INDEPENDENT MODEL TRIANGULATION OF TERRESTRIAL LASER SCANNER DATA

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ABSTRACT:

Transforming the coordinates of different laser scanning stations into a unique object reference system is mostly performer pairwise, using retro-reflective targets as tie points. This may lead to inconsistencies and model deformations. We propose a different approach, based on the simultaneous adjustment of all 3D models coming from different views, in a manner similar to that used in aerial triangulation by independent models. Given *n* models, a 7 parameters conformal transformation from each to the object system is computed using target as tie points and GCPs if available. Linearization of the equations require a set of approximate values for the unknown parameters, which are provided by an algorithm based on Hamilton Quaternions, but need a set of at least 3 points in both the scan and the object system. Provided that each model is tied to the adjacent by at least 3 tie points, a procedure is presented which computes these approximations for all the block. Tests with real and simulated data compare the effectiveness of the solution with respect to pairwise registration in several operating scenarios.

1. REGISTRATION OF 3D MODELS IN LASER SCANNING SURVEYS

Terrestrial laser scanners enable to survey the 3D surface of complex objects by acquiring a large amount of data in a short time with respect to classical topographic and photogrammetric techniques. Deriving information (e.g. a vector representation) is not as easy, though. Many problems arise in data processing: representation, point cloud simplification, feature extraction, restitution and so on. In this paper we would like to focus on one aspect, namely the fusion of 3D views of the same object coming from different laser scanner stations. The scheme of a survey by a laser scanner is similar to a photogrammetric one, being necessary to perform acquisitions from different standpoints if the object is too large (or has complex shape, so that occlusions arise which prevent to complete the survey from a single station). The output of a scan from a given station is a 3D point cloud (a sort of photogrammetric model with scale factor 1:1), whose coordinates refer in principle to an instrumental reference system, which therefore changes from station to station. All the model points must be put together, transforming their coordinates into a unique object reference system. Depending on the purpose of the survey, the coordinates may have to be referred to a pre-defined reference system or may be expressed into an arbitrary one. In the former case, ground control points (GCP) must be provided in every scan, in the latter they are not strictly necessary. The use of GCPs is highly recommendable when comparing laser-scanner surveys executed at different times to improve the registration accuracy and may be required in case other kind of topographic or photogrammetric measurements should be integrated in the survey (see e.g. Bornaz et al., 2002).

Besides, using GCPs may help reducing registration errors due to unfavourable tie point distribution or poor measurement accuracy.

The registration of each models is reduced to the computation of a *3D conformal transformation* (7 parameters), requiring a minimum number of three common points. Simplified transformations could be applied, for example by fixing the scale of each model to 1 (6 parameters). Should the Z-axis of the scanner be put vertical with sufficient accuracy, the parameters would be further reduced to 4: three model shifts in X, Y and Z directions and a rotation around the vertical Z axis; in this case only two known points would be required to register each model. We would rather prefer to use a full conformal transformation, which allows to trace possible calibration problems affecting each model.

A least squares computation of the 3D conformal transformation is recommended, to exploit any available data redundancy. Problems arise in the linearization of the system of equations, because a set of approximate values is to be provided. To this aim, several algorithms can be found in literature, e.g. based on Hamilton Quaternions (Sansò, 1973), Procrustean Transformations (Beinat & Crosilla, 2001) or other kind of linearization of the rotation matrix (Pozzoli & Mussio, 2003) among the others.

To register each model, a set of tie points must be provided. These could be either GCP, if registration to a predefined reference system is required, or points shared by two adjacent models if should they be put pairwise into the same reference system. In the last case, an alternative method to register 3D models is based on matching different surface models (see e.g. Cortellazzo et al., 2000), so that the registration is computed on the basis of a larger dataset. On the other hand, this approach cannot be used to register data to a predefined reference system, so that GCPs are strictly necessary in this case.

Two main strategies have been carried out so far in order to select and to extract single control points (which may be used as GCPs if their object coordinates are known):

1. using highly reflective targets as common points between different models, whose selection and measurement in the laser image may be performed in automatic or manual way;

2. identifying common features (natural or artificial points) by automatic or interactive procedures.

Which method is available depends on the laser scanner instrument and on the data processing software being used. In the experience of the authors, the existing systems do not provide yet a large flexibility of solutions: normally only one option is available.

