3D LASER SCANNER POINTS CLOUDS AND 2D MULTI-SPECTRAL IMAGES: A DATA MATCHING SOFTWARE FOR CULTURAL HERITAGE CONSERVATION

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ABSTRACT

Various technologies have been developed to conduct preliminary investigation prior to restoration interventions, thus resolving studies and problems regarding intervention strategy choose. Each of this technologies give to the end-user different kind of information that are useful to understand the health condition of the artwork.
This paper illustrates the development of a software that allows to integrate the set of data retrieved by the different instruments. The aim is to obtain a better knowledge and perception of damages and decline process.
In particular the software allows to elaborate laser scanner Point Clouds, it can load ply format data, and have all basic functions of zoom, pan and rotate.
The main function of the program is the possibility to create and save 3D orthofoto from not georeferenced photos that come from different kind of investigation instruments like calibrated photogrammetrik camera, common digital camera, multi-spectral camera and also termography.
This allows to study the inquiry object, matching metric 3D informations with radiometric data that could be an important way to better understand the decay phenomenon and to chose the more adapt restoration intervention.
Other possible application implemented in the software are rangemaps registration, filtering, sections extraction, shaving light simulation.
To demonstrate the functionality of the implemented software are presented some case of studies where we use the new laser scanner prototype SIDART 100 (build from CETMA with knowledge of Enea Frascati Group) for points clouds acquisition.

1. INTRODUCTION

1.1 The project SIDART

This work takes place inside SIDART (Integrated System for Cultural Heritage Diagnostic) project, whose objective is to develop hardware and software package for cultural heritage diagnostic. The project involves some partner such as ENEA Group of Frascati, INOA, and CETMA that is leader of the project.
Aim is to create an integrated system to acquire and integrate information produced by different survey instruments (laser scanner, multi-spectral camera, calibrated metric fotogrammetric camera, termography) used in cultural heritage diagnostic. This would be a new completed tool useful for restoration in architectural and cultural study application.

1.2 Project teams

Our group's rule of Laboratory of Survey, Digital Mapping, GIS of Politecnico di Milano is to cooperate with CETMA to create a software able to display and to model laser scanner points clouds. The software is build by Ing. De Pascalis of information division of CETMA of Brindisi.
The analysed clouds come from a new prototype of laser scanner product from CETMA with Enea (Frascati Group) competence. This instrument as a very good accuracy (at test phase) and assure 10^{-1} space resolution.
All test and other survey measures, such as multispectral and termographic survey are conducted by CETMA with our permanent collaboration.

2. THE SOFTWARE: LASER CLOUDS

2.1 The PLY format

The software is able to load files with PLY format.
The PLY file format is a simple object description that was designed as a convenient format for researchers who work with polygonal models. Early versions of this file format were used at Stanford University and at UNC Chapel Hill.
A PLY file consists of a header followed by a list of vertices and then a list of polygons.
The header specifies how many vertices and polygons are in the file, and also states what properties are associated with each vertex, such as (x,y,z) coordinates, normals and colour. The polygon faces are simply lists of indices into the vertex list, and each face begins with a count of the number of elements in each list.
This files come direct from the laser instrument that provide the triangulated surface of the acquired object and infrared colour information.

2.2 3D Ortophoto

The most application implemented in the software is the possibility to create 3D orthophoto from the triangulated surface and digital images. The implemented algorithm is the DLT (direct linear transformation) equation solved with least squares method. The equations of the DLT are linearised around approximate values of the parameters that we have previously obtained. We need a set of points that are known in the two spaces; each point enables to write two equations. With at least six points we get the unknowns:

So given

$$x_0 = \frac{b_1^0 X + b_2^0 Y + b_3^0 Z + b_4^0}{b_9^0 X + b_{10}^0 Y + b_{11}^0 Z + 1} \quad y_0 = \frac{b_1^0 X + b_2^0 Y + b_7^0 Z + b_8^0}{b_9^0 X + b_{10}^0 Y + b_{11}^0 Z + 1} \tag{1}$$

