Experimentations and integrated applications Laser Scanner/GPS for automated surveys

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Abstract: - This contribution is based on studies aimed to a "quick" resolution of an integrated problem about self-localizing and perimetering through mobile devices. We applied the adopted methodology, derived from research and applications, on a real case study (outdoors) by using the following surveying tools: a kinematic Global Positioning System (GPS) and a Laser Scanner supporting a "mobile platform" (deployed on a mobile platform). A "GS14" GPS receiver provided by Leica Geosystem and a two-dimensional Laser Scanner provided by the Automation and Control Laboratory of the University "Mediteranea" of Reggio Calabria were positioned on an experimental mobile system specifically designed to simulate the behaviour of a future fully automated platform. This study focuses on the experimental development of a "quick" methodology for the traditional land surveying through a Laser Scanner alongside with GPS receivers in a three dimensional centimetric resolution within a single system of reference made up of individual scans operated by a "Stop-and-Go" device.

Key-Words: - GPS – Laser scanner 3D – Self-localization – Survey

1 Introduction

This experiment was part of a collaboration between the Geomatics Lab and the Automation and Controls Laboratory of the Mediterranean University of Reggio Calabria, aimed to the possible development and implementation of an algorithm based on the use of a laser-scanner sensor for applications mobile robotics, we carried out a first experiment in the yard behind the university (Fig.1).

Fig.1: Survey area behind the university building.

Our experiment was aimed to an automated kinematic perimetering of the area under investigation with simultaneous auto-location detection sensor through the integration of laser scanner and GPS measurements.

In particular we used a rudimentary "moving platform" (trolley mobile), equipped with a laser-scanner (which currently allows to perform scans only within the planimetric) mounted on a trolley with wheels (Fig.2); on the same carriage, above the laser sensor, was placed the GPS receiver (Fig.3).

Fig.2: Mobile platform.

Fig.3: Survey operations.

The sensor is connected to the USB port of a laptop that sends to the LRF instructions to be executed through the use of the programming language Matlab (programming language used for all the algorithms implemented for the management and implementation of the system).

It should be noted preliminarily that the automation of the procedure is not yet currently available and that today the operations are carried out manually.

In particular there has been a 360 ° rotation of the basket by making the acquisitions at regular intervals of time trying to ensure the continuity of motion, simulating a behavior as much as possible regular.

Prior to the integration operations between the different survey methods, was independently carried out a perimeter of the study area through GPS survey in classic mode rtk; processing of the acquired data performed with the commercial program of the Leica LGO allowed to obtain the coordinates of the points shown in the diagram of Figure 4 representing the perimeter of the study area.

robot.txt

1011	558340.830	4219463.856	71.060
1010	558351.745	4219464.071	70.979
1009	558353.802	4219462.929	71.011
1008	558353.486	4219460.726	71.041
1007	558348.486	4219448.349	71.161
1006	558357.896	4219447.128	71.199
1005	558362.532	4219455.262	71.131
1004	558364.995	4219463.866	71.055
1003	558360.563	4219463.981	71.065
1002	558362.141	4219464.797	71.061
1001	558361.499	4219467.919	71.014

Fig.4: GPS data.

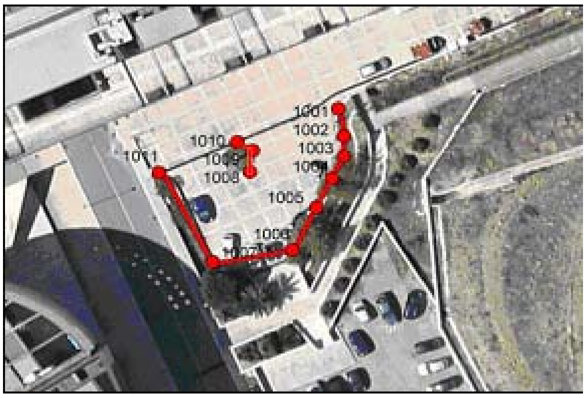

Fig.5: GPS data in map.

The same data were subsequently reported on georeferenced map; these data, connected each other, allowed therefore to delimit the perimeter of interest (Figure 5). These data are considered as data "reliable" to be used for comparison with the survey methods later proposed. In particular, it has been positioned in this regard (integrated laser scanner - GPS - mobile cart) on the platform above the laser scanner sensor, a GPS antenna in such a way to obtain simultaneous measurements.

2 Measurement by Laser Scanner

Were made seven scans with the “equipped mobile trolley” doing as said, manually moving it (360°), with a view to its future and complete automation.

For each scan was carried out at the same position detected by GPS measurements useful for linking the different scans through the measurement of external targets.

