# Image processing for the analysis and conservation of paintings: Opportunities and challenges

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# Image Processing for the Analysis and Conservation of Paintings: Opportunities and Challenges

The application of science and engineering to the analysis of priceless paintings and statues dates back several centuries. However, only over the past few decades have analytical methods developed in the physical sciences been able to glean information from the past and contribute to the analysis, conservation, and dissemination of works of art.

Possibly due to a historical division between science and the humanities, interaction between the two worlds has never been natural or cherished. This is especially the case in the arena of signal and image processing techniques for artwork analysis and restoration. As a matter of fact, the application of signal and image processing to the analysis of artworks is still a very uncommon practice, among both conservators and information and communication technology (ICT) specialists. Lately, however, there has been a greater focus on acquiring and processing artwork image data for storage, transmission, representation, and analysis. On one hand, this is due to the wider availability of digital computer storage and computational power. On the other hand, an increasing number of scientists with a background in analytical techniques and data interpretation have been approaching this field, probably stimulated by several projects funded by national and international governments (e.g., the European Commission). Efforts in this field have been supported by promising results, which have proven the potential impact of digital image processing on all related major issues, such as material analysis (and therefore dating and provenance determination), discovery and interpretation of ancient technologies, analysis of artists' environment and mutual relationships, better knowledge of conservation materials and processes, and art dissemination and fruition.

By specifically focusing on the visual arts (e.g., on the binomial image processing and paintings), it is the purpose of this column to: 1) sketch the main applications that could benefit from the introduction of ad hoc image processing tools, 2) outline the state-of-the-art, 3) describe the main peculiarities of this field, and 4) discuss the main obstacles impeding a more fruitful cooperation between the image processing community and art historians, restorers, and artists in general.

## APPLICATIONS AND OPPORTUNITIES

Since one of the most significant characteristics of paintings is that they are images, image processing seems to be a natural candidate to deal with them. As a matter of fact, there are several ways in which image processing may find meaningful applications in the art field. Roughly speaking, we can identify three main application areas: the achievement of a digital version of traditional photographic reproductions, the pursuit of image diagnostics, and the implementation of virtual restoration.

### *CULTURAL HERITAGE DIGITAL IMAGING*

Obtaining an exact (or as faithful as possible) reproduction of an artwork was one of the first developments in this area. This task involved the connected activities of archiving, retrieving and disseminating the data, which greatly profit from the digital format. Many museums, archives, and libraries are engaged in direct digital image capture of cultural heritage [1]. Many more are considering the move. An archival digital image of a work of art facilitates a variety of applications, including Web-based image sharing, color reproduction, and art historical studies and other scholarly pursuits, for which there is an increasing interest and business volume.

An important motivation for achieving high-quality images is to provide accurate means of measuring the color across the entire surface of the painting to generate a definite record of the state of conservation of an object at the acquisition time. Repeating the measurement over time supplies a controllable way to monitor the painting conditions and detect any changes that have occurred. Moreover, digital images do not deteriorate over time like traditional transparencies or photographs [2].

The possibility of automatically indexing images, enabling fast and reliable content search on semantic features, is also one of the most desirable goals.

### *ART DIAGNOSTICS BY IMAGING*

Another promising and intriguing application is the ability to infer spectral data about a painting without coming into physical contact with it. Noninvasivity of diagnostic techniques, in fact, is a highly desirable feature in a field where owners are not too trusting of invasive examinations. Most of the current techniques involve microsampling the painting for subsequent physical-chemical analysis. Noninvasive diagnostics are achieved by exploiting the fact that the materials comprising the various layers of a painting reflect, absorb, and emit electromagnetic radiation in ways that depend on their molecular composition and shape. If the radiation arriving at the sensor is measured with sufficient accuracy, the resulting spectral signature can be revealed. Until recently, the only accurate way to measure reflectance,

