INTEGRATING LASER SCANNING, MULTISPECTRAL IMAGERY AND GIS IN C&R DOCUMENTATION PRACTICES: A FIRST APPROACH USING TWO XVITH CENTURY WOOD PAINTINGS FROM CONVENTO DE CRISTO IN TOMAR.

H. Pires [1], P. Marques [1], F. Henriques [2], R. Oliveira [1]
[1] Superfície – Geomática, Maia, Portugal – {hpires, pmarques, roliveira}@superficie-geo.com
[2] Painting Conservator, Amadora, Portugal – frederico.painting.conservator@gmail.com

KEY WORDS: Laser scanning, Photogrammetry, Multispectral, GIS, Cultural Heritage, Conservation and restoration, Cooperation

ABSTRACT:

This article addresses the application of geomatic technologies in the field of painting conservation and restoration (C&R). It results from collaboration between geomatic professionals and conservators-restorers and intends to gradually integrate techniques like photogrammetry, laser scanning, multi-spectral analysis or geographic information systems in the daily work of C&R. In this phase we have focused our efforts in the specific field of retable wooden painting using as case-study paintings from the XVIth century belonging to the Convent of Christ in Tomar, Portugal, that are part of a large dimension retable composed originally by twelve pieces in the deambulatory chapel of the convent church.
Until now, at least in Portugal, painting C&R does not use any of the documentation standard procedures already applied in other cultural heritage fields like archaeology or architecture.
The conceptual plans for future research along with the results from the laser scanning and photogrammetry campaigns are presented. Preliminary achievements with a multi-spectral analysis system will also be stated as part of the work in progress.

1. INTRODUCTION

Art conservation deals with a specific class of objects from our common cultural heritage. Paintings, sculptures, papers, photos, small quotidian objects, etc, are part of the daily work of art conservators.
Technology already plays an important role in the documentation and diagnostic phases of art works conservation practices. Some examples are chemical analysis used to identify pigment components, spectrometry to classify colorimetric characteristics or photography to reproduce visual images.
Proposals to improve documentation standards are presented here as a first approach to the dissemination of geomatic technologies application in this specific field of cultural heritage conservation, following a survey process on current standards in the portuguese Art C&R community.
This study is part of an ongoing research with the contribute of a multi-disciplinary team composed by C&R professionals, pointing directions and validating data, and geomatic technicians, adapting conventional systems used in surveying and remote sensing to this field of cultural heritage.
This project was thought and carried out in the perspective of "bridging the gaps between conservation experts and heritage recorders so as to raise the level of conservation practices" [LG02], joining together both actors, information providers and users, through collaborative work.

2. GRAPHIC AND VISUAL DOCUMENTATION IN ART CONSERVATION

2.1. Current methods and techniques

Photography is the most common technique used in C&R to register and document painting features; chromatic characteristics, pictorial composition, visible alteration and degradation forms, previous interventions detection or characterization of techniques used by the painter. Chemistry also plays an important role in determinating pigments and materials composition using small samples or analysing specific points.
The most common photographic techniques are RGB images (figure 1), ultra-violet (UV) fluorescence, infra-red (IR) reflectography and X-rays, all increasingly using digital-based equipments.

Figure 1 – Photograph from the painting "Lazarus resurrection"

Analysing the superficial layer, UV fluorescence enables the detection of repainted areas, caused by previous conservation campaigns or by changes introduced through time (figure 2).

Figure 2 – UV fluorescence image from a detail on "Lazarus Resurrection" painting

To document deeper layers infra-red reflectography is the best technique allowing underdrawing detection. Underdrawing designates the compositional sketches done in initial phase where the painter structures his work (figure 3). These elements are of great importance to C&R professionals as they can provide crucial information about authorship, "Pentimenti" (changes in the painter original intentions) and previous C&R interventions. Finally, X-Rays cross the complete set and provide information about support conservation state.