$$N_X = b_1^0 X + b_2^0 Y + b_3^0 Z + b_4^0 \tag{2}$$

$$N_y = b_5^0 X + b_6^0 Y + b_7^0 Z + b_8^0 \tag{3}$$

$$D = b_9^0 X + b_{10}^0 Y + b_{11}^0 Z + 1 \tag{4}$$

$$b_i = b_i^0 + db_i, i = 1, \ldots\ldots 11 \tag{5}$$

$$\begin{bmatrix} \frac{X}{D} & \frac{Y}{D} & \frac{Z}{D} & \frac{1}{D} & 0 & 0 & 0 & 0 & -\frac{N_X X}{D} & -\frac{N_X Y}{D} & -\frac{N_X Z}{D} \\ 0 & 0 & 0 & 0 & \frac{X}{D} & \frac{Y}{D} & \frac{Z}{D} & \frac{1}{D} & -\frac{N_Y X}{D} & -\frac{N_Y Y}{D} & -\frac{N_Y Z}{D} \end{bmatrix} \cdot \begin{bmatrix} db_1 \\ db_2 \\ db_3 \\ db_4 \\ db_5 \\ db_6 \\ db_7 \\ db_8 \\ db_9 \\ db_{10} \\ db_{11} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \end{bmatrix}$$

Figure 1. The DLT system

The DLT methods guarantee in that case sufficient precision because the laser surface and digital image has very deep resolution.
Furthermore the surface have infrared information, that allow to pick points and particular with optimal accuracy.
We implement also the possibility to create Ortofoto 3D of flat surface. In this case we use the omografy algorithm.

2.3 Multispectral and thermographic analisy

In the course of the years the methods of diagnostic of cultural heritage is changed: once this depended on the skill of operators and on visual surveys of the studied object. Now the diagnosis and the conservation in entrusted to more and more accurate survey technique found on optoelectronic technology.
Aim of SIDART is to realize a system for integrate different diagnosis technique (Laser scanner, thermographic, multispectral) to give o good instrument of valuation of condition of a cultural object.
The presented software let to georeference different kind of digital image. We test with multispectral image (infrared, ultraviolet) and also with image from thermocamera.

2.3.1 Termographic Analysis

Thermographic analysis allows to examine the thermic condition of the object. Accentuated thermic gradient can cause accelerated deterioration of the object.
The thermo vision is a invadingless kind of diagnosis that have a large field of application: the survey of ampness zones, the location of hidden architectural elements (f.e. walled up window) or of the detachment of plaster and also the characterization of matter of the building.
To collect points on thermographic images, where the particulars are not so evident, we use some topographic target that will be acquired with laser and then they are covered with aluminium sheet during thermographic acquisition. This kind of material behaves like a mirror and in the thermo image you can see a black point. In this way is possible to recognise target and make the colour transfer.

2.3.2 Multispectral analysis

Reflectometry UV /IR: The infrared rays filter more deeper through the object surface and are useful to investigate the substrate The UV reflectometry is useful to collect some information of the surface of the object such as to distinguish different kind of pigment that you can not see with naked eye.
Fluorescence: Specially used inspecting organic material: the matter absorbs the ultraviolet light in one particular colour in visible range and gives different response (coloured fluorescence) depending on his chemical composition. The observation of fluorescence can distinguish and/or highlight the presence of material that can't be seen clearly with visible light
False colour: The image don't have true colours: the red colour is indication of reflectance of matter to the infrared radiation. The final image hold information of the different behaviour of material to the IR radiation.

2.4 Clouds registration

Is possible to register clouds range maps. In the software is implemented the rototraslation with direction cosine. You need three common point between two rangemap to complete tha registration.
Always for the good resolution and accuracy of the laser, the precision of this procedure can be considered adeguate.

2.5 Cut plane and multiple section extraction

In the software is implemented the possibility of choose some cut plane and extract the corresponding sections. This procedure works on the triangulated surface. This is different from other software that normally create sections collecting points between two planes that are very close. In this case you don't have a real line section but a little slice of point that need to be interpolated and approximated with other software or application. In our software the cut plane dissect a triangulated surface so return a "line of point" that is the intersection between the plan and the sides of each triangles.

2.6 Other applications

Other application implemented in the software are the surface **filtering**. In the ply surface can be some "long triangle" due by laser rays hitting some edge. The triangulation create so long triangle from point that are on different plane. This triangle had to be delete and the hole can be filled from other clouds taken from different position.
Another application is **decimation** of points to return a lighter surface when the geometric information are redundant.
Shaving light simulation is also implemented. This can be useful to inspect the surface and to study micro elevation, fractures or little defect of the surface such as paint detaching. This is possible always thank the high resolution and precision reached with laser scanner that can detect very little particular.