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absorbance, or emission was to take spot readings of spectra using a spectrometer and then record a rough position of the sample on a photograph. With multispectral imaging techniques, the entire surface of a painting is measured with good accuracy. The radiating sources may not be limited to the visible range, but cover the spectrum from ultraviolet (UV) to infrared (IR) wavelengths. Similar to the medical field, various sensing techniques (such as spectroscopy, UV-induced visible fluorescence analysis, reflectography, and X-ray scanning) based on different physical principles capture different and often complementary information. Many crucial issues in artwork diagnostics, such as assessment of the conservation state, knowledge of the realization techniques, evaluation of the historical period and attribution of the painting, and the possibility of keeping trace of any modification of the artwork shape, depend on different modalities that must be joined to draw reliable conclusions. The comparison of datasets is usually an interactive process conducted by the art historian (or conservator) studying the work. Therefore, professionals in the field are greatly interested in the possibility of automatically and meaningfully combining different diagnostics modalities [3]. Custom algorithms, similar to the ones common in remote sensing applications, may be used to process the gathered hypercube for material detection, classification, change detection, and unmixing.

### *VIRTUAL RESTORATION OF ARTWORKS*

The third important cluster of applications of image processing techniques to paintings is that of virtual restoration. Different methods have been studied, with various goals. The present visual appearance of a painting may be altered due to aging or unfortunate events. It is certainly questionable whether a real conservation treatment should aim at bringing the artwork back in time to its appearance at the moment the artist completed it. However, on a virtual representation of the artwork, many more options are possible. For example, crack removal is a rather straightforward application, which has improved the readability of images to a significant extent. Virtual cleaning is a controversial issue. The varnish that is usually laid over a painting is easily altered by time, and the legibility of the painting greatly suffers from this deterioration. Varnish removal is a challenging task for a conservator, and it is often debated how and even whether to proceed. Virtual cleaning intends to help conservators arrive at such a decision, showing images of several hypothetical procedures. Such a process has been fiercely opposed by some conservators because the process may possibly suggest a target that is not always achievable; it is feared the restorer may be blamed for not successfully cleaning the painting. This a typical case showing the importance of an effective communication between the conservation and image processing communities.

Another increasingly pursued task is the virtual composition of fragments of a painting. This approach achieves obvious advantages and impressive results, virtually joining portions of paintings that are hosted in different museums or paintings that are lost but reproduced in some old postcard.

## WHAT'S OUT THERE

### *IMAGE ACQUISITION DEVICES AND METHODS*

Depending on the application and its requirements, the devices employed for image acquisition use passive or active detection schemes as well as several kinds of sensors and radiation sources (lasers, LEDs, X-ray tubes, and lamps). However, most of the current developments are concentrated on processing and analyzing the visible and near-R range images. Commercial red-green-blue (RGB) digital cameras are sometimes employed, where each sensor element has either a red, green, or blue filter in front of it. With these cameras, a simultaneous RGB image is acquired. More frequently, custom devices for spectral imaging are developed. They are mainly based on two approaches, using in front of the detector either appropriate filters or a dispersive element. In systems using filters (interferential or tunable), a (small) number of monochromatic images are gathered, one for each transmission band chosen. For systems of this type, the sensor may be a single element [8], a row of sensors [4], or a two-dimensional array [5]. In systems using imaging spectographs, a line polycromator is coupled to a sensor array and mounted on a moving device. In this manner, the image is scanned and simultaneous acquisition of the wavelengths of a painting line is obtained with spectral resolution of about 1 nm. With multispectral imaging, it is possible to achieve advantages such as higher color quality [6]. However, the killer application is image spectroscopy, where the final goal is to achieve the spectral signature of each imaged element of the artwork. The number of filters in the solutions proposed in the literature varies from seven to 32. The choice of these filters is a compromise between narrow-band filters, which provide specific information in a spectral region, and broad-band filters, which transmit sufficient light intensity and prevent an impractical number of imaging modes. Typically narrow wavebands measure about 10 nm and wide bands measure about 40 nm. In the framework of one of the very first projects to tackle this subject [2], [18], seven filters were used. More recent systems have been designed with 13 [4], 18 [7], and 32 [8] filters.