Once control and ground points have been selected, model registration can follow two different strategies. If enough GCPs are available in each 3D model, they can be straight-forward registered to the given reference system. Otherwise, the registration is computed by starting from a model which is chosen as reference, and by registering independently to it all adjacent models sharing a sufficient number of tie points. Then, neighbouring models are registered, and so on until the whole block is oriented.

From an operational standpoint, using a possibly large number of GCPs require topographic measurements, which results in longer survey times and decreases the advantage of using a laser scanner in many applications.

We propose a different approach, based on the simultaneous adjustment of all 3D models coming from different views, in a manner similar to that used in aerial triangulation by independent models. The mutual registration of different models is guaranteed by tie points, while GCPs are used to constrain the whole block into a given reference system. The procedure, implemented in a software called TRIAMODEL, is executed in two stages: in the first all the approximations for transformation parameters and tie point coordinates are computed; in the second, a least squares adjustment of the independent 3D models is computed. Finally the estimated registration parameters can be used to transform each point cloud into the global reference system.

In the next section the strategy proposed will be explained in more detail, while in section 3 two experimental tests with either simulated and real terrestrial laser scanner blocks will be presented.

2. THE PROCEDURE FOR LASER SCANNER BLOCK TRIANGULATION

Given a set of n models acquired by a laser scanner, we want to compute a set of conformal transformations from their intrinsic reference systems to a common reference system: this can be either the reference system of one of the models, arbitrarily chosen, or a GCP-defined reference system.

Retro-reflective targets, easily identified in the point cloud by laser scanner software, are used to register each model to an adjacent scan or to the object system, if they were surveyed and therefore can be treated as GCPs (see Fig. 1).

Both types of points can be used, in full analogy with a photogrammetric block triangulation by independent models, within a global least squares adjustment which provides the solution of the 3D conformal transformations. Targets not surveyed will act as tie points while GCP, if available, will fix the object reference system and control block deformations. If no control points are available, the reference system of an arbitrary model will act as object reference system (i.e. its targets will be treated as GCP).

A minimum of three points is required to compute the registration between two adjacent scans or the orientation to the object system: therefore, if the laser survey has been executed carefully, we will always have enough tie or control points common to adjacent scans.

Approximate values for the transformation parameters are provided by an algorithm based on Hamilton Quaternions (Sansò, 1973) which need a set of at least 3 points common to both reference systems. An approach similar to that proposed in Scaioni & Forlani (2002) for the orientation of close-range photogrammetric blocks is used. If one or more models contain enough GCPs, they are oriented first; otherwise, one of the models is arbitrarily chosen and its reference system becomes the object system of the whole block. Now the coordinates of the tie points of all oriented models can be computed. Thanks to overlaps between scans, the same tie points can be found in adjacent models, providing the information to perform an approximate registration. If the targets (the tie points) are carefully placed, there will be always at least 3 tie points common to every pair of adjacent model and the procedure will run through all models smoothly. At the end, approximate values for orientation parameters and point coordinates in object system will be available for the final l.s. adjustment by independent models.

As far as the distribution of GCPs and tie points are concerned, different strategies are available for different cases:

1. a number of GCPs, included in one model only, just or more than enough to orient a first model and start the orientation procedure;

2. GCPs positioned rather apart from each other, enough to define only a global constraint (the object reference system and some control), but not to register directly any single block to start the procedure. In this case one model is selected to instantiate a temporary reference system: all the other models are registered to this. The reference model is that with the highest number of common points shared with other models. At the end of the procedure, all the models are then globally oriented by using the set of GCPs;

3. no GCPs are available; in this case the model providing the reference system is selected by the user or as in case 2; afterwards, the registration of all the models proceeds again as in case 2.

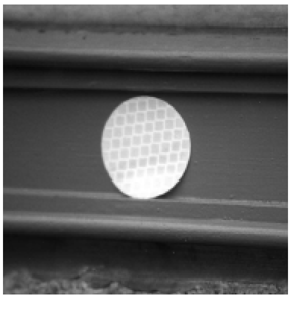

Figure 1 – A retro-reflective target (Riegl)

3.1 Computation of the Approximate Transformation Parameters

Approximate transformation parameters from the intrinsic reference system of each model to the global reference system are obtained in two stages: computation of initial values, which are then refined by a least squares solution.