2.7 Working and saving

All the operation that are described above can be saved and the operator can work using the laser surface preserving previous application results. In particular the assigned colour from Ortofoto procedure can be saved in the ply file and all other operation can be done using this useful information providing a great sense of reality and major control during the diagnose.

3. TEST AND APPLICATION

3.1 S.S.Stefani of Vaste

The crypt of S. Stefani is excavated in the stone and is formed by three naves separated with pillars. The crypt is decorated with frescos, even if some of them are in abandonment condition. The frescos show images of Saints, Archangels, Our Lady and Christ. The original frescos date back to Xth century, but they were substituted with other paints afterwards (about XIVth and XVth century). In the following figures are represented some example of laser clouds and Ortofoto 3D of S.S. Stefani crypt.

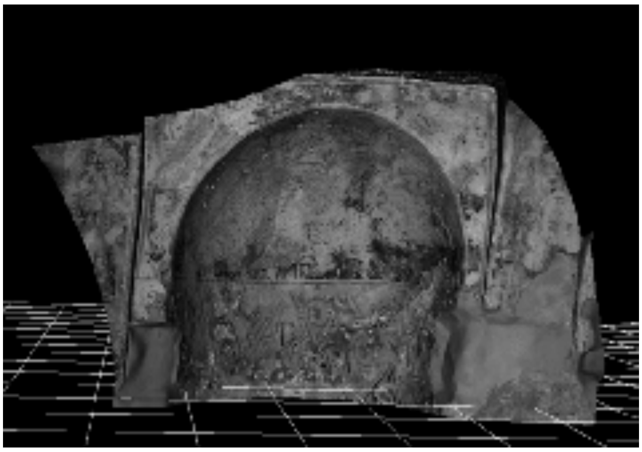

Figure 2. Surface of central apse. Spatial resolution of 1 mm. It's visible the colour information on infrared range

Figure 3. Ortophoto 3D from a digital image of metric camera (16Mpixel) Rollei

Figure 4. Particulars of the 3D ortophoto

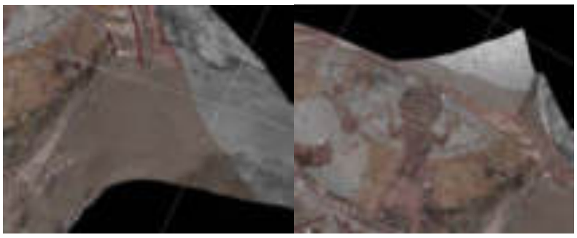

Figure 5. Some particulars. Image residuals is 2 pixel that correspond to 0.0014 m on the surface

Figure 6. Complete 3D Ortofoto of the three apses that are registered in the same reference system

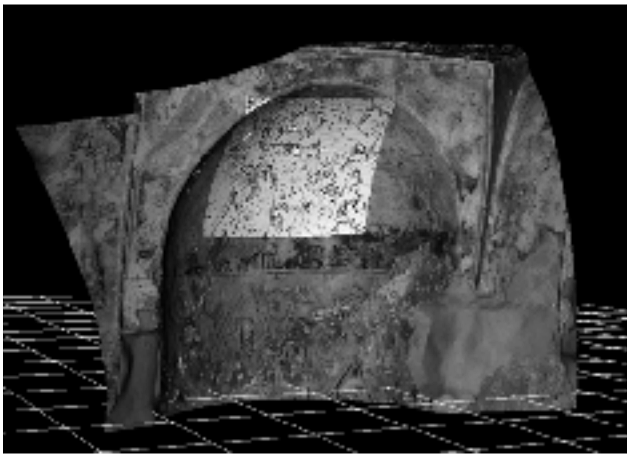

Figure 7. Application of a filtered digital image. This demonstrate how useful can be this method for analyse an object. In this case we have georeferenced a digital image from multispectral camera on infrared range and with the applied filter we can highlight the contours of the image. This can help the operator to analyse the fresco on the apse