As far as the spatial resolution is concerned, it may depend on the number of active elements on the detector or on the sampling grid, if the system is realized with a single element sensor that is moved by translation slides and scans the acquisition area. In the systems using line polycromators, the horizontal and vertical resolutions are generally different since they depend in one case on the sensor and optics and in the other case on the dimension of the polychromator slit. In some cases, a geometrical distortion is observed in the captured image, which needs to be corrected by postprocessing. Illumination uniformity is also generally necessary, and its absence needs to be taken into account when processing the image to get reliable color data. In many cases, it is not possible to obtain, with the desired quality, an unique digital image of the artwork in a single acquisition. When several images representing subparts of the painting are acquired, it is possible to reconstruct an unique digital image representing the whole scene by means of image processing, as described later.

### IMAGE PROCESSING TOOLS FOR PAINTING ANALYSIS

A first application of image processing in the fine arts field is in the analysis of paintings. Usually, art theorists classify a painting based on a set of attributes, called painting style, that give an artwork its character and allow it to be attributed to a particular artist, school, or period. Some papers have recently proposed algorithms for the digital analysis of painting images, providing to art theorists some specific quantifiable features in the paintings that could be useful for their classification. Such features include brush strokes [9], a set of global features of paintings, or the color relief of skin patches in painting.

The challenge of image retrieval is also becoming increasingly important since many conservators can access for their studies the large image databases of several museums and galleries around the world. In particular, content-based retrieval of images of artworks appears to be a difficult challenge, as the image content covers a vast range of subjects. In general, content-based image retrieval techniques are rooted in the comparison of features like color distribution, texture, outline shape, and spatial color distribution [10].

If a painting is represented through several subimages, it is possible to reconstruct a unique digital image with mosaicing algorithms that join a certain number of overlapping subimages of the scene to be reproduced [11]. Mosaicing is also very useful when one needs to obtain a flattened version of a painting or a fresco applied to a curved surface. It is interesting to have a view of the painting as if it is flat and not curved [12]. A problem similar to image mosaicing has been proposed in [13]; here, a methodology is introduced for the computer-aided reconstruction of fragments of wall paintings.

Another useful image processing tool for the analysis of paintings is the registration procedure. Registration is the determination of a geometrical transformation that aligns points in one picture with corresponding points in another picture. It is a useful procedure in the case in which the analysis of the painting can be performed by gaining the information coming from different images taken at different times (e.g., historical pictures versus current pictures), from different points of view, or from different sensors acquiring the images in different spectral bands (e.g., IR reflectograms or X radiographies [19]).

Several approaches have also been proposed for the enhancement of images of paintings to reduce degradations engendered by low-quality acquisition or degradation of the picture with time [14]. Other papers, like [15], propose different methods for noise suppression in color images representing artworks.

### VIRTUAL RESTORATION OF PAINTINGS

As tools for artwork restoration, image-processing techniques serve two purposes [16]. They can be used as a guide for the actual restoration of the artwork (computer-guided restoration). Alternatively, they can produce a digitally restored version of the work. While valuable by itself, the digital restoration is only virtual and cannot be reproduced on the real piece of work (virtual restoration). The tools for virtually cleaning dirty paintings belong to the first class of methods. Several phenomena can degrade the colors of paintings, deteriorating their appearance. Cleaning is usually performed by conservation experts with a trial-and-error approach. Different chemical cleaning substances are applied in small regions of the painting to select the most appropriate for cleaning the entire painting. A digital color restoration technique, relying on the cleaned small patches of the painting, can foresee the final result when the same cleaning methodology is applied to the whole piece. Restorers can then use this tool to choose which cleaning procedure is likely to yield the best result. The aim of the algorithm is to find a mathematical transformation that maps the dirty colors onto the cleaned ones within a patch. Subsequently, the same transformation is applied to the entire image, obtaining a virtually restored image.

In the class of methods for virtual artwork restoration, we can include the algorithms for removing cracks from paintings and frescos. Cracks are often caused by a rapid loss of water in the painting's varnish. When the painting itself is located in a dry environment, a nonuniform contraction of the varnish covering can cause the birth of cracks. With image processing tools, it is possible to entirely remove cracks by means of interpolation techniques. In this manner, the painting, even if in a virtual version, achieves again its original beauty as intended by the artist who created it.