The first stage is based on the approach proposed by Sansò, (1973). Given a set of n common points defined in both object and model reference systems, let $\mathbf{X}_i$ and $\mathbf{U}_i$, be the vectors containing the 3 coordinates of point P_i in both systems.

The 7 parameters trasformation relating the two systems is defined as follows:

$$\mathbf{X}_i = \mathbf{T} + \lambda\, \mathbf{R}\, \mathbf{U}_i \tag{1}$$

where **T** is the translation vector, λ the scale factor and **R** the rotation matrix.

Coordinates of all points P_i in both systems are first referred them to the respective gravity centers $\mathbf{X_g}$ and $\mathbf{U_g}$, obtaining the vectors $\mathbf{x_i} = \mathbf{X_i} - \mathbf{X_g}$ and $\mathbf{u_i} = \mathbf{U_i} - \mathbf{U_g}$.

The scale factor λ, in case of laser-scanner data registration could be omitted because different models should have the same scale. However, computing λ may help to check for outliers: for instance, a labelling error of two or more control points would result in a scale factor significantly different from unity. The scale factor can be computed by the formula:

$$\lambda = \sqrt{\frac{\sum_i |\mathbf{x_i}|^2}{\sum_i |\mathbf{u_i}|^2}} \tag{2}$$

In a second stage the rotation matrix **R** between **x** and **u** is computed through an algebraic representation of rotations based on *Hamilton Quaternions*. Given a 3D rotation, it can be always represented by the uni-modular quaternion $q = [\ q_0\ q_1\ q_2\ q_3\ ]^T$, which allows to derive the classical Rodriguez matrix **R**:

$$\mathbf{R} = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & -2q_0q_3 + 2q_2q_1 & 2q_0q_2 + 2q_3q_1 \\ 2q_0q_3 + 2q_2q_1 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & -2q_0q_1 + 2q_3q_2 \\ -2q_0q_2 + 2q_1q_3 & 2q_0q_1 + 2q_2q_3 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix} \tag{3}$$

Sansò (1973) demonstrated that the quaternion q can be derived from the solution of a homogeneous linear system of 4 equations. This system, written down in matrix form, results as:

$$\mathbf{A}\, q = \rho\, q \tag{4}$$

where q is the eigenvector corresponding to the eigenvalue ρ of the simmetric *design matrix* **A,** that can be constructed directly from **x** and **u**:

$$\mathbf{A} = \frac{1}{n}\begin{bmatrix} -\Sigma_i \mathbf{u_i}\cdot\mathbf{x_i} & -\Sigma_i(v_i z_i - w_i y_i) & -\Sigma_i(w_i x_i - u_i z_i) & -\Sigma_i(u_i y_i - v_i x_i) \\ & \Sigma_i \mathbf{u_i}\cdot\mathbf{x_i} - 2\Sigma_i(u_i x_i) & -\Sigma_i(v_i x_i + u_i y_i) & -\Sigma_i(w_i x_i - u_i z_i) \\ & & \Sigma_i \mathbf{u_i}\cdot\mathbf{x_i} - 2\Sigma_i(v_i y_i) & -\Sigma_i(w_i y_i - v_i z_i) \\ & & & \Sigma_i \mathbf{u_i}\cdot\mathbf{x_i} - 2\Sigma_i(w_i z_i) \end{bmatrix} \tag{5}$$

Which of the 4 solution of eq. (4) gives the correct quaternion is decided on the basis of the eigenvector of the matrix **A** corresponding to the smallest eigenvalue.

Once q has been computed, then matrix **R** can be written and, if required, the rotation angle explicitly derived.

Finally, the translation vector **T** can be derived by inverting eq. (1) and by considering the gravity centers positions $\mathbf{X_g}$ and $\mathbf{U_g}$:

$$\mathbf{T} = \mathbf{X_g} - \lambda\, \mathbf{R}\, \mathbf{U_g} \tag{6}$$

The important advantage of this method to compute the approximate solution is that it requires only the minimum number of points (3); furthermore, unlike iterative methods, no convergence problems arise. This allows to determine large rotations as easily as the small ones. This feature is very valuable when dealing with laser-scanner terrestrial data, because rotations between adjacent models may be very large (see the experimental test section).