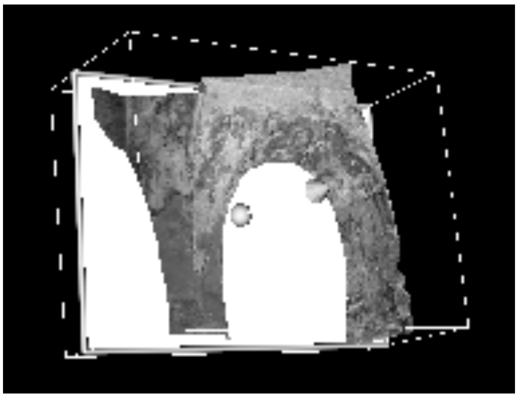

Figure 8. Application of the cut plane on the laser surface

3.2 Cross of Rosano

It' s a painted wooden cross temporarily sited by "Opificio delle Pietre Dure" in Florence for restoration.
This cross probably represents the most ancient example of the Florence school of painting (XIIth century). It represents the Christus triumphans with the passion story at the side of principle table

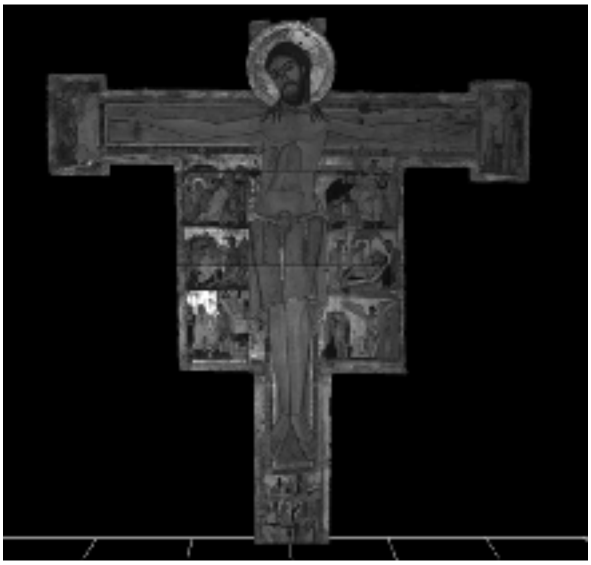

Figure 9. Laser scanner surface of Rosano cross. The scanning was made with 0.1 mm of spatial resolution

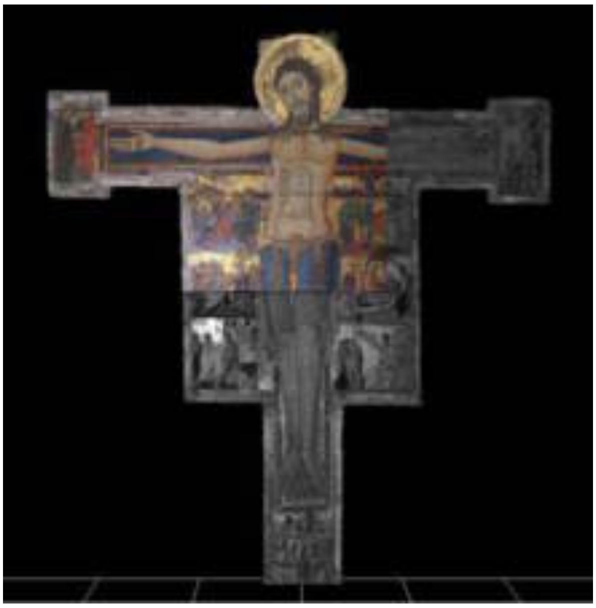

Figure 10. In this case the cross is to be considered flat, so was used the omography algorithm to create the 3D Ortofoto with a digital image coming from commercial digital camera (Nikon 4 Mpixel)

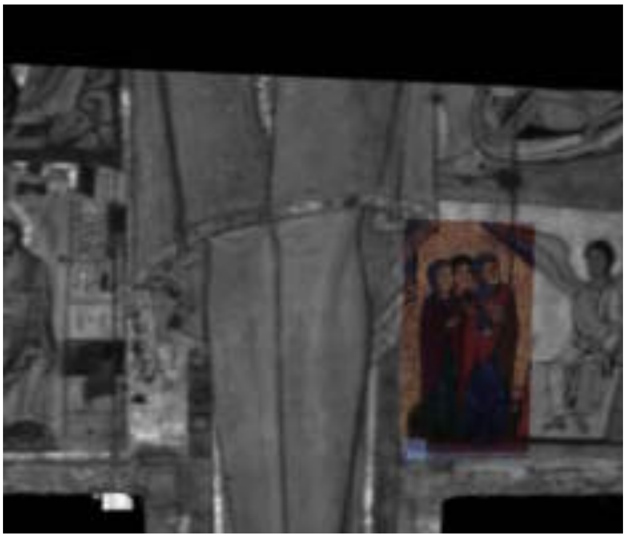

Figure 11. Colour application from colourimetryc data from INOA. RMS on the image is 4 pixel that correspond to 0.0009 m on the laser surface