Figure 3 – Digital NIR camera image from painting detail of "Christ's Entrance in Jerusalem" where underdrawing and "*Pentimenti*" (size of thumb) are clearly visible.

Regarding area examination these are the most common methods although new systems are being increasingly applied, namely hyperspectral imagiography (Casini et al, 2007). During a conventional painting conservation campaign image acquisition is done in several phases; before intervention, during each principal phase (cleaning, repainting, etc.) and at the end of the work.

2.2. Identified problems

Usually, in painting conservation, the visual documentation process includes a complete photographic coverage of each cultural object from full framed photos to detailed close-ups. This multi-scale approach creates a problem of data management and handling. Full frame photos provide a representation of the complete scene but present very low detail while close-ups provide high detail images but without possibility of full-frame perception. The most commonly technique used by C&R professionals that intents to solve this problem is the manual assemblage of high-detail photos using image editing software in order to build full picture mosaics. As it would be expected, one of the main problems that arise from these procedures is geometric deformations. Even with a careful planning of image capture, perspective geometric deformations, caused by camera position and attitude and lenses distortion, do not allow perfect matching. Using this method the correction of these deformations is a hard and long manual iterative process that can lead to a poor final result. The transition between overlapping areas usually presents visual discrepancies and the image final geometry does not comply with the object real proportions. In practical terms, due to the pointed reasons, the high-detail photos are used as stand-alone images.

2.3. The step from photography to photogrammetry

The similarity between documentation needs in landscape or buildings and art conservation is clearly identified on the above description. The proposed solution is to incorporate photogrammetry in art C&R image capturing procedures.
Close-range photogrammetry as evolved from complex and expensive equipments to simple and low-cost systems requiring no more than off-the-shelf photographic cameras and computers. Apart from drastically reducing the amount of hardware investment, this technique allows a certain amount of freedom in data collection tasks, meeting C&R needs, like liberty of choosing different levels of detail or desired points of view and adapting to multi-spectral coverage.
Compared to normal procedures, a photographic coverage for photogrammetry requires some changes in the normal workflow. The first one, and maybe the odder for non specialist is camera calibration. This process corresponds to internal parameters calculation that will allow photogrammetry software to correct distortions caused by lens deformation. To achieve good results one condition must be accomplished, stable internal geometry of camera-lenses set. This means that functions like autofocus or zooming can not be used during calibration and photographic coverage.
We have used Photomodeler Pro 5.0 monoscopic photogrammetry to achieve the proposed goals. The photo coverage needs some planning in order to achieve good results. A convergent photo set must be taken, with at least three images capturing the entire scene, followed by high detail coverage, parallel to the painting at a regular distance, where the pixel spatial resolution is similar to the desired level of detail (figure 4).

Figure 4 – Example of an orthoimage made from 12 different UV fluorescence photographs, from a painting belonging to the Convent of Christ.

Because no focusing adjustment between the two sets can be used one should set the camera to a sufficient depth of field in order to acquire focused images in both distances. If these procedures are accomplished the photogrammetric coverage is ready for data processing.

2.3.1. Laser scanning

Although laser scanning (LS) still is an expensive tool, its application in painting conservation can greatly improve some aspects of diagnostic and documentation tasks (Blais et al, 2005). In this study we have used LS for two main purposes: quantification of mechanical deformation in painting's support and image acquisition through reflectance intensity measurement. LS have the ability to capture enormous amount of three-dimensional data in very fast acquisition time (figure 5). The point clouds produced by this kind of equipment can be spatially analysed and transformed into wireframe or solid meshes. The resulting models are high detailed 3D virtual repliques of the original objects that are used for several morphological analyses. In wooden paintings, usually built from a set of planks, these models can be used to quantify deformations, providing C&R professionals with important information that can help them to better identify origin and causes of mechanical stress. Furthermore, if a second scan is done after conservation tasks, a comparison between the two sets can provide information about the changes and validate the applied correction procedures.

