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Innovative methodology for the integration of range-data and image-based systems.

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Abstract – **Most of the survey techniques used in archaeology and architecture are currently focused on range-data (laser scanning) and image-based systems (digital photogrammetry/photoscanning). The paper aims to highlight a different methodological approach in the procedures of acquisition and processing of numerical data. The proposed methodology suggests an alternative integration between point clouds from laser scanner and image-based system, exploiting the properties of the ICP algorithms. Three different experimentations were performed at different level in order to achieve the suitable procedure. Some graphics show the comparison between the classic approach and the new procedure. The results are very interesting for what concerns the elaboration of the numerical models. The correct position of the points in space contributes the next step of the surface reconstruction (meshing process) and the final 2D representation.**

I. INTRODUCTION

This research arises from the need to find accurate solutions in the survey discipline that currently suffers the technological development and the automated procedures. The paper is a preliminary note of a wider project that investigates the survey issues through different instrumentation and software. Most of the survey techniques used in archaeology and architecture are currently focused on range-data (laser scanning) and image-based systems (digital photogrammetry).

The two modalities are based on completely different geometric principles, although the results are similar (point clouds). Laser scanning systems are based on the principle of polar acquisition. The instrument is able to collect accurate and detailed amount of 3D information in a short time. The results are point clouds with 3D coordinates and the reflectance information (besides RGB value, fig.1) [1].

Image-based systems are based on the geometric principle of the "space forward intersection". Also this system is able to collect 3D information of a subject, but it uses algorithms for the automatic recognition of the homologous points [2]. In this way it is possible to carry out point clouds similar to those of a laser scanner with colorimetric value associated (but without reflectance information, fig.2).

Fig.1. Point cloud of the main façade of Palazzo degli Ambasciatori in Rome, Coppedè district.

The main difference between the two systems consists in the structure of the data [3]. Laser scanning systems are made up of structured data, included in a regular grid with known characteristics such as the exact number of rows and columns of the point clouds, coordinate of the points, the reflectance information of each point and the RGB value taken from a sensor built in the scanner. For each scan it is known exactly the centre of projection, recognized as the source of the laser beam. This characteristic allows to remove noises from the data and to add further information such as the orientation of the main surfaces (local tangent planes).

Fig.2. Point cloud of the Facchino's fountain generated with image-based system.

Image-based systems are made up of unstructured data, not included in a regular grid due to the different principle of the geometric reconstruction. The point cloud is characterized only from the coordinates of each point and the related RGB value. As known, the physical characteristics of the subject can influence the accuracy and the uniformity of the results so that the points are irregularly distributed [4]. From the point cloud is only possible to calculate the different position of each camera frame (external orientation) and not a single centre of projection. Due to these characteristics it is not possible to add any further information and the results could contain noisy areas.

The paper aims to highlight a different methodological approach in the procedures of investigation and the processing of the numerical data in archaeology and architecture. The idea was to study different methods of acquisition and integration of data between laser scanner and digital photogrammetry, comparing the final results performed through the innovative procedure. The survey pipeline can be divided in four main steps:

- The acquisition on the field;
- The elaboration of the numerical models;
- The reconstruction of the surfaces (mesh);
- The bi-dimensional representation;

The experimentation was focused on the acquisition and the elaboration of the pipeline. This two phases evidence some problems that often are not considered during a survey.

The integration between different survey techniques is often only theoretical due to the difficulties to manage a large amount of data coming from different sources. Research groups are frequently focused on the use of only one of the two methods due to own characteristics and personal experiences made directly on the field.

Using one of the two technique it is possible to perform adequately a complete survey, but the question is if we are able to integrate correctly data from different sources in the survey discipline and what is the correct procedure for obtaining the best results. The idea was to systematize the integration between the two methods in order to underline a different and rigorous procedure useful for the archaeologist and architects.

II. THE INTEGRATED SURVEY

Until few years ago the main survey method was usually based on the integration between laser scanner (TOF) and topographic systems (total station and/or Global Navigation Satellite Systems). With the aid of a total station, closed traverses were performed in order to register the scans of a survey and to decrease the error propagation of each scan of the laser. The entire scan project was registered through the use of planar targets, the *Ground Control Points* (GCPs; fig. 3) [5]. Precisely each single scan of the laser behaves like the main nodes of a total station, due to the same principle of acquisition (polar), in fact the difference consists only in the number of collected points. Each vertex of the closed traverse suffers from an error that have to be compensated with known formula in topographical discipline (angular and distance compensation). This allowed to reduce the mutual position of the scans in the space [6].

