MULTI-MODAL DATA VISUALIZATION AND ANALYSIS OF "THE BEDROOM AT ARLES" BY VINCENT VAN GOGH

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ABSTRACT:

In this paper we present an open source software platform for providing high resolution multi-modal visualization and analysis of advanced heterogeneous scientific imagery. The system has been designed around the needs and requirements of cultural heritage and provides a powerful, flexible and easy-to-use means for conservators, researchers or art historians to interact and analyze scientific imagery of works of art. The platform allows cultural heritage institutions to manage and maintain very large image data sets and for multiple simultaneous users to remotely visualize heterogeneous data at high resolution using efficient image streaming techniques. As a case study, we present an example of a recent laboratory analysis carried out by the C2RMF of a work by Vincent Van Gogh: The Bedroom at Arles. The extensive range of imaging techniques carried out for this painting was unique in it's depth and range and showcase the potential of multi-modal visualization techniques.

1. INTRODUCTION

1.1 Motivation

In order to accurately and more fully document works of art for conservation or scientific study, multiple orthogonal digital acquisition techniques are often required. High resolution scientific imaging techniques, such as multispectral imaging, 3D structured light acquisition, high dynamic range (HDR) imaging, light transmission imaging, X-ray radiography, UV florescence, raking light and infra-red reflectography all provide different views of the holistic whole. Although each technique can be used in isolation, in order to fully understand the nature of the work of art, the ensemble of data needs to be brought together in a meaningful way. Advanced software tools adapted to the needs of cultural heritage are necessary for restorers, art historians and the general public to make sense of such data. The fusion and visualization of these very large and diverse data sets not only allow existing images to be better exploited, but also allow new kinds of analysis to be carried out.

1.2 The Painting

The subject of this study was a painting by the Dutch postimpressionist painter Vincent Van Gogh (30 March 1853 – 29 July 1890). La Chambre à Arles or the Bedroom in Arles is a composition showing the interior of the bedroom of his house at 2, Place Lamartine in Arles, France. Three versions of the composition exist: at the Van Gogh museum in Amsterdam, the Art Institute of Chicago and the Musée d'Orsay in Paris.

The first version, believed to be that currently at the Van Gogh museum, was painted in 1888 with the other two painted in 1889. The different versions are similar, but are not exact copies having several details differing. In addition the third version, that of the Musée d'Orsay, is significantly smaller than the others, measuring 57.5 x 74 cm compared to 72×90 cm for the other two. It is this third version that was the subject of this particular study.

1.3 Multi-national Study

An extensive range of scientific analyses was carried out at the *Centre de Restauration et de Recherche des Musées de France* (C2RMF), the national restoration and research centre for French museums, housed within the Louvre Museum. The analyses carried out formed part of a multi-national study involving all three of the museums holding versions of the painting. Good timing and the availability of equipment allowed us to apply an unprecedented range and combination of advanced imaging techniques to this particular version of the painting.

2. DATA ACQUISITION

The imaging data acquisition involved numerous different kinds of equipment and imaging technique as well as different teams of scientists.

2.1 Ultra High Resolution Colorimetric Imaging

A high resolution and high fidelity color rendering is an essential part of any image acquisition of a painting. Color digital cameras, however, are limited in their resolution and color accuracy. In order to fully study this painting, it was necessary to go well beyond the limitations of our camera hardware. Our high-end Imacon/Hasselblad digital SLR has a good native resolution of 20 mega pixels. However, we were aiming for a resolution of around 20 pixels per mm on the painting, which equates to around 180 mega-pixels of data. In order to achieve such a resolution with our equipment an image mosaic approach was required. Numerous images of

details were taken under fixed lighting conditions and camera geometry and stitched together. Corrections were made for lens distortion, vignetting and key-stoning etc. Color accuracy was crucial, so a full colorimetric characterization of the camera and lighting was made. This involved dark current correction, pixel sensitivity normalization, measurement of the lighting inhomogeneity, spectral measurement of the light source and target calibration using a MacBeth ColorChecker SG reference chart. The resulting high resolution image was profiled to CIEL*a*b* color-space. Verification of the final result (Figure 1) was carried out both visually under daylight D65 lamps and using photo-spectrometer spot tests on several points on the painting.



