Integration of TLS and thermography for the morphometric characterization

V. Barrile, G. M. Meduri, G. Bilotta

***Abstract*—**The laser scanner is a detection technique essential for the 3D modeling of objects and it is well known its capability to acquire large amounts of data relatively in short times with a high degree of precision. So it is widespreadly used in broader research's fields from engineering to medicine and to the study and protection of cultural heritage.

Through integration with other radiometric techniques you can get an overview on the state of conservation, particularly with the three-dimensional models obtained by integrating 3D laser scanner data with images obtained with the infrared camera, that is able to deliver, over the dimensional characterization, also information on possible anomalies, dimensional and in shape, invisible to human eyes and other techniques.

In particular, this application with the integrated use of terrestrial laser scanning instrumentation and advanced infrared camera can test a possible use for cars, after packaging and transport, in order to detect any damage caused by transport.

***Keywords*—**3D modeling, Advanced Infrared camera, Laser scanner, Termography.

I. Introduction

THE integration between a three-dimensional digital model, realized by scanning laser terrestrial systems, and the radiometric information, obtained by advanced infrared camera, allows to investigate, also to a high degree of detail, some particular characteristics of an object at very different dimensional scales, resulting in what is called in the literature *Texture mapping*. Using *target* [1]–[2], thermo-rendered recognizable, it was possible to perform the texturing of the virtual models with IR images, thus obtaining the integration between spatial and radiometric data.

II. Operations and tracking mode

The integration between geometric and spectral data enable to extract quantitative information concerning the extension of thermal anomalies or special events that take place within a historical artefact or a modern opera [3]. To perform this procedure is generally required to manually identification of homologous points between 3D model and 2D image [4]. The method that permits using the pairs of points identified is Direct Linear Transformation defined, DLT. To allow the reconstruction of geometric model, first, and texturing, after, is necessary to know the orientation parameters inside of the tools used [5], known and physically and rigidly tying the tools it has been possible consider constant the roto-translation between them. It was therefore possible to consider a global reference system, and referring the orientation of the thermal chamber relative to the internal reference of laser scanner through a physical and rigid bond between the instruments with a steel bar. After identifying which surface of the car acquire and textured, you place the target (minimum three), which are the points of support of the georeferencing of the point clouds and images (both thermal and radiometric) on the virtual model. It is therefore necessary to study the most suitable and homogeneous distribution on the area to be investigated, in order to ensure an equally homogeneous projection of the image on model. The targets, moreover, can be preferentially arranged especially in areas with greater undulation of the surface, so as to achieve greater accuracy, reducing the errors due to the geometric distortion of the scene arising from a not good recording of 2D data (images) and 3D data – point cloud or mesh [6].

The target, in addition to allowing the rototranslation of point clouds acquired in the same reference system, allow the texturing of the images on the three-dimensional global model. The signals used in this study are highly reflective and retro-reflective signs, measuring 3" x 3" used for high-resolution scans of detail (laser scanner Leica HDS 3000). We detected and calculated the center of these signals semi-automatically with the software implemented in the instrument that associates to the center of gravity of the signal in the point cloud the respective coordinates in a reference system with origin in the center of the instrument [7]. The surface is then scanned with a laser scanner type Leica HDS 3000: a laser time of flight (TOF Time of Flight) that allows to acquire in a few minutes the three-dimensional coordinates of large quantities of points distributed on the surface in question according to a regular grid. To get coverage of the entire surface, thus limiting the areas or items in shadow, were usually also acquired even more point clouds of the same area.

When the scan surface scans are carried out in detail, with the same Leica HDS 3000, centered on each of the target on

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the surface: the signals are manually identified on the point cloud and acquired by the instrument which, in the end, automatically identifies the target scanned. The uncertainty in the calculation of the coordinates of the target depends on the uncertainties and mistakes of the laser scanner. In order to be univocally recognized in the thermal image and to perform in this way a correct texturing, it is necessary that the targets are also thermally visible, and then chromatically recognizable, compared to the context of the surface in which they are located. For this reason they have been sprayed with a spray cold, or dry ice. It is a phase to be performed with a certain speed, since the effect of instantaneous cooling of the signal has a rather short duration in time (few minutes).

