints could be grouped with known ones. In the group of collotypes in particular, the materials found were similar and did not allow to distinguish any further. Following the idea that each production method used a coherent combination of pigments, binders, supports and varnish, leading to different color rendering, the colors of artworks (gamut) were compared in CIE31 and CIE76 color spaces. Directions of the three colors layers yellow, blue and red were compared as well as black and white point and global shape. Several prints were thus grouped and dated by comparison of gamut. Coherence of all other optical and chemical analysis were verified. Figure 2 shows examples of several gamut of dated works and similar gamut of non dated one.

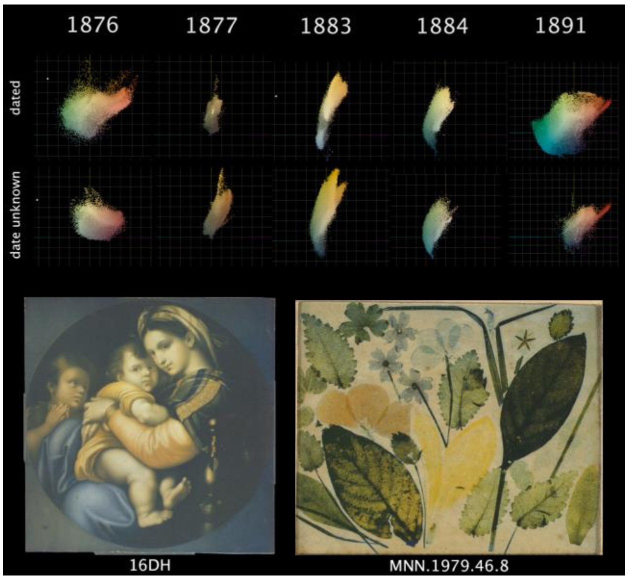

Figure 2. *Gamut of dated artworks from Ducos du Hauron (first line) and similar gamut of non dated one (second line). The two artworks in third line have similar gamut and were probably made the same year 1883.*

The second example is about preservation of contemporary art. Visual appearance has been used for the preservation of audiovisual artworks. Indeed, the technological obsolescence of reading and projection equipment makes them inaccessible today. To overcome this, museums are resorting to the massive digitization of their collections. The project (2008-2011) aimed to assess the impact of changing technology from film to digital [10]. Starting from the idea that the important thing was the film final visual rendering seen by the spectator, we sought to know if the differences in rendering were quantifiable? preventable? acceptable? This work was based on the particular corpus of avant-garde and experimental films. Indeed, these works are often based on visual effects created specifically for the film medium, and the transition to digital can alter the rendering of the film to the point of losing its meaning. We tested two major visual attributes: color and flicker (flicker: rapid temporal variation of luminance). Attributes have been measured during silver and digital projection and during several protocols of digitization. We linked the history of art, human vision and film techniques, while respecting the particular angle of conservation of cultural heritage works. We concluded that neither color nor flicker was preserved. Colors obtained from digitization were not well controlled because devices used were designed for television or cinema industry (Figure 3) [11]. Exact color reproduction is not needed for those industry as final rendering is made after this step following director's recommandations. Digital file formats used in the 2000s were not either suitable for artists' films : movie compression algorithms were not designed for non realistic movies and ruined most of visual effects. The last step of projection can be controlled in color but not for the flicker. Professional cinema projector integrates anti-flicker algorithm made to correct old movies, but that canceled visual flicker effects of the films we selected. As film scanners are far too expensive for museum, recommendations were issued to assist collection curators.