Figure 1: Colorimetric 180 mega-pixel mosaic of *The Bedroom* at Arles by Vincent Van Gogh, oil on canvas, 1889. Copyright © C2RMF 2009

2.2 Multispectral Infra-Red Imaging

Two forms of multispectral imaging were carried out in the near (NIR) and short wavelength (SWIR) infra-red spectral regions. These infra-red regions are particularly useful for pigment identification as many pigments with similar colors are only distinguishable by their spectral signatures in this region (Casadio, 2001).

2.2.1 Narrow-band imaging: Narrow-band multispectral imaging was carried out by the Cultural Heritage group of the National Institute of Applied Optics (INOA-CNR - Gruppo Beni Culturali) of Italy. The system used was an experimental multispectral imaging system based on an InGaAs photodetector linked to interferential filters through fiber optics. These fiber optics relay light from a single source lens mounted on an automated mechanical X-Y translation stage (Bonnifazzi, 2008). In effect, the apparatus acts as a high speed spectrometer that automatically takes millions of spot readings along the entire surface of the painting. The advantage of such an approach is that it avoids errors due to the lens and foreoptics, and due to geometrical mis-alignment caused by the different refractive indices of the filters. In all, 14 narrow-band filters with an approximate band-width of 50nm were used for this scan with an overall spectral range of 800-2300 nm and a spatial resolution of 2.5 pixels per mm. The resulting data was corrected for noise, gain, normalized using reference targets and compiled into image files per filter.

2.2.2 Wide-band imaging: In addition to the multi-spectral infra-red imaging, wide-band infra-red imaging was carried out using the high resolution InGaAs based Osiris camera (Falco, 2009). This camera was used with bandpass filters of 900-1200nm and 1200-1700nm to obtain several infra-red acquisitions with higher spatial resolution than was possible from the narrow-band multi-spectral apparatus. Affordable InGaAs sensors are often of relatively low resolution. Thus, in order to obtain sufficiently high spatial resolution, the camera is able to automatically employ a mosaicing technique.

Figure 2 shows a selection of the wide and narrow-band infrared images.



Figure 2: Infra-red images: wide-band 900-2300nm (top), narrow-band 1600nm (bottom). Copyright © C2RMF 2009

2.3 Structured Light 3D Imaging

The paintings of Van Gogh often possess a strong coarse brushwork. This is certainly the case for the *Bedroom at Arles*, making a 3D acquisition of the surface particularly interesting. The 3D scanning technique used was that of structured light (Frankowski, 2000). In this method, a sequence of pattern fringes of different sizes is projected onto the surface of the painting and scanned by a digital camera. The distortion in the fringes resulting from the surface roughness makes it possible to calculate the height at each point (Figure 3a). This is done by a combined Gray Code/Phase shift technique (Park, 2001). The scan itself was carried out by the Breuckmann company (Breuckmann, 2000) using their OptoScan system (Figure 3b). In order to obtain a sufficiently high spatial resolution, once again a mosaic technique was used. The resulting dense point cloud of three dimensional coordinates for the surface of the painting had a spatial resolution of around 20 pixels per mm in X-Y and a resolution in Z (depth) of approximately 20µm.





Figure 3: (a) Principal of Structured Light Projection, (b) Breuckmann OptoTop equipment

2.4 Infra-red, Ultra-violet Florescence and X-ray

Together with the advanced techniques used above, more mainstream scientific imaging were carried out at the C2RMF. To cover other important parts of the electro-magnetic spectrum, UV florescence and X-rays were used. In addition, techniques such as raking light photography (from multiple directions) and light transmission imaging (where the light source is placed behind the painting) was carried out in both the visible and infra-red regions. Indeed the range of imaging techniques applied to this painting was quite unprecedented. Never before had a painting been so comprehensively photographed at the C2RMF with such a wide range of equipment and techniques.

3. MULTI-MODAL REGISTRATION

Because of the differing imaging techniques, optics, acquisition geometries and sensor characteristics, registration of the different images was not straightforward. Geometric distortion, key-stoning, chromatic aberration, and errors in the image mosaics all make a simple linear transformation impossible. In addition, the content of the images themselves can not always be exactly correlated. For example, raking light images show the shadow cast by a feature on the surface of the painting and not the feature itself. X-rays and Infra-red images penetrate into the painting and are not, therefore, in the same geometric plane as, for example, a UV florescence image, which originates at the upper surface layer of the painting.