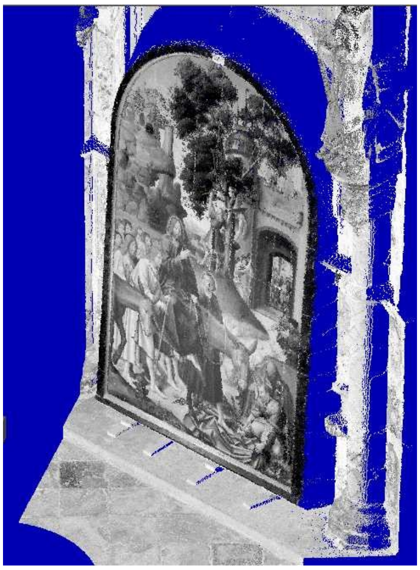

Figure 5 – "Entrance of Christ in Jerusalem" screenshot from reflectance coloured 3D point cloud

Another innovative application of this technology is image acquisition through reflectance measurements. Some LS equipment has the ability to measure radiometric values of laser beam reflectance in an 8-bit grayscale. Each value is intrinsically related to the corresponding 3D point. Because these types of LS are active sensors, external illumination conditions do not affect the reflectance image. The result in flat surfaces like paintings is a homogeneous image without any chromatic aberrations (figure 6).

3. DATA PROCESSING

3.1.1. Image data

The production of orthoimages allows C&R professionals to have simultaneously undistorted images and a real mapping tool. The intrinsic metric characteristics of these images allows the determination of (x,y) coordinates for any feature in the image. These features can be related between several images or between spatial data in the same coordinate system. Using orthoimages to register interventions allows the creation of a georeferenced database that will be used in a GIS system. The proposed improvement in the C&R workflow is to orthorectify images from the different sensors used.

During the field campaign we have tested the potential of LS as imaging devices. The equipment captured reflectance intensity values for each measured point corresponding to the wavelength of the laser beam, 785 nm, which after orthorectification was compared with other NIR imaging devices. In terms of underdrawing capture the results were very similar to those achieved by digital NIR photographic cameras.

Figure 6 – "Christ's Entrance in Jerusalem" NIR Orthoimage from LS reflectance intensity data

3.1.2. Morphological data

In conventional C&R practices painting support deformation is evaluated empirically. In the specific case of wooden paintings the disassembly and reassembly of the wood planks is done in order to correct deformations and to reinforce the structure. The deformation evaluation is critical in this phase. It can provide C&R professionals with information regarding mechanical actions that can be used to correctly plan actions to be taken. It can also provide information about support weaken areas that need extra reinforcement. If a second model is done after these tasks then an inspection map can be achieved comparing the final support geometry to the initial one. The results can be used to validate the work and are a precious registry for future campaigns.

3.1.3. Multispectral analysis systems

Multispectral imagery has been an important resource of data in earth studies since the last decades of the past century, as they are an effective tool when there is a need to identify spatial units. The use of this technology applied to paintings is increasingly being applied (Colantoni et al, 2006). Several methods are used to improve spectral analysis, techniques that are commonly known as "digital image processing". Our ultimate goal was to enhance the images and improve the interpretation of the painting features. In order to achieve our objectives, we have used Principal Component Analysis statistical transformations (PCA) and arithmetic combinations (Band rationing). A Principal Component Analysis is a statistical approach that maximizes the spectral variance and reduces redundancy in multispectral data (Lillesand et al, 2004). Band rationing consists of mathematical calculations on the original data, performed on a pixel-by-pixel basis. This has been one of the most widely used methods in the remote sensing field, as these operations are very useful for discriminating subtle spectral variations in a scene (Lillesand et al, 2004). The selected software to perform the multispectral analysis was GRASS (GRASS, 2006) (figure 7), an open-source GIS suite, with valuable imagery tools. This software was used to gather the imagery data on a common coordinate system and then perform the transformations mentioned before.

