Digital Image Processing for Art Restoration and Conservation

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Abstract : Over a long period of time, physical and chemical changes degrade the visual appearance of paintings. As a part of the restoration and conservation of these paintings, they are digitally scanned and analyzed for anomalies. As art museums are digitizing their collections, a cross-disciplinary interaction between image analysts, mathematicians and art historians is emerging, putting to use recent advances made in the field of image processing. This paper aims to highlight the extensive use of Digital image processing in Art restoration and conservation while studying its various methods and techniques. The paper gives an overview of the digitization of art and applications of image processing for restoration and conservation.

IndexTerms **- digital image processing, art, restoration, conservation, painting, enhancement, colour restoration, crack detection.**

I. INTRODUCTION

Paintings are made up of materials that can suffer damage with the passage of time. The protective varnish layer over paintings is affected by atmospheric conditions, fluctuations in temperatures, humidity and sunlight. As the years roll by, a number of defects appear in paintings like the development of cracks, scratches, discolouration of the varnish layer, accumulation of surface grime, loss of paint, etc. Hence, the restoration of such old degraded paintings includes stabilization, surface cleaning, the removal of discoloured varnish, the repair of tears and punctures, filling areas of paint loss, and expert retouching. Since most of the restoration procedures are irreversible, a great amount of planning is necessary before each operation, especially when the work of art that is being restored is of great historical and artistic importance.

Digital image processing and analysis can be of great help to painting restoration experts, museum curators and art historians so as to determine the authenticity of the painting, amount of damage and possible restoration methodologies. It provisions a non-destructive way to plan and test a restoration operation on a digital image, before proceeding to its actual implementation on the painting thus ensuring no harm is caused to the original art by extensive chemical cleaning. Digital processing and restoration enable the art historians and conservators to visualize how the painting used to look in its initial state, and also post conservation for a detailed comparison between them to ensure accuracy in the art restoration.

The initial stage of digital processing of art image is a thorough and extensive scan of the painting using various imaging technologies like X ray, Radiography, Infrared and Ultra Violet reflectography, microscopy, photogrammetry, and high dynamic range imaging. Using these techniques an analysis of the harm caused by ageing to the paintings is made. Structural anomalies, paint cracks, previous restoration attempts and original sketching is studied using these scanning procedures. The digital study of the painting provides the correlation of degradation with the quantitative measures such as entropy and standard deviation of the points cluster of the image in the colour space.

II. EXAMINATION

The painting is thoroughly examined via numerous digitized imaging technologies before conducting any kind of restoration over it. The entire painting is first X-rayed thoroughly providing the conservator a detailed view of the structural anomalies in the frame as the painting. The X-ray also highlights numerous minute details in the painting and the fine lines of the sketches made by the artist. After this step, the painting is further scanned using X-Radiography which reveals the extent of old damages on the painting which have been concealed by past restoration. This technique can show the different elements of a painting, from the canvas or panel it is painted on up to the top layer. Next, using Infrared Reflectography, all the underlying layers of paint are made visible on the screen. The quality and type of paint used and the canvas fabric can be studied using this procedure. The cracks, damages and other anomalies of the painting resurface using this method. On the completion of the structural and objective study of the painting, the process of removal of discoloured varnish is carried out. This helps the original colour to resurface and shine on the image. The cleaned painting is then studied under Ultra Violet light which shows any remaining varnish layers and highlights all the previous restoration attempts by making them fluoresce. The dark colours and spots on the painting under the UV light indicate any previous restoration attempts and old degrading varnish presence. Later minute samples of the paint and fabric are taken for Microscopic study which enables the conservator to learn about the composition of the paint and other structural anatomies.