An algorithm for crack removal is usually a two-step procedure: the cracks must first be detected, and then the selected cracks are filled in. The crack-selection step can be semi-automatic or automatic. In the first case, the user is requested to choose a starting point of the crack, from which it is possible to begin an iterative process to identify the entire crack. In automatic crack selection, cracks are identified by means of a proper filter. Yet, with this approach, brush strokes and other texture characteristics may also be detected. This problem can be solved by discriminating brush strokes and cracks on the basis of shape, hue, or saturation values. Let us note that crack analysis can also be used as a feature for the analysis of an artwork, e.g., it can be useful for the evaluation of the material used or the work's authenticity [17].

Another technique belonging to the class of methods for virtual artwork restoration is lacuna filling. Lacunas are a common form of damage that can occur to paintings and more often to frescos and wall paintings when some parts of the fresco collapse and fall down. In this case, the effect is the creation of areas, sometimes large, where the original image is lost. Actual restoration techniques tend to fill these areas with a uniform color or a set of colors, to give the impression of continuity of the image. With image processing tools, it is possible to accomplish the same task on the digital version of the artwork by applying restoration techniques similar to the real techniques carried out by the restorers [16] or by using a texture synthesization procedure [14].

## CHALLENGES AHEAD

This research area presents a number of interesting challenges of great relevance to the knowledge and dissemination of works of art and their related culture. Several issues, such as the ones regarding colorimetric recording of image data and accurate reproduction, are common to the general research area of digital color imaging. However, conservation issues are especially important for art objects. The digitizing process must not harm the artwork, and damage could easily occur by excessive handling and irradiation by high-intensity light sources. In general, it is not possible, or not desirable, to move art objects, even when their position is not ideal for scientific investigation. Clearly, it is also desirable to digitize the artwork once, in a manner that facilitates a variety of applications. This imposes highly demanding requirements on the acquisition devices and methods.

However, the true peculiarity of this field lies in the fact that each work of art is, by its nature, unique. Dimensions, materials, and techniques may vary enormously between western and eastern production, for artworks produced in different periods and by different artists. Moreover, each object is without an equal because of its specific history. Exposure to different environmental conditions, accidents or interventions by past owners or conservators, and the simple passage of time transform the original piece in an unmatched manner. It is therefore difficult to infer definitive data about original materials and conservation conditions. The variables are so numerous that when it comes to such tasks as classification or material discrimination, there is a general lack of collected data to reliably compare results. Clearly, this is also due to the relatively infant state of this type of application and to the interdisciplinary expertise needed. The fields involved are optics, image processing, color science, computer science, art history, and painting conservation. As a matter of fact, there is the need to bring together scientists with different backgrounds and from different cultural areas. In many cases, the main obstacle to the application of image processing technologies to the art field is the cultural clash between researchers with a technical background and researchers belonging to the humanistic area. For signal processing specialists, images are the starting point; specialists expect to be provided with as many images as possible. Meanwhile, museums may be unexplicably jealous. We must consider that artwork images are actually an important part of a museum's unique belongings, and the curators depend of these holdings to earn a living. In spite of the above difficulties, there is a clear demand for new computational tools to help learn more about works of art. Hence, there is no doubt that the application of image processing to the investigation of visual art works will be one of the hottest signal processing research areas in the years to come.

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## REFERENCES

[1] R.S. Berns, "The science of digitizing paintings for color-accurate image archives," *J. Imag. Science Technol.*, vol. 45, no. 4, pp. 305–325, July–Aug. 2001.

[2] K. Martinez, J. Cupitt, D. Saunders, and R. Pillay, "Ten years of art imaging research," *Proc. IEEE,* vol. 90, no. 1, pp. 28–41, Jan. 2002.

[3] R. Bellucci and C. Frosinini, "A 'model' for integrated diagnostics," *Kermes*, vol. 53, pp. 29–38, Jan./Mar. 2004.

[4] N. Ludwig, "Tecniche di spettroscopia d'immagine," Ph.D. dissertation, Univ. Florence, Italy, 2004.

[5] F. Imai, M. Rosen, and R. Berns, "Multi-spectral imaging of Van Gogh's self-portrait at the national gallery of art Washington, D.C.," in *Proc. IS&T's 2001 PICS Conf.*, Montreal, Quebec, Canada, 2001, pp. 185–189.

[6] G. Sharma, "Digital color imaging," *IEEE Trans. Image Processing*, vol. 6, no. 7, pp. 901–932, July 1997.