Recently a series of algorithms for the correct mutual position of the scans have been developed (fine registration). Such algorithms are known as Iterative Closest Points (ICPs) [7]. Despite they have been already discovered in the 90's, different implementations have made them common for the software of 3D point clouds managements. After the pre-registration step, performed manually, ICP are able to move a point cloud over another point cloud (the reference one) on the basis of thousands of points (5.000 to 20.000 and over), thus reducing the final overlapping error (fig.4). Usually ICP

Fig.3. The geroreferencing process based on the choice of planar GCPs distributed on the surface, Benedictine Monastery of Subiaco.

algorithm works with laser scanner data and its interface is composed by different values that can be changed by the operator. In order to satisfy the algorithm two scan have to be pre-registered manually on the basis of 3 or more points. It is not important the pre-registration error but certainly the mutual starting distance between the scans can affect the final result. Most of the software of point clouds management employ ICP tool: some time it is possible set the values, other time the process is in automatic (*Faro Scene, JRC Reconstructor, Cloud Compare, Leica Cyclone*).

This new approach allowed to change completely the procedure during the acquisition step. At present it is more important to have a good overlap among the subsequent point clouds in order to satisfy the requirements of the ICP algorithms. The fine registration allows to reduce the error propagation, effectively excluding the topographical approach. The risk is that the acquisition of the GCPs with a total station can increase the error of the registration among different scans. The topographical method could be used only for georeferencing the different scan projects in the same reference system.

III. THE INNOVATIVE PROCEDURE

One of the main issues of the processing step is the integration of the two data sources (laser scanning and digital photogrammetry) within a same reference system (local or global). The idea was to reconstruct a numerical model that was the result of acquisitions performed with different techniques, maintaining a final good quality.

For that reason an innovative procedure that integrates the two set of data has been developed, exploiting the potentiality of ICP algorithms. For this experimentation point clouds were used instead of the surfaces (mesh), indeed the surface reconstruction alters the results of the numerical model making an interpolation of the whole data set. Also the point clouds are an interpolated results and their accuracy depend mainly from the intrinsic characteristics of the instruments (laser or camera), the environmental situation, the position of the instruments compared to the investigated subject and the acquisition method. For instance if the position of a laser scanner is very close to a tall subject, most of the projecting rays will be tangent to the surfaces, reducing the quality of the cloud. In the image-based system it is very important to apply a correct acquisition of the subject by using two possible different methods: convergent or parallel acquisitions [8].

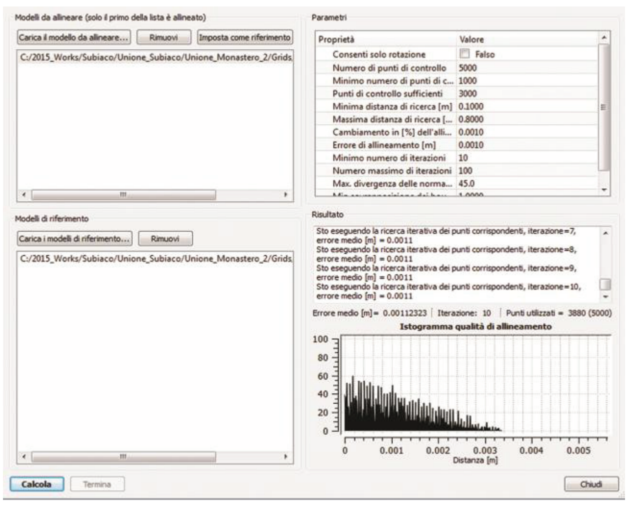

Fig.4. Example of ICP interface where it is possible to set different values.