In order to exploit the availability of redundant points, a least squares solution for the transformation parameters of each model is computed, based on the linearization of 3D conformal equation (1) using the computed approximate values. The l.s. solution also provides with a set of quality parameters for the unknowns, as well as sigma nought which measures the goodness of the fit.

Thanks to the knowledge of the conformal transformation, also model points which are not in the set of control points can be now transformed to the global reference system, becoming available for the registration of other models.

3.2 Least Squares Block Triangulation

The orientation of single models computed so far are merely based on control points linking the models themselves pairwise. In order to exploit the whole structure of ties within the block, a final adjustment of all the models is performed by l.s. This is expected to improve the accuracy of the solution, because all links between different models are used as well as points visible on more than two models.

But the importance of this final l.s. adjustment also stands on the strategy proposed in this paper for the laser block orientation. The approximate orientations are computed by starting from a core of GCPs, or from a model assumed as reference for the others. All other models are pairwise registered through different iterations to the already oriented models. By this approach, small orientation errors are propagated without any control, because new models which are oriented become reference for the following ones. In many cases (as it is reasonably expected after a correct block design), the geometry of the block (e.g. a block taken all around an object) or using many and well distributed GCPs, give rise to constraints which may be very effective in controlling deformations and in computing the orientation parameters.

Block triangulation is carried out by means of the block and network adjustment program CALGE (Forlani, 1986), developed in 1986 at the Dept. I.I.A. R. of the Politecnico of Milan and updated several times ever since. Block adjustment of laser-scanner models is not different from that of aerial blocks, when the independent model approach is used. The only difference is the need to provide approximation for all the orientation parameters and for the object coordinates of tie points. Indeed, unlike aerial photogrammetry where ω and ϕ angles are always very small, here rotations may be large in κ. Should to define a phisical position for the perspective center of the scanner becoming possible, this information could be included in the adjustment, reducing so that the number of control points to use. Careful planning of terrestrial laser-scanner surveys when putting in place ground and tie points will turn out in a stable block configuration, so that the use of perspective centers as further tie points is not required.

An example of the real advantage of using a block adjustment to define the orientation of each model will be shown in the next section, concerning experimental tests.

3. SOME EXPERIMENTAL TESTS

The procedure for laser blocks triangulation will be illustrated in this section, togheter with two groups of experimental tests, concerning either simulated and real data.

The first group refers to a simulated block, made up of 8 models acquired from different positions around a building. The main goal of this test has been to check the capability of the TRIAMODEL software to compute the orientation of a set of concatenated views, with control points shared by 2 or at most 3 models. In a block configuration such this, the advantage of using our method should be apparent. Different configurations for the block constraints have been compared. Furthermore, a comparison between a block approach with a global adjustment of all models (i.e. the approach of TRIAMODEL) and the standard registration based only on the pairwise registration of views has been performed.

The second group of tests has been carried out considering a real object, with the purpose of assessing how the software works in an operational context. The object acquired is a scale model of a preistorical *mammuth*, surveyed by laser scanner stations from all around. In this case different sets of control points have been tried, in order to investigate the minimal configuration which guarantees an accurate registration of the views.

4.1 Tests with simulated data

The test reproduces a common configuration in architectural surveys, i.e. a low raise building which was scanned from 8 positions all around it. The shape of the simulated building and the stations positions are shown in Figure 1. The geometric parameters of each scan are thought to be representative of today's laser-scanners, with a scanning range of ± 40° (80° total) in horizontal and vertical directions and a measurement accuracy of ± 1 cm. No assumptions about angular resolution and scanning time are needed for this test, because only the knowledge of ground and tie points is required. The accuracy of GPC coordinates has been assumed to be ± 5 mm, that of control points in laser-scanner models to be ± 10 mm.

The number of control points measured in each model is in the range 8÷13, as reported in Table 3 together with the orientation parameters.

Different configurations for the block constraint have been tried and results have been evaluated either by means of the theoretical accuracies of l.s. adjustment and by a test with a set of check points. Five different constraints have been used, while keeping the same set of tie points for all cases:

a. 5 GCPs only on a side of the building;

b. 5 GCPs on a side plus 3 more on the rest of the building;

c. 4 GCPs far apart, distributed on the whole block;

d. no GCPs, with a model selected as reference by the user.