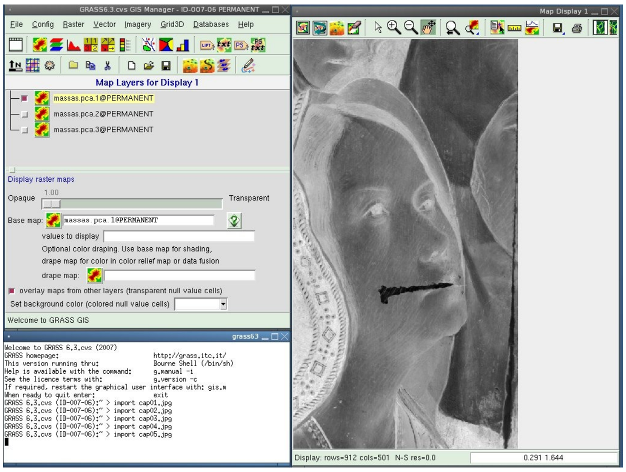

Figure 7 – Screenshot from GRASS working environment

The processing produced results in terms of highlighting specific features on the painting such has: particular tones, underdrawing and areas that had gone trough a cleaning process.
The use of GIS as the standard platform to manage all the acquired data from the paintings will allow the creation of a multi-temporal registry. This database will relate spatial information with alphanumerical data describing techniques, materials and options taken during the work. Other data sources like chemistry analysis or microscopic imagery can also be referenced to the same coordinate system. Until the present moment this platform was only used for orthoimage referencing and multispectral analysis.

4. CASE-STUDY

4.1. Object of research

For this preliminary work, where we have tested some of the proposed improvements, two paintings from the Convent of Christ church in Tomar, Portugal, were used. This monument is a UNESCO World Heritage site dating back to the XIIth century. Both paintings, of monumental dimensions, are assigned to the royal painter Jorge Afonso, and were probably executed during an architectural work campaign between 1510 and 1515, demanded by the Portuguese king D. Manuel I. One of the paintings represents "Lazarus Resurrection" and the other the "Christ's Entrance in Jerusalem".

4.2. Data collection, processing and achieved results

This work was accomplished with a medium range scanner using phase shift technology (Boehler et al, 2002). LS was used to acquire spatial data describing the paintings shape and to produce NIR reflectance images. The 3D model of each painting was used to calculate a deformation map. One of the paintings was close to the ground, in an accessible place, and the other was in its original position on the wall, 3 meters above ground level (figure 8).

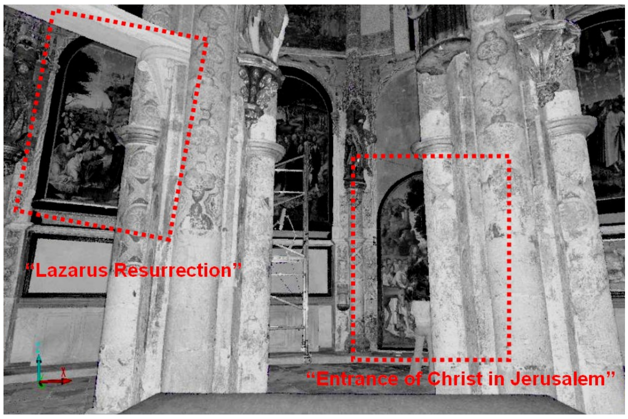

Figure 8 – Painting's positions in the deambulatory chapel.

Their different positions were important to test system applicability for objects that can not be removed from their places. The deformations maps were calculated through the point cloud comparison with a mean plan calculated using the same data. The results show different mechanical behaviours in each painting. The "Entrance of Christ in Jerusalem" presents a slight curvature effect along vertical axis (figure 9). "Lazarus Resurrection" presents differential warpening deformations in the plank structure (figure 9). Both maps were affected by the point cloud noise related with surface reflectivity. Darker areas in the paintings presented a biggest linearity error than brighter areas. The darker pictorial compositions appear in the deformation map as water marks.