It is also important that the sizes of the vaporized area are as small as possible, so that the corresponding area on the relative IR image is equally limited by avoiding to affect the final result. Then an acquisition is made with thermal imaging camera (Reference image) initially with a single outlet in automatic mode to highlight the range of temperatures recognized. It is more convenient to acquire a greater number of thermal images to cover the entire surface rather than acquiring a single image, especially in the case of surfaces structurally complex, considering also the lower sensitivity of the detector with increasing distance.

III. Data Processing

The process of data processing can be summarized in the following steps:

- Alignment of point clouds
- Meshing point clouds
- Estimation of interior orientation parameters
- Calculation of guidance
- Texturing infrared

The different scans acquired to cover the entire wall in question are aligned with one another in the *Cyclone software* environment, (version 5.3), because the phase of texturing is an operation which must necessarily be done on a continuous surface (as provided by the software used in this methodology), on which the image will then be projected. Therefore, we transformed the point cloud into virtual surfaces of *mesh* type, in most cases forming triangles of irregular shape. For this operation is still used *software Cyclone* environment. The quality of the operation of *meshing* depends on the algorithm itself and by the parameters that are selected, ie the direction along which to project the triangles and the size of the triangles. This means that the mesh is not created simply by the interconnection of the point cloud, but that in any event is generated by a network mesh uniform, so some points are interpolated.

For the estimation of the interior orientation parameters we used the *software PhotoModeler*. Following the usual procedures were performed manually searching operations of the points on the mesh, the referencing of homologous points and, finally, the calibration of the camera after setting the scale factor.

The geometric model implemented is based on parameters such as:

- principal distance (c);
- coordinates of the principal point (x_0, y_0) ;
- compensation coefficients of radial distortion (k_1,k_2);
- compensation coefficients of tangential distortions (P_1, P_2).

After evaluating the rotation matrix and the translation vector, which we will consider constant during the operations of recovery of point clouds, with the function "*Merge project*" of *PhotoModeler* we reduce the standard deviation of the rotation matrix and the translation vector. This is because the targets in thermal images are made to match homologous points in the mesh. The meshes have a higher resolution and therefore greater accuracy.

Finally, in *RapidForm* 2004 environment, the infrared image is textured on the *mesh*, using as support points the *target laser scanning* on the real surface. Having made the *target* thermally recognizable, with the dry ice we made the same as a distinct color in the image, corresponding to a temperature much colder compared to the context in which they are found. Thermal infrared cameras for building, like the one used, hardly have higher resolution then 640 x 480 pixels, this justifies the uncertainty of higher values than those in the visible. Performing the texturing using multiple points of support, even if not recognizable automatically by the *laser scanner*, the result would be very good. But, not being able to cover the surface of study with a high number of targets for practical matters-operational and in order not to generate additional shadow zones, you should always get a good compromise between target number for image and final quality of the textured model.

Another approach to align the camera images with the scanner coordinate system is to use a calibration procedure. Each camera has unique parameters that define how a point (X,Y,Z) in world coordinates is projected onto the image plane. These parameters are calculated through a process known as geometric camera calibration. Given the focal length (f_x, f_y) of the camera and the camera center (c_x, c_y), image coordinates (x,y) are calculated as:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X/Z \\ Y/Z \\ 1 \end{bmatrix} \quad (1)$$

Given the radial distortion coefficients k_1, k_2, k_3 and the tangential distortion coefficients p_1, p_2 and $r = \sqrt{x^2 + y^2}$ the corrected image points (x_c, y_c) are calculated as:

$$\begin{pmatrix} x_c \\ y_c \end{pmatrix} = \begin{pmatrix} x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 y + p_2(r^2 + 2x^2) \\ y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2y^2) + 2p_2 x \end{pmatrix} \quad (2)$$

Once all the points are in the camera coordinate system the projection to the image can be defined up to an factor s using equation (3):

$$s\begin{bmatrix}x\\y\\1\end{bmatrix}=\begin{bmatrix}f_x & 0 & c_x\\0 & f_y & c_y\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r_{11} & r_{12} & r_{13} & t_1\\r_{21} & r_{22} & r_{23} & t_2\\r_{31} & r_{32} & r_{33} & t_3\end{bmatrix}\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix} \quad (3)$$

The maximum likelihood estimate of the transformation between the scanner and camera coordinate system is obtained by minimizing:

$$\sum_{i=1}^{n}\sum_{j=1}^{m}||\mathbf{p}_{ij}-\hat{\mathbf{p}}(\mathbf{A},\mathbf{D},\mathbf{R}_i,\mathbf{t}_i,\mathbf{P}_j)||^2 \quad (4)$$

where n is the number images of the calibration pattern, m planar points on the pattern A is the camera calibration matrix, R_i the rotation matrix, t_i the translation vector, and D the distortion parameters.