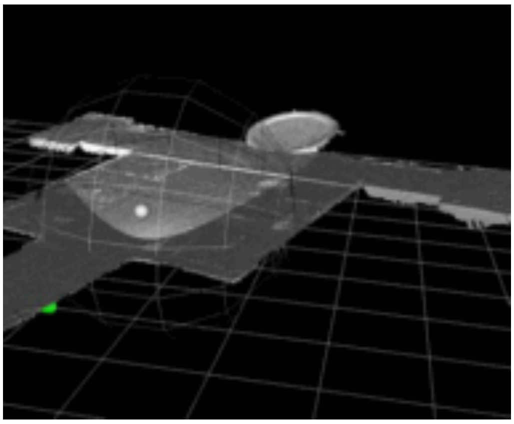

Figure 12. Shaving light simulation on Rosano cross

3.3 S. Maria Antiqua

Figure 13. Colour application from Multispectral camera of a ultraviolet image

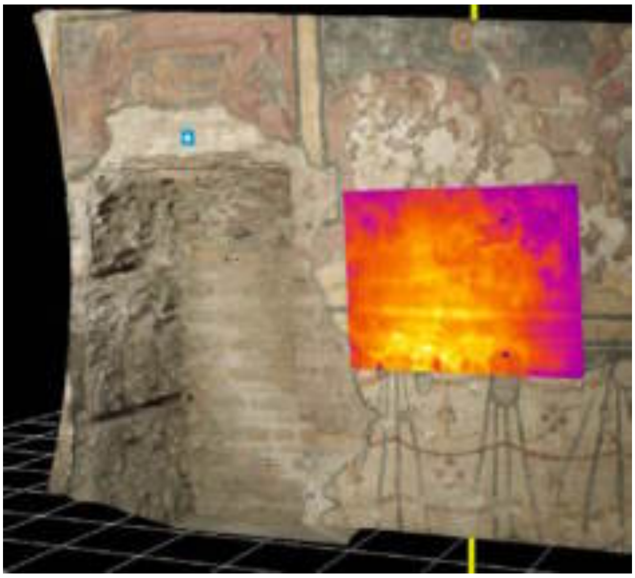

Figure 14. Colour application from Termografic camera image. The "mirror target" are good visible on the image

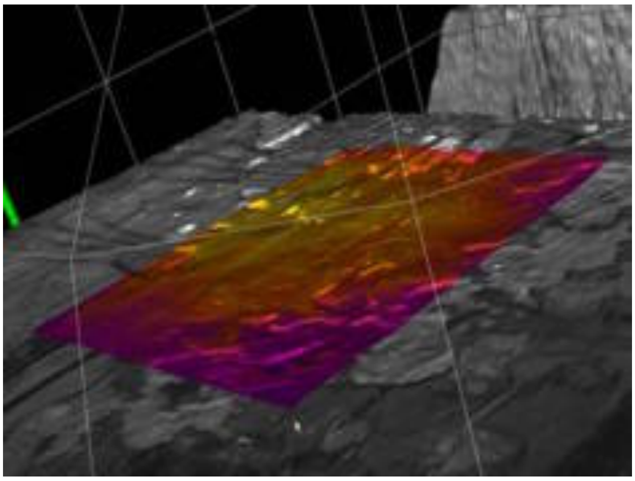

Figure 15. Great example of iteration of different information. Shaving light simulation on the surface with termografic image

4. CONCLUSION

The software proposed in this paper allows to work with laser clouds and several type of diagnosis image. We focused our attention on some applications such as 3D Ortofoto generation, rangemap registration and section extraction using simply procedures that guarantee good precision also because we have at disposal a high resolution laser prototype: the picking of corresponding point between laser and images is very accurate and cause little error. In the future we will implement all this system to permit the software to work with different kind of laser scanner clouds and to increase the precision of the operations. In particular we are already studying and developing algorithms of approximation and interpolation of points that come from section extraction procedure and implementing ICP algorithm for a more accurate results in map registration.

Figure 16. Colour application of digital high resolution image,The pick point and the result of the operation are showed

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