Scans are shown above (Fig.6).

Single scans were processed and linked together by means of an algorithm implemented in Matlab (lab AeC), in the testing phase.

3 The Algorithm

The algorithm implemented in Matlab and used in this experiment does not use the common return target detected externally but makes a connection of several scans through statistical autocorrelation methods by using the distinctive features that the robot (mobile equipped trolley) is able to perceive the environment through the use of the laser scanner sensor. These characteristics may be the geometric shapes, such as edges, circles or rectangles, or additional data such as barcodes. The features must have a precise and fixed position within the environment and should be easily detectable by the sensor.

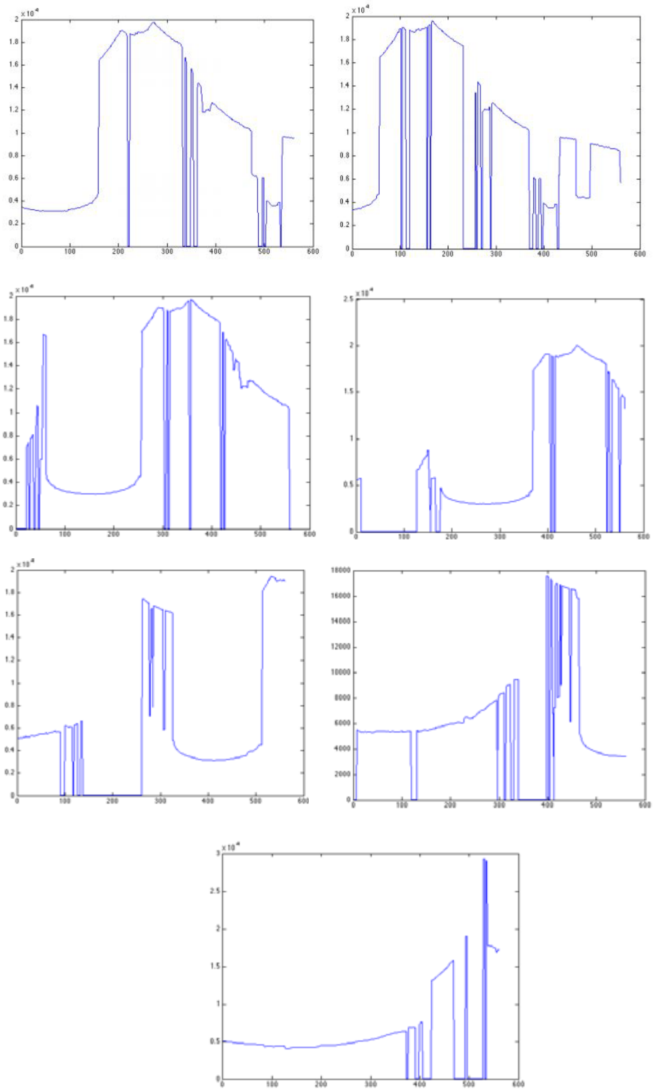

Fig.6: Laser Scanner scans.

The methodology we used can be divided into two phases:

- extraction of features from the measurements made by the sensors;

- coupling between features belonging to different measures so as to determine the deviation between the two measures in terms of a shift (Dx, Dy) and a rotation Dα. We thus introduced an algorithm of "SLAM" based exclusively on information from a laser scanner. This algorithm introduces a new model for the prediction of the future state (described in Fig.7).

The methods of location-based laser odometry differs depending on what data are used to search the correspondence between scans.

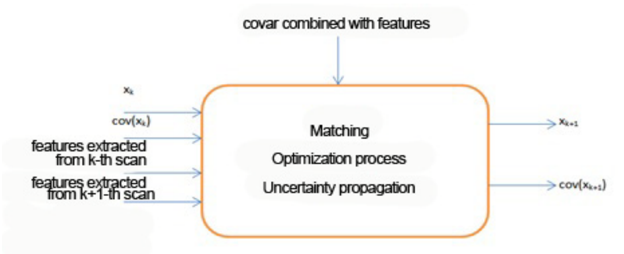

Fig.7: Prediction model of future state.

The algorithm that will be described below is based on matching through the use of features and is shown schematically in Fig.8:

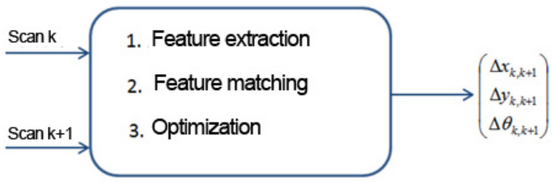

Fig.8: Diagram of localization algorithm based on use of features.