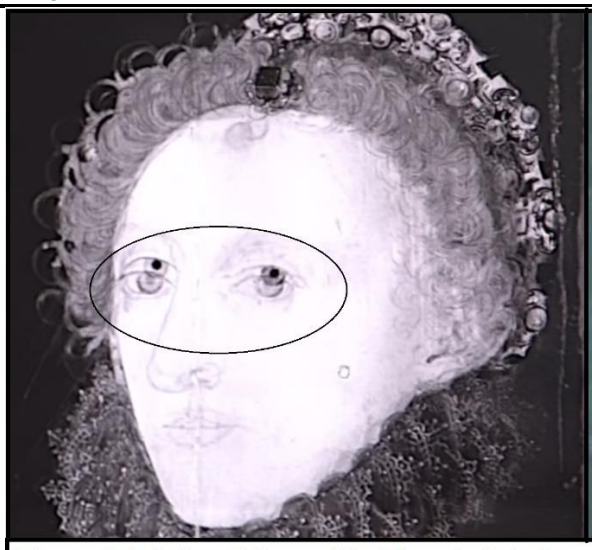

Figure 2.1: Infrared Scan of the Phoenix Painting of Queen Elizabeth 1 showing orginal sketching

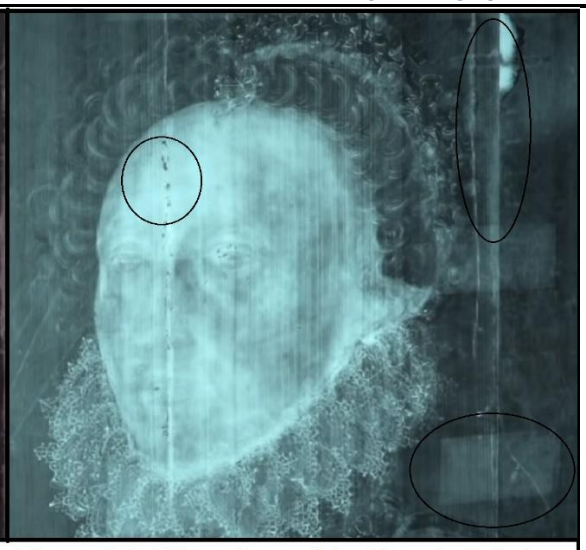

Figure 2.2: X-Ray Scan of the Phoenix Painting of Queen Elizabeth I showing patches & defects

III. Analysis

Each digitized scanning methodologies produce important data and crucial compositions of the painting which need to be studied meticulously before restoration. The structural anomalies visible in the X-ray help the conservator study the type of wood used in the frame to mount the painting and the fabric of the canvas. This study is crucial for the restoration of the physical assembly of the painting. The minute details which the X-ray displays play a major role in studying the original artist's style of sketching and painting. This data is crucial for the final retouching of the painting to mimic the original work. The analysis of the results generated by X-Radiography enables the conservator to predict the artist's modus operandi. It reveals major details of the underlying painting layers and shows the actual sketching of the art thus providing a layer by layer study of the entire painting. The analysis of the composition and quality of the paint and fabric can be studied from the results of the Infrared reflectography. This method also brings up the numerous layers of the art and the canvas all up to the microns of the fiber. This data is implemented to study the damages caused to the painting so as to repair them with the correct elements. Over a period of time, due to oxidation and deposition of dirt and smoke, the varnish layer becomes opaque, resulting in a picture being viewed as if through an amber or even brown or black filter. It has been observed that due to the dirty varnish layer, the standard deviation and entropy of the image decreases. The removal of this varnish enables the original paint layers to resurface and be studied even more meticulously. On studying the paint and fabric samples the conservator is able to analyze the painting combination used and the fabric tears up to numerous microns. This data helps the conservator to use the right combination of reversible paint during the retouching of the paint and also helps them to select the right type of linen fabric to repair the torn areas.

Figure 3.1a: Cleaned painting Flowers in Glass Vase by Nicolaes van Verendael

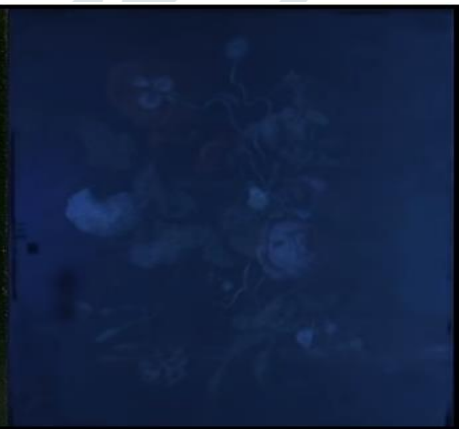

Figure 3.1b: UV scan of painting showing previous restoration in fluoresce

IV. Restoration

The most important aspect of applications of image processing techniques to painting images is virtual restoration. The present visual appearance of a painting may be altered due to ageing, damages or other impairments. However, on a virtual representation of the artwork, many more options are possible. The colour restoration or even the crack removal is rather straightforward applications, which prove to improve the readability of the image to a significant extent. Another increasingly pursued task is the virtual composition of fragments of a painting, which achieves obvious advantages and impressive results.