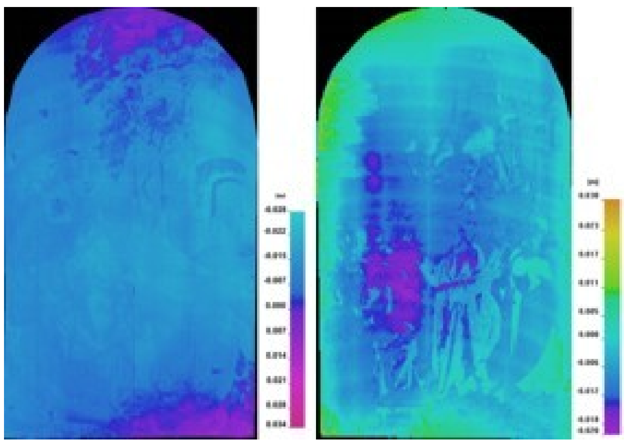

Figure 9 – Deformation maps from "*Entrance of Christ in Jerusalem*" (left) and "*Lazarus Resurrection*" (right).

The reflectance image from LS was orthorectified and compared with images previously taken with a digital NIR photographic camera. The results were very similar in terms of underdrawing and restorations detection (figure 10). One of the major improvements was the time needed to accomplish this task. LS took 10 minutes to acquire the image while the conventional method needed one day of work and the use of stairs to acquire a mosaic of close range images from the entire painting surface.

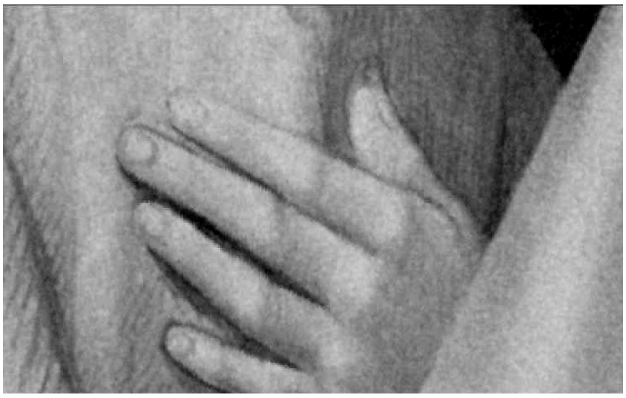

Figure 10 – LS reflectance intensity NIR image from painting detail of "Christ's Entrance in Jerusalem" to be compared with figure 3.

As mentioned before, the chosen GIS platform was the open source software GRASS. Using a principal component analysis we were able to extract important information: enhanced images of the underdrawing, fillings detection, jewellery detailed features, red and blue tones separation and auxiliary border lines (figure 11).

Figure 11 – Results from RGB principal component analysis (PC2) where underdrawing and fillings (near the mouth) from the last C&R intervention are clearly visible

Simultaneously, arithmetic operations produced profitable results. We were able to produce images with a notable separation of cleaned areas from others that had not been object of intervention (figure 12).

Figure 12 – Results from a UV fluorescence image analysis using arithmetic operation. Compared with initial image, already cleaned areas were enhanced (left side) and some odd features were detected (circle in the top left side)

The use of "stimuli" formula in accordance with the principals of colour perception (Harris et al, 1999), along with a colour table directed to enhance the differences on an image, improved the original data, providing a new image where there is a prominent exalt of a specific tone of red (figure 13).