In order to resolve this, a combination of different registration techniques adapted to each imaging type was employed (Zitová, 2003). This consisted of a combination of semiautomatic registration based on cross-correlation, phase correlation as well as manual alignment in certain cases.

4. VISUALIZATION

4.1 Remote Visualization

In order to be useful for conservators, researchers or member of the public, the large quantity of heterogeneous data produced by scientific imaging needs to be synthesized and made available to the user in an efficient manner. In order to achieve this, remote visualization software was employed.

4.2 IIPImage

The remote visualization platform is based on IIPImage^{*}, an open source image streaming system for ultra-high resolution and scientific imagery (Pitzalis, 2006; Saunders, 1999). It works by streaming tiles corresponding to the area currently under view at the requested resolution to the client. In this way, the user can efficiently view, navigate and zoom around at the maximum resolution possible. In addition to sRGB imagery, scientific image types such as 16 bit, colorimetric CIEL*a*b*, multispectral and 3D height/normal data are supported. The software is based on a client-server architecture with an imaging server providing tiles, image processing and metadata resources via a RESTful protocol. In order to be as efficient as possible and reduce the load of the server, image data is stored in a multi-resolution tiled TIFF format.

The client software, embedded within a web interface, is platform independent, giving users access to multi gigabyte size scientific images without having to install any 3rd party software or requiring any particular hardware / software configuration or operating system. Excellent performance is available even on old or slow hardware. The client incorporates numerous functions allowing the user to easily navigate and zoom within the data. In addition several more advanced features exist.

4.3 Image Blending

The ability to easily compare and contrast any of the images and do so interactively is a potentially extremely powerful tool in order to fully understand the material composition, layering or technique of a painting. An extension to the IIPImage client has been especially designed to give the user the ability to select any pair of registered images and then simultaneously navigate and zoom within both. At any time, the user can perform a superposition and smooth blending back and forth between the pair of images. Subtle differences that may not be apparent on viewing them statically and separately can be far

^{*} Project website: http://iipimage.sf.net

more easily discerned from such an interactive manipulation. An example of the blending between the colour and X-ray is shown in figure 4.



Figure 4: Image blending showing the superposition of the color and X-ray images and the blended smooth transition between them

4.4 Spectral Visualization

The ability to determine the spectral reflectance at any point on the painting gives crucial information on the material composition of the paint layer. Spectral curves can be compared to reference spectra for pigment or material identification. Within IIPImage, a graphing area is available within the interface, allowing the user to click on any point on the painting and instantly see the spectral curve for that point. This feature was applied to the narrow-band multispectral infra-red data acquired (Figure 5).



Figure 5: Spectral reflectance curve for any point on painting

4.5 3D Hillshade Rendering

High resolution 3D data is not easy to stream or make multiresolution. Furthermore as our software is essentially imagecentric, a 2D rendering approach to visualization was favoured. Inspiration was taken from the domain of cartography and the surface of the painting was considered as a digital relief map (DEM). In order to facilitate the integration of such data into IIPImage, the 3D model data was converted to point data representing the vector normal at each point and the height at each point. In this form, they are able to be stored in standard TIFF format, and are thus able to be tiled and used directly for multi-resolution streaming with IIPImage. A basic rendering technique is that of hill-shading (Horn, 1981) where a virtual directional illumination is used to create shading on virtual "hills". A fast hill-shading algorithm has been implemented in IIPImage allowing the user to interactively set the angle of incidence of the lighting source and view a dynamically rendered hill-shaded relief map. By moving the light source, a better understanding of the surface relief is possible.



Figure 6: Hill-shading applied in two different directions to 3D model data

5. CONCLUSION

Advanced imaging techniques give conservators, restorers and researchers unprecedented access to highly detailed information from numerous kinds of analytical technique. However, this heterogeneous mass of data can often be unwieldy and difficult to view let alone undertake basic analyses with. We have presented here an open source streaming-based solution designed around the needs and requirements of cultural heritage that addresses these issues. The example of *The Bedroom at Arles* provided us with an exceptional and unprecedented range of imaging data to handle. The integration of the ensemble into a single visualization system demonstrates the potential of such a platform for museums and researchers. In addition, ability to stream the data online make it especially useful when research is undertaken by different research teams or in an international context.

In addition to the already implemented functionality, many potentially interesting applications are conceivable. For example automatic pigment spectra classification or identification. Or the use of the height data from a 3D acquisition to provide renderings of cross sections etc.

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