A. Digital Colour Restoration

The varnish which is usually laid overpainting is easily altered by time, and the legibility of the painting greatly suffers from it. It is also observed that the point cluster volume of the painting decreases due to decrease in the standard deviation and image entropy thus decreasing the point cluster volume, which makes an only limited range of colours available to represent the image giving it an amber colouration and hiding the vibrant colours beneath. Varnish removal is a challenging task for a conservator, and it is often debated how and even whether to proceed. In many cases, a trial and error approach is implemented on small parts of the painting in order to select the most appropriate substance to be used to clean the entire painting.

Virtual cleaning intends to help in taking such a decision, showing images of several hypothetical procedures. Digital image processing techniques can be used to simulate colour restoration without extensive chemical cleaning of the painting surface. For changing the appearance of an old painting to a cleaned one, we have to match its colour point's cluster to another sample cleaned painting, which has a similar colour distribution as the old painting.

B. Mosaicking

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 a lack of it needs to be taken into account when processing the image, in order to get reliable colour data. In certain cases, like murals painted in the interior of arches and vaults, paintings on the surface of cylindrical items etc., the surface where a painting is created is not flat but curved. For restoration purposes, it is sometimes preferable to unfold or flatten them to obtain a view of how they would have looked like if they were painted on a planar surface. Since, in most cases, these paintings are of considerable dimensions, the image capturing in partially overlapping parts is required in order to minimize geometry/perspective distortions and obtain efficient resolution. Sub-images are subsequently synthesized to obtain the whole image, and this procedure is known as mosaicking.

In order to proceed to the flattening of the acquired partial images, we have to know or estimate

(i) the equation describing the painted cylindrical surface with respect to the object coordinate system, i.e., a system with one of its axes being the cylinder's revolution axis, and

(ii) the transformation that relates coordinates in the camera coordinate system with coordinates in the object coordinate system.

C. Digital Crack Restoration

The algorithms for removing cracks from paintings and frescos is also a major application of digital artwork restoration. Cracks are often caused by a rapid loss of moisture in the painting's varnish. The physical location of the painting, adjoining weather, and sometimes even falls or damages, influence the creation of cracks. It is possible to entirely remove cracks by means of interpolation techniques using the image processing tools.

An algorithm for crack removal is usually a two-step procedure wherein first, the cracks have to be detected and then, the selected cracks are filled in. The crack selection step can either be semi-automatic, or automatic. In the first case, user spot's out the starting of the crack, from which it is possible to start an iterative process able to identify the whole crack. In automatic crack selection, cracks are identified by means of a proper filter. However, this approach detects even brush strokes and other texture characteristics as well. This issue can be solved by discriminating the brush strokes and cracks on the basis of shape, hue or saturation values. These cracks are digitally filled using image processing tools which provide a guideline to the actual restoration.

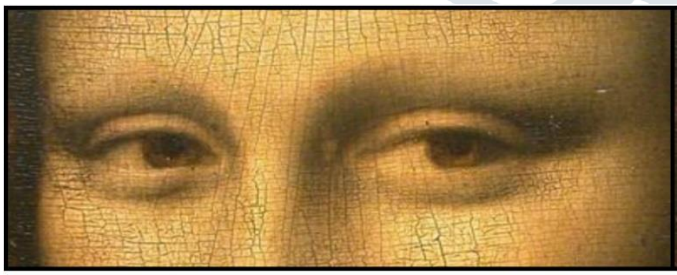

Figure 4-c-i: Section of orginal painting of Mona Lisa cracked.