As known, data from image-based systems are not scaled (when they are not stereoscopic) and the integration is often performed on the basis of some points picked directly on the point clouds of the laser scanner. This procedure allows to scale the unstructured model and reference the clouds in the same coordinate system. The positioning error depends on many factors such as the choice of the points (disposition) and the different resolution of the two compared numerical models. The same points can be described with a different number of pixels. However the mean squared error appears to be low in the chosen points but in other areas the overlaps may be incorrect. This evaluation can be performed comparing the distance between two clouds.

The pipeline of the suggested procedure is shown below:

- Range data acquisition of a subject;
- Image-based data acquisition of the same subject;
- Scaling of the image-based system using reference points of the laser scanner;
- Transformation of unstructured data into structured data through *Vitual Scan* tool;
- Fine Registration Cloud to Cloud (ICPs);
- Evaluation of the error comparing the distances;
- Generation of different cross sections;

The acquisition is the first step of the pipeline. Laser was set up for recognising data at high quality, maintaining a 60% of overlap among the acquisitions.

In order to have defined images and a good field depth the camera settings were modified by using automatic shutter, diaphragms at f11/f14, ISO sensibility at 100 and infinity focusing. Acquisitions have been made maintaining the same distance of the laser from the subject in order to reduce the difference of representation of the points.

As mentioned above in order to integrate the two data set points of laser scanner are used to scale the model derived from digital photogrammetry. The accuracy of the transformation depends from the number of points taken, form their position on the model and the mutual registration in the same point. This process is without doubt correct but comparing the two clouds it is possible to evidence differences in overlapping. These errors depend also from the dimension of the subject and can influence the step of the surface reconstruction.

The innovation consists in the application of ICP algorithms for the correct integration between two different data sources. In order to accomplish this process it is important to transform unstructured data (photoscanning) in structured data such as the laser scanner. This transformation has been carried out through a simple tools known as *Virtual Scan*, developed by Gexcel (*JRC Reconstructor*).

This tool allows to make a virtual scan of an object in the virtual space. Once an orthographic camera that includes the numerical model (unstructured) is established, it is possible to acquire the whole point cloud at a specific resolution, such as a laser scanner. At the same time it is possible also to create a spherical or a cylindrical camera in any virtual position, simulating the same movement of a panorama scanner (fig.5). By using the spherical camera the tool allows to register an equirectangular grid (360x180) composed by image-based points without altering their position.

This particular operation gives the same characteristics of the laser scanner to the (unstructured) point cloud, useful for the ICP data registration. Knowing the exact projection centre of the new cloud (spherical, cylindrical or orthographic) software is able to pre-process data conferring new information such as the orientation of the surfaces. After matching the two scans, it is possible to perform the fine registration with the ICP algorithms that will find the best position between the two point clouds. The algorithm find the best position iterating the process different times and rototranslating the mobile cloud over the reference one.

The next step consists in the evaluation of the error by measuring the distance between the two clouds after and before the ICP registration. *Cloud Compare* tools were used to inspect the distance and the results are very interesting.. Different planes have been created in order to compare the sections of the three numerical models and evaluate the error (laser scanner, image-based system, ICP image-based).

IV THE EXPERIMENTATIONS

The experimentations were carried out on three different subjects, at different level, in order to achieve the suitable procedure. The acquisition was performed with a different phase laser scanner Faro 120 (distance accuracy up to ± 2mm at 130 m) and with a Canon Eos 5D Mark II, with 28/50 mm fixed optic lens.

The survey concerned a little historical fountain in Rome (*The Facchino's Fountain*), the main front of an historical building in the Coppedè district (*Palazzi degli Ambasciator*i, Rome) and the first span of the Upper Church of the Benedictine Monastery of Subiaco.

Facchino's Fountain represents a little monument preserved in Rome useful for the study of freeform surfaces. The face and the chest of the sculpture are very articulated and damaged. These conditions allowed to operate with the method suggested above. Two scan at very high resolution (indoor 20 m, beam iteration 4x) were performed and they were shot about 10 images from a tripod in parallel acquisition. For the face other images were taken close to the statue with convergent acquisition. The numerical model of the laser was composed by 25 million of points while the numerical model of the image-based system was composed by 11 million of points. The mean squared error of the projected points from laser is 0.0025 m. Despite the error was very low, the ICP transformation was able to reduce further the value to 0.0015 m. Comparing the clouds it is possible to notice the different distribution of the error before the ICP registration and after (fig.6). Blue colour evidences the exact correspondence of the clouds while green colour evidences a major distance between the clouds included in a threshold of 0.007 m. The second image shows the best fitting of the clouds but the green colour is distributed on the sculpture maintaining a constant error.