[7] S. Bruni, F. Cariati, L. Consolandi, A. Galli, V. Guglielmi, N. Ludwig, and M. Milazzo, "In-situ and laboratory spectroscopic methods for the identification of pigments in a Northen-Italy XI century fresco cycle," *Appl. Spectr.*, vol. 56, no. 7, p. 827, 2002.

[8] P. CarcagnÏ, A.D. Patria, R. Fontana, M. Greco, M. Mastroianni, M. Materazzi, E. Pampaloni, and L. Pezzati, "A scanning spectrometer for multispectral color imaging of painted surfaces," in *Proc. EVA2005*, Florence, Italy, March 14–18, 2005, pp. 174–179.

[9] M. Lettner, P. Kammerer, and R. Sablatnig, "Texture analysis of painted strokes," in *Proc. 28th Workshop of the Austrian Association for Pattern Recognition (OAGM/AAPR), Schriftenreihe der OCG,* 2004, vol. 179, pp. 269–276.

[10] P.H. Lewis, K. Martinez, F.S. Abas, M.F.A. Fauzi, S.C.Y. Chan, M. Addis, M.J. Boniface, P. Grimwood, A. Stevenson, C. Lahanier, and J. Stevenson, "An integrated content and metadata based retrieval system for art," *IEEE Trans. Image Processing (Special Issue on Image Processing for Cultural Heritage)*, vol. 13, no. 3, pp. 416–429, Mar. 2004.

[11] M. Corsini, F. Bartolini, and V. Cappellini, "Mosaicing for high resolution acquisition of paintings," in *Proc. Seventh Int. Conf. Virtual Systems and Multimedia (VSMM 2001),* Berkeley, CA, Oct. 25–27, 2001, pp. 39–48.

[12] N. Nikolaidis and I. Pitas, "Digital image processing in painting restoration and archiving," in *Proc. IEEE Int. Conf. Image Processing 2001 (ICIP2001),* Thessaloniki, Greece, vol. 1, Oct. 7–10, 2001, pp. 586–589.

[13] C. Papaodysseus, T. Panagopoulos, M. Exarhos, C. Triantafillou, D. Fragoulis, and C. Doumas, "Contour-shape based reconstruction of fragmented, 1600 BC wall paintings," *IEEE Trans. Signal Processing,* vol. 50, no. 6, pp. 1277–1288, June 2002.

[14] S.-C. Pei, Y.-C. Zeng, and C.-H. Chang, "Virtual restoration of ancient chinese paintings using color contrast enhancement and lacuna texture synthesis," *IEEE Trans. Image Processing (Special Issue on Image Processing for Cultural Heritage)*, vol. 13, no. 3, pp. 416–429, Mar. 2004.

[15] M. Barni, V. Cappellini, and A. Mecocci, "The use of different metrics in vector median filtering: Application to fine arts and paintings," in *Proc. 6th European Signal Processing Conf. (EUSIPCO-92)*, Brussels, Aug. 25–28, 1992, pp. 1485–1488.

[16] V. Cappellini, M. Barni, M. Corsini, A.D. Rosa, and A. Piva, "Artshop: An art-oriented image processing tool for cultural heritage applications," *J. Visual. Comput. Animation,* vol. 14, no. 3, pp. 149–158, July 2003.

[17] F.S. Abas and K. Martinez, "Craquelure analysis for content-based retrieval," in *Proc. 14th Int. Conf. Digital Signal Processing (DSP 2002)*, Santorini, Greece, July 2002, vol. I,pp. 111–114.

[18] R. Fontana, M.C. Gambino, M. Greco, L. Marras, E. Pampaloni, A. Pelagotti, L. Pezzati, and P. Poggi, "2D imaging and 3D sensing data acquisition and mutual registration for painting conservation," in *Proc. Videometrics VIII*, San Jose, CA, January 18–20, 2005, pp. 51–58.

[19] V. Cappellini, A. Del Mastio, A. De Rosa, A. Piva, A. Pelagotti, and L. Pezzati, "An automatic registration technique for cultural heritage images," in *Proc. Art'05*, Lecce, Italy, May 15–19, 2005, pp. 1–13. [SP]