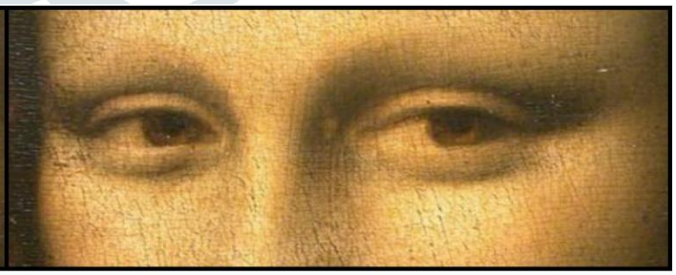

Figure 4-c-ii: Cracked section of the painting digitally restored from cracks.

D. Lacuna Filling

Another technique belonging to the class of methods for virtual artwork restoration is lacuna filling. Lacunas are very common damage which 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 colour or a set of colours, to give the impression of the 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 or with a texture synthetization procedure.

V. CONSERVATION

The reversible paints and good quality varnish ensure the physical conservation of the painting. Digitally these paintings are conserved using systems based on relational database scheme that features a user-friendly graphical user interface (GUI) that combines predefined queries and reports with user-defined SQL queries. Access to the database can be achieved through a client-server model with a specialized client application. A more powerful version that provides access to the database through any web browser is also available. A painting entity is created, that consists of more than forty attributes containing information on the numerous topics like physical details, restoration details, creation data, current physical conditions, storage information, historical data, artistic style, etc. For each painting, multimodal digital images resulting from different acquisition schemes (i.e., infrared, visible, x-ray, ultraviolet and microscopy) can be stored. Furthermore, the scheme supports image mosaicing (tiling) when an image is stored as a set of sub-images (tiles) in order to increase the resolution. The relative position of the microscopy image with respect to the entire painting is stored in the corresponding record. Storage of spectroscopy signals and colourimetry measurements is also supported. The spectroscopy signal entity includes fields that describe the spectroscopy type and the absolute coordinates of the signal with respect to the image. The coordinate information can be used to display an image simultaneously with its signals. These digital images ensure to keep a maintained record of the painting in its original glory and form a reference palette for future restorations and also for art enthusiasts can enjoy its beauty despite the anomalies in the physical version.

Figure 5a: The Phoenix Painting of Queen Elizabeth I pre-restoration (with discoloured varnish & surface grime)

Figure 5b: The Phoenix Painting of Queen Elizabeth I mid-restoration (varnish removal and structurally restored)

Figure 5c: The Phoenix Painting of Queen Elizabeth I Restored and Conserved.

VI. CHALLENGES

The research area presents a large number of interesting challenges, of great relevance for the knowledge and dissemination of works of art and of the related culture. Several issues, like the ones regarding the colourimetric recording of image data and accurate reproduction, are common to the general research area of digital colour imaging. The process of digitizing must not harm the artwork in anyway. But damage could easily occur by excessive handling and irradiation by high-intensity light sources. 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 regarding the painting may vary enormously between western and eastern production, for artworks produced in different periods and by different artists. Moreover, each object is without equal because of its specific history. Exposition to different environmental conditions, accidents or interventions of past owners or conservators, and simply the passing of time, transform the original piece in an unmatched manner. To infer definitive data about original materials and conservation conditions is therefore hard. There are numerous variables to be studied and various fields like fact optics, image processing, colour science, computer science, art history and painting conservation need to come together do so. As a matter of fact, there is a need to bring together scientists with different backgrounds and belonging to different cultural areas. In many cases, the main obstacle to the application of image processing technologies to the art field is represented by a sort of cultural clash between researchers with a technical background and researchers belonging to the humanistic area. In spite of the above difficulties, digitized paintings are majorly successful and effective in art restoration and conservation endeavors.

VII. CONCLUSION

Digitization of art gives a wide range of solutions for restoration and conservation. Art restoration and conservation is a very sophisticated venture as it uses really advanced and avant-garde technologies for imaging. Expensive and intricate methodologies like Infrared and UV reflectography, X-Radiography ensure extreme accuracy in the collection, storage and analysis of data. Tools like ArtShop and TMS Conservation Studio enable the art conservators to digitally restore and conserve the painting ensures no trial and error methodologies harm the original painting. Thus, the application of image processing in digital restoration and conservation of paintings will be one of the hottest signal processing research areas in the years to come.

VIII. REFERENCES

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