Different considerations can be proposed:

the ICP correlation is more accurate in flat areas (such the blue colour suggests), the mismatching of the two clouds (mainly on the sculpture) could depend from the

Fig.5. Application of the Virtual Scan from a spherical camera similar to the projection centre of a laser scanner.

reconstruction algorithm in the photoscanning software that altered the geometry of the monument (Agisoft Photoscan) [9].
The second experimentation was about the first span of the Upper Church of the Benedictine Monastery of Subiaco. The application was performed for an internal subject characterized by complex shapes. In particular the application was used to analyze the correspondence for the cross vault, positioned at 7 m from the floor. The referencing step was aided from the condition of the painted frescoes. In particular the eyes of the characters have been the reference points among the two systems. In this example it has been decided to evidence the overlapping error through the cross sections. The image show the upper part of the cross vault (fig.7). The black line represents the section generated from the laser scanner. The red one the referenced model from the image-based system. The green section shows the performance of the ICP algorithm applied to digital photogrammetry. In this way it is possible to measure exactly the distance among different part of the numerical model. Even if the complex shape of the curvature is not well overlaid compared to the flat part, the final error decreased of about 0.01 m.
Last case study was carried out on the façade of *Palazzo degli Ambasciatori* in Rome. Built between 1917 and 1921, it is the most representative building structure of the Coppedè district. It consists of three separate units combined in two triangular wings connected by a large arch, representing a triumphal entry. The work focused on the south tower of the complex due to the complex style used for its characterization (*liberty style*). In this case only one scan has been used (outdoor 20 m and over) and 30 images taken from the camera, trying to maintain the same distance from the main façade.
The laser model was composed by 44 million of points while the photoscanning model by 53 million. As in the other cases the procedure was applied to correct the positioning error derived from the manual referencing approach. In this case two different virtual scanning of the point clouds has been generated (fig.8). The first one is based on the spherical projection centre while the second is based on the orthographic camera with a projection centre focused to infinity. The comparison among three different numerical models points out some important aspects. The mean squared error of the projected points from laser is 0.015 m. Despite the error may be accepted, the ICP transformation was able to reduce further the value to 0.012 m (spherical camera) and 0.007 m (orthographic camera). This second approach reduced considerably the overlapping error on the façade but it does not take into account the problem of undercuts.

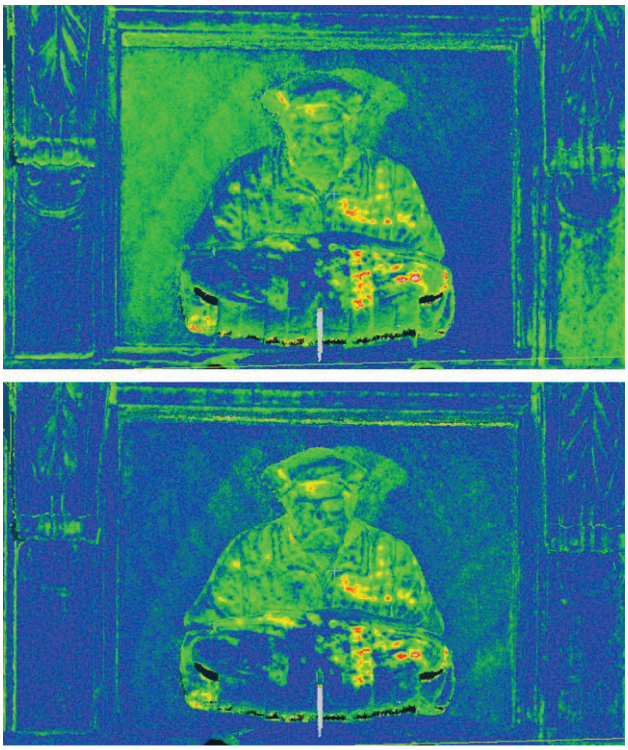

Fig.6. The overlapping error shown through the comparison of the distance.