$\hat{p}(A,D,R_i,t_i,P_j)$ defines the projection of point P_j in image i, according to equation (3) and (2).

This approach assumes that we have a number of points identifiable in both the laser scan and the image.

IV. Case Study

In the case under study were acquired images of two different cars (Fig. 1, Fig. 2).

They are a Fiat Punto and a Peugeot 206, the first damaged the left rear, the second on the front left.

Fig. 1 - Fiat Punto crashed in the area of the rear bumper left

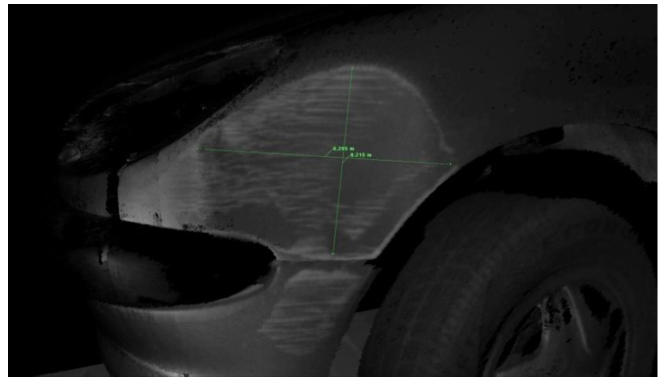

Fig. 2 - Peugeot 206 crashed in the front left side of the headlight

Once simulated the packaging (Fig. 3), on each of them were placed three targets, distributed homogeneously on the surface of interest. The 3D survey with the laser scanner Leica HDS 3000 of the wall was carried out by two acquisitions from different points of stationing to limit the shadow zones, with a sampling step of 5 mm and a laser scanner - car distance of about 5 m: were thus obtained two point clouds. The three targets were scanned in detail with the laser scanner and below, images were acquired in the range of infrared cameras Flir B2 with the camera at a distance camera - car about 2 m.

Fig. 3 - Simulation package on two cars

After roto-translating the coordinates of the points of the scans acquired in the local frame of reference of the support points (with a maximum error of mosaicking of 1 mm), from the final 3D model (in *Cyclone* software environment), was performed a triangulation that provided a continuous surface of mesh type. With the software *RapidForm 2004*, after highlighting the coordinates of the target as recognizable geometric reference entities on the mesh, we proceeded with the texturing of the image.

The texturing with IR images was carried out through the manual recognition of the 3 target identified in the mesh as reference geometry and the thermal image with a color indicating the points that are cooler than the surface (thanks to the expedient of ice spray used before the acquisition with the thermal camera, Fig. 4).