From the knowledge of the current pose of the robot, x_k, its covariance, $cov(x_k)$, the extracted features to scan the k-th and k+1-th scan and the covariance associated with the features you want to calculate the pose of the robot to the next step, x_{k+1}, and its covariance, $cov(x_{k+1})$. To do this you must perform three steps:

- Extraction of set of features F_1 belonging to scan S_1 and of set of features F_2 belonging to the scan S_2 subsequent respect to S_1;
- Matching between features of the two scans that will be a subset of those extracted, F_1 and F_2;

$$\tilde{F}_1 \subseteq F_1 \,, \tilde{F}_2 \subseteq F_2$$

- Optimization process: calculation of the deviation between the two scans through the calculation of the transformation excellent in terms of rotational translation that allows to map $\tilde{F}_2$ in $\tilde{F}_1$.

3.1 Features extraction

The matching techniques through the use of features presuppose a preliminary phase concerning the extraction of features from the scan. The features are divided into two types: "jump-edges" and "corners".

To detect the features jump-edges, a scan is divided into groups (called "clusters") of consecutive scan points. In this way, each cluster consists of a starting point, p_i, and an end point, p_j, and the k-th cluster is defined in the following way:

$$c_k = \{p_m \mid p_m \in S, i \le m \le j\} \qquad (1)$$

The start and end points of each cluster are candidates to become features jump-edges as long as these points are invariant with respect to the movement of the robot.

To extract the features "corners" within a scan is instead necessary to extract lines from each cluster using an algorithm such as "split-and-merge". Each line extracted is characterized by the following parameters: $l_q=[\alpha_q,n_q,len_q]$, where α_q is the angle between the line and the x-axis; n_q is the number of points that constitute the line and len_q is the length of l_q.

If the intersection of two successive lines is such that $|\alpha_{q+1}- \alpha_q|>\Delta\alpha_{th}$ and that, for both for l_q that l_{q+1}, or len > len_{th} or $n_q > n_{th}$ (where len_{th} is the minimum length and n_{th} is the minimum number of points of the lines that make up the corner) then p_{cc}, which is the end point of l_q, is a candidate to become a feature corner.

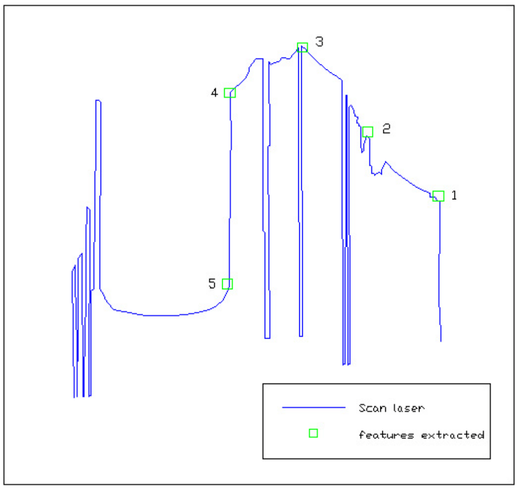

Fig.9: Features extraction from a laser scan.

3.2 Matching between features

Once extracted, by two successive scans, the features that represent the same physical point of the environment, is necessary to couple. To do so we use a matching algorithm which is based on a function of dissimilarity, *d*.

We define this function for two points p_i and p_j, belonging to two successive scans:

$$d(p_i, p'_j) = \|p_i - p'_j\|_2 + B \qquad (2)$$

If $|\alpha_{next} – \alpha'_{next\ j}|$ o $|\alpha_{pre,i}–\alpha'_{pre,j}|$ exceeds a certain threshold, p_i and p_j are not coupled and B becomes equal to infinity, otherwise B is equal to zero. Once constructed the matrix containing all the functions of dissimilarity (called dissimilarity matrix), the smallest value of this matrix is eliminated and the corresponding features are coupled. This is done at each step, until all the elements of the matrix are eliminated or until the remaining elements have a value above a certain threshold.

Fig.10 and Fig.11 show the matching phase between the features extracted by two laser scans. The red and blue curves in Fig.10 represent, respectively, the first scan and the second scan. The numbered green squares represent the features extracted from each scan. The features with the same number are coupled.

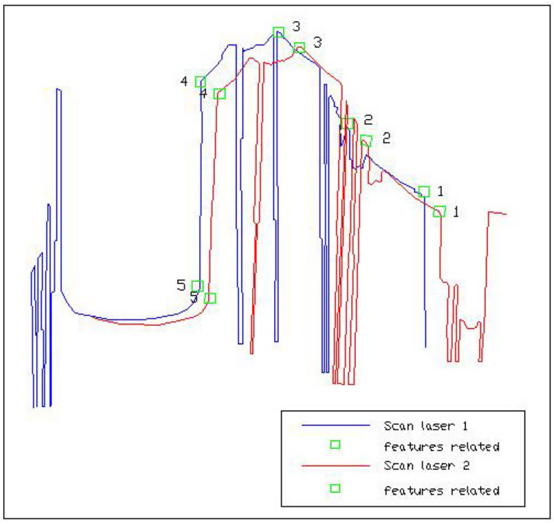

Fig.10: Matching between two laser scan.