IV. CONCLUSION

The results are very interesting for the integration of the point clouds derived from different sources. The described process evidence further analysis for the point clouds management. The correct position of the points in space aids the next step of the surface reconstruction (meshing) and the final 2D representation. Through this procedure it is possible to assure a best fitting in the point clouds integration. Next step will be analyzing the effect of the procedure on other case studies close to the archaeology discipline.

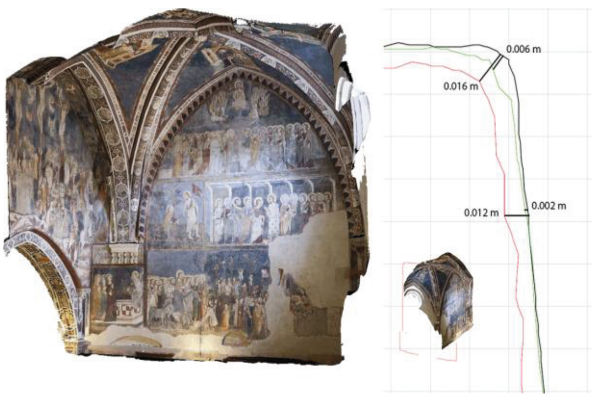

Fig.7. Cross section of the cross vault of the Upper Church of the Benedictine Monastery of Subiaco.

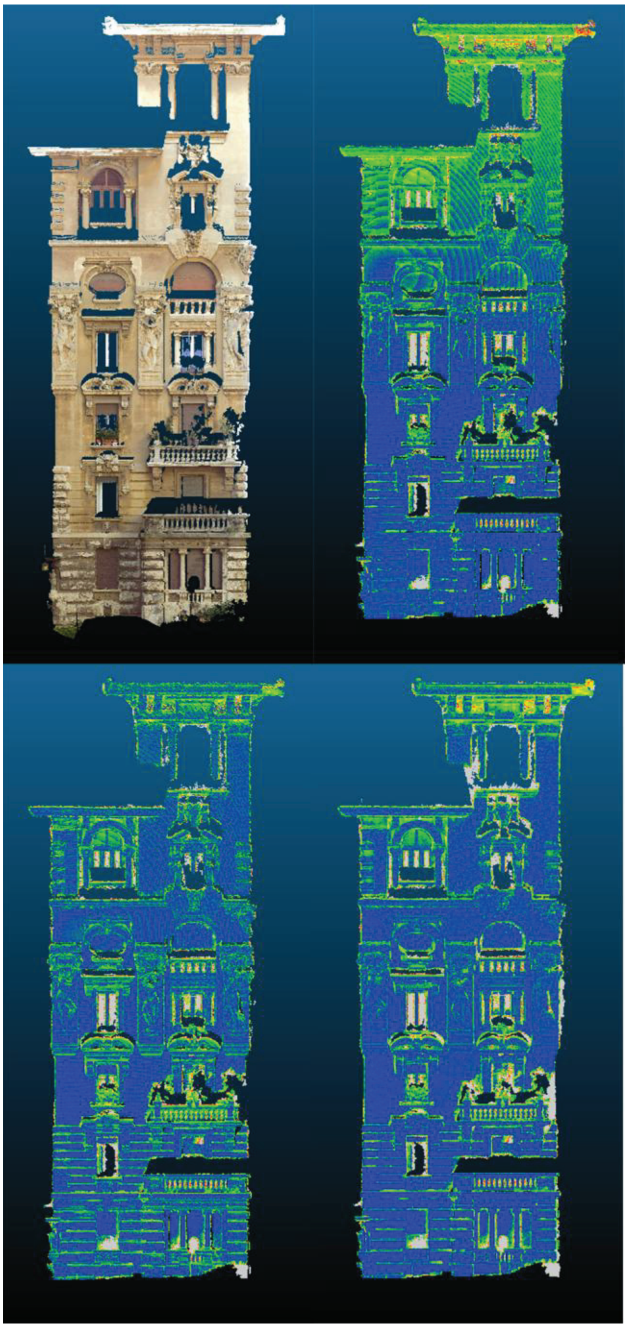

Fig.8. The three numerical models have been compared to evaluate the distance among the points.

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