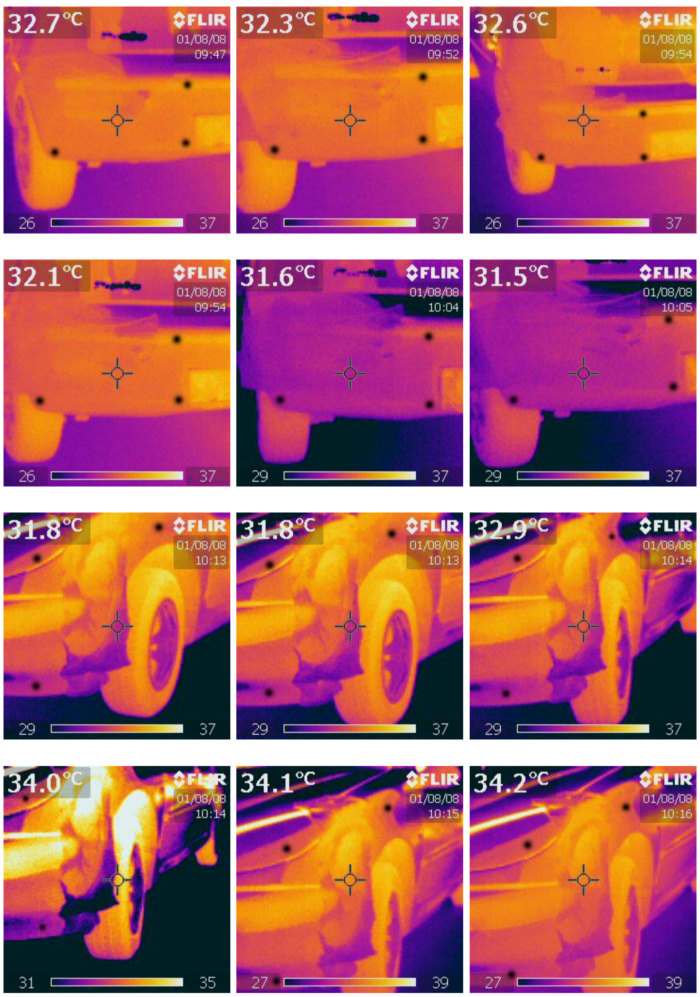

Fig. 4 - Reference image

The texturing was then carried out using the laser scanners target: were not used natural points (such as edges, references the wheels) precisely because of the difficulty of finding the same point in the thermal image and in the triangle mesh. As emphasized by the below images (Fig. 5), the integration of point clouds obtained by laser scanner and thermal imagery provides accurate information on the progress of morphometric alterations characterizing the damage due to accidents. The color distribution in the thermal images and precise alteration of the same is evident proof of the presence of damage. However, the only thermal images cannot be considered sufficient for a reliable estimate of the state of the object under investigation.

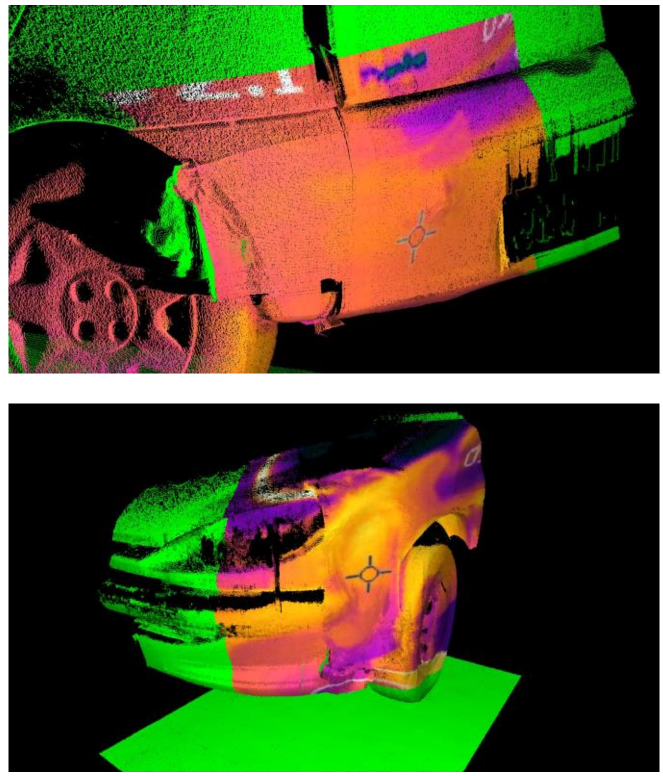

Fig. 5 - Texturing of the images in the infrared range, with a resolution of 800 x 600 pixels

For information purposes, we report the thermographic images (Fig. 6) of one of the two cars investigated (Peugeot 206) in undamaged condition, to facilitate a more simple assessment of discoloration found to take over the damage.

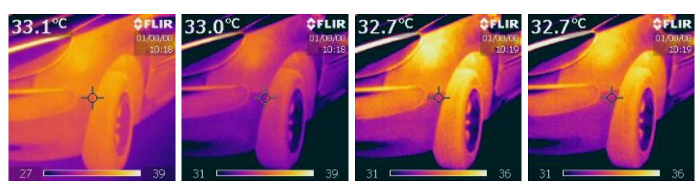

Fig. 6 - Reference image Peugeot 206

V. Conclusions

The limit of the texturing is in the fact that it is not an automated procedure [3], however, the results have confirmed the applicability and the validity of the methodology that allows to perform the texturing of thermal images on mesh surfaces produced by laser scanning point clouds, that highlighted texture mapping of good quality.

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