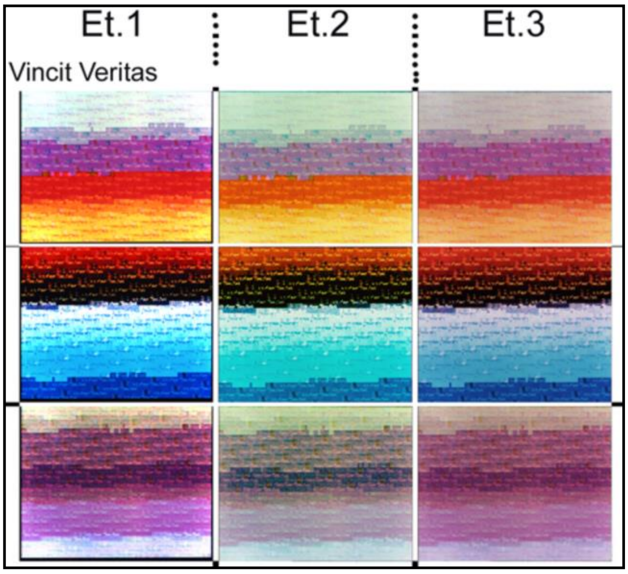

Figure 3. *Three photograms (lines) with three digitization protocols (column) of film Vinci Veritas, reMI, 2002, 35 mm. Colors are not the same, and do not correspond to original film. Taken from [11].*

Register gloss of artworks

History

Gloss is defined by the ASTM as "Angular selectivity of reflectance, involving surface reflected light, responsible for the degree to which reflected highlights or images of objects may be seen as superimposed on a surface" [12]. On the other hand, Obein et al. [13] define gloss as "an attribute of visual appearance that originates from the geometrical distribution of the light reflected by the surface; (...) given that gloss is a perceptual attribute, a full characterization of it will depend on both the particularities of the visual response to gloss and the underlying physics of the phenomenon".

In 1937, Hunter [14] suggested six dimensions of gloss, where two of them are perceptual dimensions, distinctness-of-image (DOI) gloss and contrast gloss [15, 16]. Leloup et al. [17] report that aspects influencing gloss perception are illumination, object properties, and viewing conditions (motion and binocular vision playing a role as well). Moreover, illumination geometry and type influence gloss judgements [18, 19, 20, 13].

In cultural heritage, as in various industries such as paint and printing, glossmeters are standard for gloss measurement [21]. C2RMF acquired a gloss meter around 1990, that measures the amount of light reflected in the specular direction in 3 angles of illumination. But it was not intensely used as there is little correlation between values measured by the glossmeter and glossiness perception [22, 17, 13]. Another disadvantage of glossmeters is that they provide an integrated measure of gloss over a surface and the measurements must be done at close range, at smooth or flat measurement surface. Some gloss measurements have been made using a spectrophotometer with fiber optic for source and sensor, moving by hand the angles of illumination but this method was too time consuming and lacked precision. Until recently gloss attribute of cultural objects did not have to chance to be evaluated.

Applications

Measuring, modeling and reproducing gloss could have many applications and perspectives in the field of cultural heritage. Some examples are to measure gloss as a monitoring tool to evaluate results of a restoration, and to gain knowledge about materials and manufacturing techniques or degradation processes. The modeling and reproduction of gloss, whether physically or digitally, can help in the reproduction or reconstruction of cultural heritage. Thanks to advances in optical and computing technologies, two PhD were recently conducted in C2RMF on gloss for cultural heritage.

The first research presented was conducted by Page et al. aims at measuring and reproducing the appearance of matte materials for the restoration of cultural heritage objects, using glossy 2,5D printer ink [23, 24]. The interest in this application comes from the wide range of cultural heritage objects which have a matte appearance and from the new possibility of using 3D printing for filling missing part during restauration. The work consisted of an appearance capture stage, followed by an appearance reproduction stage. For the appearance capture, the 3D shape of the object was scanned, and different attributes such as color, roughness and gloss were acquired. In order to reproduce the appearance of the desired object, the surface roughness was modulated to predict the gloss of the material. For this, a 3D shape was printed, followed by a gloss modulation layer, and a final color layer (Figure 4). In order to predict the gloss of the surface, different patterns of surface roughness were evaluated, using different pillar heights. A model was created which allowed to predict the gloss of the surface by changing the height of the pillars of a specific pattern. Moreover, psychophysical experiments were conducted to evaluate if the reproduced gloss corresponded to the perceived gloss. Finally, this method was used for the reconstruction of a missing piece from a Roman wheel tire from 2000 BCE. The reconstruction had a low gloss when observed at a distance higher than 50 cm, which was suitable for the needs of the conservators (filling must be detectable).