Furthermore, with the configuration "d", a comparison between using or not the final block adjustment has been carried out.

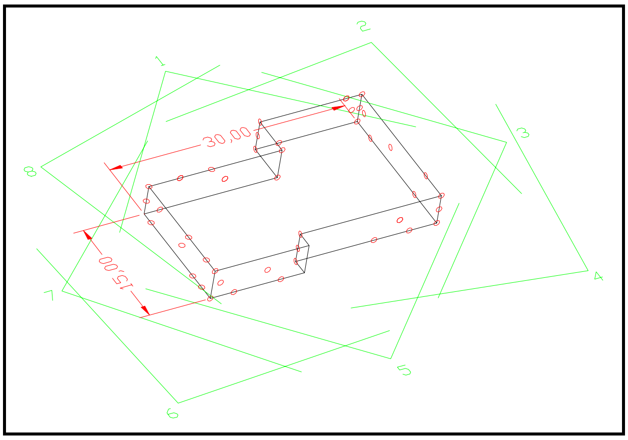

Figure 2 – Geometric scheme of the simulated block

n.	**# TPs**	**T$_x$ (m)**	**T$_y$ (m)**	**T$_z$ (m)**	**ω (gon)**	**ϕ (gon)**	**κ (gon)**
1	9	154.00	145.00	1.40	0.550	-0.500	198.000
2	8	178.00	141.00	1.60	-0.500	0.920	240.000
3	9	184.00	121.00	1.50	2.090	0.850	303.000
4	10	182.00	99.00	1.50	-2.500	3.150	348.000
5	11	154.00	94.00	1.70	-1.300	-1.300	398.000
6	8	128.00	96.00	1.50	1.900	-3.040	347.000
7	13	125.00	117.00	1.40	-1.020	4.000	299.000
8	13	133.00	136.00	1.80	-3.200	0.500	270.000

Table 3 – Simulated block: orientation parameters of each scan; the scale factor is intended as always unitary

4.1.1 Results of test "a"

Enough GCPs are available to start the computation of approximate orientation, because 4 can be seen on the model *1*. As a matter of fact, 3 full GCPs would be sufficient to compute the orientation of a single block, but TRIAMODEL is set up to work with a least number of 4 GCPs, in order to have a (minimum) control.

Once model *1* has been oriented, the object coordinates of other 4 points can be obtained; thanks to these points, all the other models of the block can be oriented.

Table 4 shows the results of the final l.s. block adjustment. Under "corrections to approximate coordinates of tie points" the mean values and the standard deviation of the differences between the object coordinates of tie points computed before and after the l.s. adjustment have been computed. The column concerning "RMS of st.dev of tie point coordinates" concerns the accuracies derived from the estimated covariance matrix. In the last column RMS of residuals on check points are presented. Because the block is simulated, the true coordinates of all tie points are known and then were used as check points.

4.1.2 Results of test "b"

The set of GCPs used for the test "b" is based on that of the previous test, integrated by further 3 points positioned on the opposite side of the building to that covered by model *1*. The total amount of GCPs adds up to 8.

The orientation procedure starts as in the test "a", with the model *1* oriented first and then all the other that are solved for their approximate values. As shown in Table 4, the corrections to the approximate values for the 3D coordinates of tie points feature smaller standard deviations, meaning that the knowledge of more GCPs is an advantage for the algorithm that computes approximations. Also values of RMS of theoretical st.dev. after l.s. adjustment of the whole block improves with respect to test "a", because of the better stability of the block. However, residuals on check points are about the same as those obtained using only 4 GCPs. In conclusion, if all models are tightly linked by a sufficient number of tie points, also a small set of GCPs located only on a part of the block are enough to constrain it.

4.1.3 Results of test "c"

Only 4 GCPs evenly distributed over the whole block have been considered. This is not enough to allow the computation of the approximate orientation parameters of any model, but only to give a global constraint to the block as a whole in the final adjustment. Therefore a model is chosen as reference and the others are registered to it. Which model is more suitable to this aim is done on the basis of its ability to orient other models.

For every model, the number of other models which sharing with it at least 4 tie points are counted; the one with the largest number of connections becomes the reference.