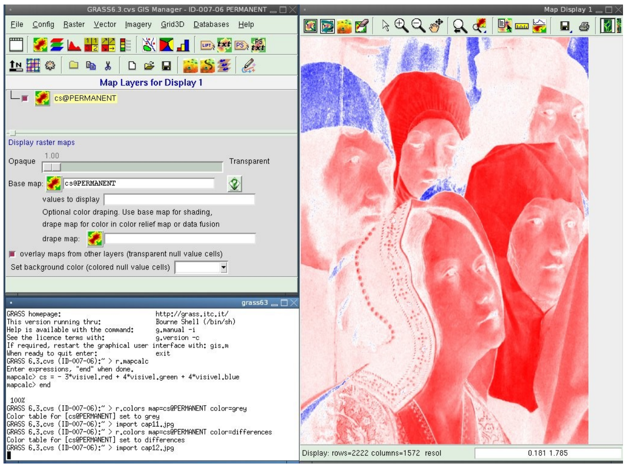

Figure 13 – Screenshot from GRASS showing the result of "*stimuli*" calculation and colour table to enhance tonal differences

5. CONCLUSIONS

This paper describes the use of geomatic technologies in painting conservation and restoration. Potential benefits in documentation work in this field of cultural heritage were also stated. These approaches, usually applied in earth sciences, produced noticeable results and they are, in our opinion, a valid methodology to apply in future C&R studies.
As final conclusions we think that:

- The actual level of knowledge and expertise in geomatic can be of great benefit for specific cultural heritage fields,
- Laser scanning is a technology that can largely contribute to the improvement of standards in heritage documentation. Recent developments in multi-spectral LS will confirm this statement (Hemmleb et al, 2006),

- Orthoimages present large benefits when compared with conventional photography,
- GIS is the most suitable platform to be used in painting C&R documentation, allowing multi-temporal approach in order to document and evaluate present C&R techniques.
- Close collaboration between conservation professionals and heritage recorders is of great benefit for both.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Jorge Custódio and Mr. Rui Ferreira from the Convent of Christ-IPPAR for the kind permission and support for the study of the paintings. We also would like to express our gratitude to our colleagues at Superfície, L.da and at CaCO3, L.da for their support and encouragement. Finally thanks to Mario Silva for its contribution for this work.

REFERENCES

Blais, F.; Taylor, J.; Cournoyer, L.; Picard, M. ; Borgeat, L. ; Dicaire, L.-G.; Rioux, M.; Beraldin, J.-A.; Godin, G.; Lahnanier, C.; Aitken, G.; 2005. High resolution Imaging at 50 µm using a portable xyz-rgb colour laser scanner. International Workshop on Recording, Modelling and Visualization of Cultural Heritage, Centro Stefano Franscini, Monte Verita, Ascona, Switzerland.

Boehler, W.; Marbs, A.; 2002. 3D Scanning instruments. CIPA, Heritage Documentation. International Workshop on Scanning for Cultural Heritage Recording, Corfu, Greece.

Casini, A.; Lotti, F.; Uno scanner iperspettrale per la spettroscopia ad immagini di opere d'arte, Firenze, Italy http://www.ifac.cnr.it/webcubview/ (acessed 20 Jan 2007)

Colantoni, P.; Pillay, R.; Lahanier, C.; Pitzalis, D.; 2006. Analysis of multispectral images of paintings. 14th European Signal Processing Conference (EUSIPCO), Florence, Italy

GRASS Development Team, 2006. Geographic Resources Analysis Support System (GRASS) Software. ITC-irst, Trento, Italy. http://grass.itc.it (acessed 10 Dec 2006)

Hemmleb, M.; Weritz, F.; Schiemenz, A.; Grote, A.; Maierhofer, C.; 2006. Multi-spectral data acquisition and processing techniques for damage detection on building surfaces. Image Engineering and Vision Metrology, ISPRS, Dresden, Germany.

Harris, J. ; Viljoen, D. ; Rencz, A. ; 1999. *Remote sensing for the Earth Sciences – Manual of Remote Sensing, Third Edition – Volume 3*; John Wiley & Sons Inc., New York, pp. 307-354.

Lillesand, T.; Kiefer, R.; Chipman, J.; 2004. *Remote sensing and Image Interpretation, Fifth Edition*; John Wiley & Sons Inc., New York, pp. 491-624.