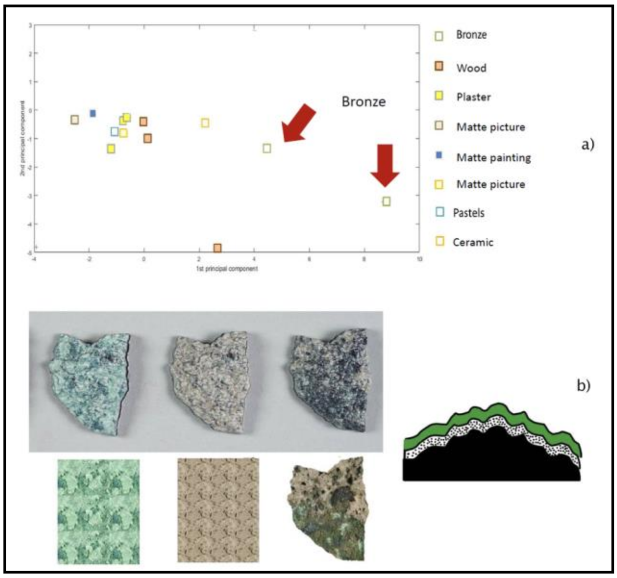

Figure 4. *a) Gloss values of a range of matte cultural heritage materials. ACP calculated with 12 roughness and specular gloss parameters. b) Printed object filling with different textures and color. The 2,5D printer did 369 layers, the middle white one is made with 80 µm pillars to generate mat , the upper layer is the color one. Taken from [23]*

The second research was conducted by Arteaga et al. aims at measuring and modeling the appearance of gilded surfaces, focusing on the gloss of metallic and non-metallic types of gilding [25]. Commercially available devices such as glossmeters and multi-angle spectrophotometers were used to acquire the appearance of the surfaces. It was found that the glossmeter values were not representative of the perceived gloss of the different types of gilding [26]. The research also found the multi-angle spectrophotometer was not adequate for a complete capture of the appearance of the gilded surfaces since the angular resolution near the specular reflection angle was not high enough [27]. As an alternative, an imaging-based method for the acquisition of the bidirectional reflectance of the materials was designed and evaluated [28]. Using this method, the bidirectional reflectance of the different types of gilding was acquired. The BRDF of the surfaces was modeled using the GGX distribution based on Smith's attenuation factor. The DOI and contrast gloss are calculated from the BRDF model coefficients of each type of gilding and used to evaluate their appearance. The differences between different types of gilding is characterized, as well as the effect of varnish (Figure 5). Notably, it is found that varnishing increases the contrast gloss of both water and oil gilding. However, in the case of oil gilding, varnishing increases its DOI gloss, while in the case of water gilding the DOI gloss decreases. The two different types of gilding have similar values of contrast and DOI gloss after varnishing. Imitation gilding is found to have the lowest DOI gloss and highest contrast gloss due to the different light matter interactions at the surface and sub-surface of the material [29]. Moreover, this method has been used to evaluate different chemical varnish removal methods commonly used in restoration. Based on the DOI and contrast gloss, the method which causes the smallest appearance change was used for the restoration of a 15th century gilded panel painting [25, 29]. This works lead to develop a miniature and transportable device to punctually measure the gloss of artworks. With this new tool, the measurements can be made but all the applications

for cultural heritage are still to be developed.

Figure 5. *Adobe SRGB render of the gloss and color appearance of the different types of gilding. Taken from [17]*

Conclusion

The visual appearance of heritage objects is what gives us access to these objects. It is through vision that we apprehend them, appreciate them. One of the goal of restoration is to preserve this appearance or, if surface treatment is needed, to restore an appearance closer to the original state. Color is a well known attribute but there are still some issues : if the color of paintings is well recorded today with images, it is not the same for 3D objects where the color calibration is not uniform. The texture is recorded in photography and in micro 3D scan but the results are not really exploited beyond the condition report. Translucency has been little investigated except by Simonot and al. [30, 31]. Being able to measure appearance attributes and extract information to understand the object is a goal for a center dedicated to heritage, it is still a wide area to explore.

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