In this case, TRIABLOCK has chosen the model *3*, which allows to register directly on it models *2* and *4*. All the others are then oriented by using all new points with known object coordinates.

Thanks to the knowledge of 4 GCPs, it is now possible to compute the final l.s. adjustment by means of CALGE software. The approximations for parameters and control point coordinates have to be computed again, though, because they describe the transformation from model to *provisional* reference system. A 3D conformal transformation between the *provisional* reference system and the reference system defined by GCPs is computed on the basis of the 4 double points. Let $\mathbf{T}_\mathbf{u}$, $\mathbf{R}_\mathbf{u}$ and Λ_u be the computed parameters. All points can be then transformed into the object system by applying these parameters through eq. (1). We need to find the sets of parameters transforming points defined in the original reference system of each model to the object system. They can obviously computed as:

$$\mathbf{T}_\mathbf{fi} = \mathbf{T}_\mathbf{u} + \Lambda_u \mathbf{R}_\mathbf{u}\mathbf{T}_\mathbf{i} \tag{7}$$

$$\mathbf{R}_\mathbf{fi} = \mathbf{R}_\mathbf{u}\,\mathbf{R}_\mathbf{i} \tag{8}$$

$$\Lambda_{fi} = \lambda_i\,\Lambda_u \tag{9}$$

In this way all the approximation required by CALGE to compute the l.s. adjustment of the block are known.

Also in this case the results on check points are about in the same order of accuracy of those obtained in the previous tests.

4.1.4 Results of test “d”

Test “d” is really equivalent to the first stage of test “c”, with the only difference that the model to be assumed as reference is selected by the user and not by the software itself. This options is interesting when no GCPs are available, but out of the models of the block there is one which could be preferably fixed with respect to the other. For instance, the model *1* could be thought as placed in front of the main side of the building, so that it has been selected as reference.

After the l.s. adjustment, the computed object coordinates of tie points cannot be directly compared to those of check points, being different their reference systems. Therefore, a 3D conformal transformation is computed, and residuals considered to evaluate RMS on check points. Results obtained (as shown in Table 4) are similar to that of test “a”, because also in that case the model *1* has been oriented first and the other models have been registered to it.

4.1.5 Advantage of l.s. block adjustment *vs* pairwise model registration

The procedure proposed in this paper differs from all the strategies which are currently used in commercial softwares for laser-scanner data processing because it is based on the computation of a final l.s. adjustment of the block. Which are the advantages of using this approach?

The most commonly used strategy for computing the orientation of each model is based on a pairwise concatenation, without any final re-computation of the orientation by considering the block as a whole. This approach is in fact that used in the first stage by TRIAMODEL to compute initial approximations.

In order to evaluate the improvement in terms of tie point accuracy introduced by the l.s. adjustment, we have considered the same configuration for the block as in test “d”. Then we have performed a test on check points also at the end of the first stage, i.e. after the computation of approximations. RMS on check points have resulted as 28 mm in X direction, 26 mm in Y and 31 mm in Z. Comparing these results to those obtained in the test “d”, where the final l.s. adjustment has been computed, results are clearly worse, meaning that the proposed procedure works very well. From the analysis of other tests carried out on the same block by reducing the number of tie points, we also observed that advantages of l.s. adjustment can be exploited only if models are linked by a sufficient number of tie points (at least 4-5 points between adjacent models and possibly some points visible on three or more models). In case few tie points have been measured on each model, using or not a final l.s. adjustment is equivalent.

4.2 Tests with real data

Another test has concerned the orientation of a block coming from a real laser-scanning survey, having as object a reproduction of a “Mammuth” conserved in a museum of natural history. The aim of this test has been to assess the effectiveness of the TRIAMODEL procedure to deal in an operational context.

test	# eq.	# constr.	# check pt.s	σ_0 (mm)		Corrections to approx. coord.s of tie pt.s (mm)		RMS of theoretical st.dev of tie points (mm)	Residuals on check points (mm)
						mean	st.dev		
a	243	15	28	8.8	X	9	18	16	14
					Y	1	15	16	8
					Z	7	20	32	7
b	243	24	25	8.4	X	4	10	8	13
					Y	4	7	8	8
					Z	6	10	8	8
c	243	15	28	8.9	X	5	17	13	11
					Y	3	16	13	12
					Z	9	25	18	6
d	243	15	32	8.2	X	-20	29	14	16
					Y	8	29	14	10
					Z	-14	26	24	13
Mammuth	167	18	-	7.5	X	2	3	6	-
					Y	2	4	6	-
					Z	2	3	7	-

Table 4 – Results of test carried out on the simulated block with different constrain configurations

Scans have been taken by a laser scanner LMS-Z210 manufactured by RIEGL-Laser Measurement Systems (Horn, Austria); more information about this instruments can be found in Boccardo & Comoglio (2000) as well as at URL `www.riegl.com`. This scanner operates with a scan angle of 300°, with an angular resolution of 0.24°, corresponding to a linear step of about 1 mm at a distance of 10 m.

8 scans have been acquired from around the "Mammuth" (see Figure 5); 20 reflective target (see Figure 1) have been placed as control points in the room where the object is located, either on its basement and on the background. No topographic measurements have been carried out, but one model has been selected as reference. The displacement of targets follows another criterium with respect to that adopted for tests with simulated data, because there is a core of 5-6 control points that are visible in all scans. The measurement of control point coordinate in each model reference system has been done by software 3D-RiSCAN by Riegl, which is equipped by a tools able to locate and to measure all the reflective targets into a scan, thanks to their contrast on the background in the *intensity* image; one out of the intensity image of the block is reported in Figure 6. All measured points have been labeled and their coordinates exported into TRIABLOCK.

The model *4*, made up of 6 control points, has been selected as reference; all the others models have been directly registered on it. The l.s. adjustment has been computed by using all 6 points of model *4* as constraints; results have been reported in Table 4. The small entities of corrections to approximate values means that the large abundance of control points in every model allows an accurate computation of the approximate parameters, which are only slightly modified during the l.s. adjustment.

We would like to point out also the different operating approach of TRIAMODEL with respect to 3D-RiSCAN. In TRIAMODEL all ground and point coordinates in every model are needed, so that an operator may measure them by considering only one model at time. Then the orientation process is carried out in autonomous way by the software. In 3D-RiSCAN the method of pairwise registration is used, so that the operator must select manually the pair of scans to process.

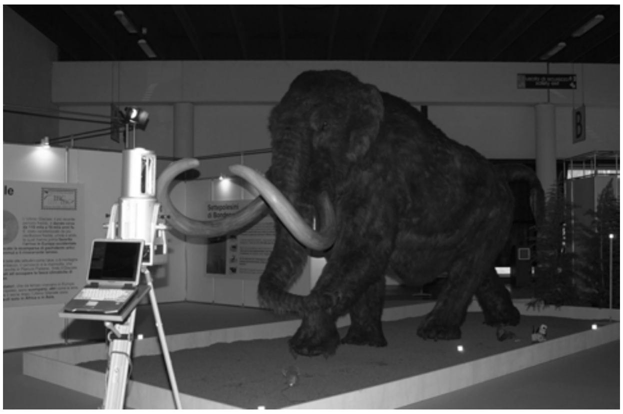

Figure 5 – Image of a stage of the "Mammuth" survey by a laser-scanner LMS-Z210 by Riegl; some reflective target appear on the background

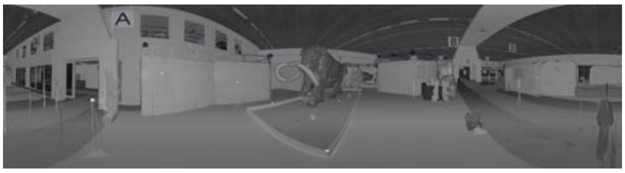

Figure 6 – An intensity image of the block "Mammuth"

5. CONCLUSIONS AND FURTHER DEVELOPMENTS

A procedure for the automatic registration of laser scans into a given reference system has been presented, which exploit the independent model method of photogrammetry. Its main feature is the capability to provide initial approximations for the orientation parameters even with large rotations between actual and object reference system and its ability to handle different operating scenarios (with or without GCP, with different GCP configuration, etc.). Tests on simulated and real data demonstrated the flexibility of the program and its advantages over pairwise orientation of the models. A more extensive series of tests if foreseen to deepen the understanding of the error propagation depending on the number and location of the targets in the block. Besides, since the procedure now requires the targets to be already labeled in each model, methods for their automatic numbering will be investigated.

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