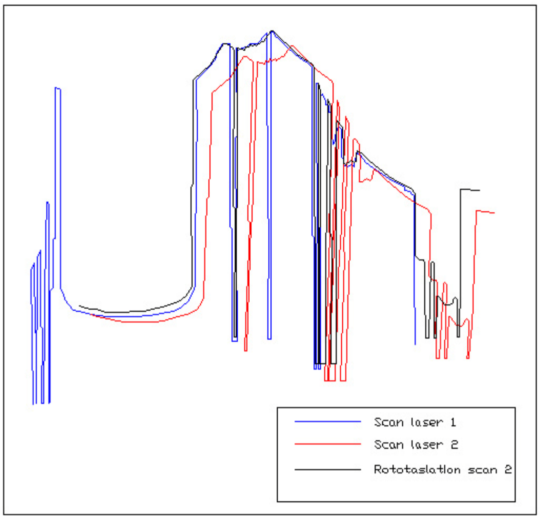

Fig.11: Result of the optimization algorithm for calculating deviations between the two scans.

In Fig.11 is shown the result of the optimization algorithm. In particular, the curves of blue, red and black respectively represent the first scan, the second scan and the result of the roto-translation of the second scan using the parameters of translation and rotation obtained by the minimization process.

3.3 Optimization process

Following the construction of the two vectors F_1^{match} and F_2^{match} containing the features related to the same position, it is necessary to perform an optimization process in order to obtain the deviations in terms of position and orientation between the two successive scans.

To get these parameters is necessary to derive the optimal transformation able to map F_2^{match} on F_1^{match}.

Intuitively, this means that we need to find a rotation component $R_{\Delta\theta}$ of an angle $\Delta\theta$ and a translational component $\Delta t = (\Delta x, \Delta y)^T$ such that the differences between the features of the previous scan F_1^{match} and the corresponding features of the next scan F_2^{match} roto-shifted by an amount equal to $\Delta p = (\Delta x \ \Delta y \ \Delta\theta)$, are minimized.

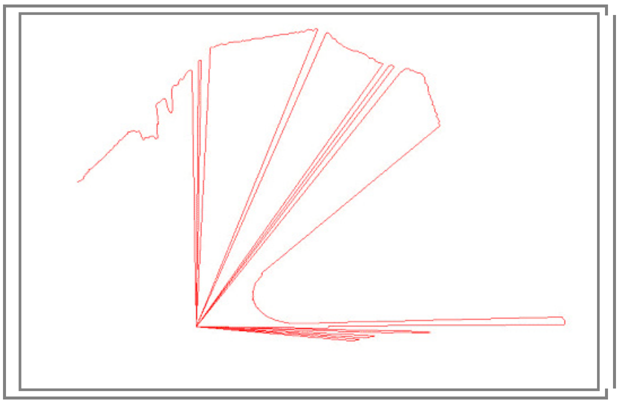

Fig.12: Result of the localization algorithm.

3.4 Extracting occupancy grid from the map

As known, the drift phenomenon that affects the localization consists in the fact that the errors made in the estimation of the robot pose tend to be additive in time. This means that, if the segment of the route taken by the robot between successive updates of the pose is sufficiently large, even after a short period of time after the start, the error of the pose estimation is high compared to its real location.

This phenomenon can be found primarily in cases in which a localization is performed based only on odometric sensors and is due to systematic errors, such as the presence of wheels with different diameters or the misalignment between the wheels, and non-systematic errors such as slippage of the wheels or the presence of irregular contact surfaces.

We could then face the drift problem by comparing a highest possible number of laser scans. There are various solutions to the drift problem, most of which are based on the “sensor fusion”, doing measurements by multiple sensors that interact in order to obtain an estimate of the pose that is as close as possible to the real one.

There are several methods to achieve this goal, among which the most popular are the so-called “Bayesian filters” that estimate a state x from noisy sensory measurements. This category includes the “Kalman Filter” (with its extensions) and “particle filters”. Looking at the problem from a probabilistic point of view, the robot does not have, instant by instant, the certainty of where he is, but can believe (“belief”) to be in a certain position with a certain uncertainty. On the basis of this statement, the localization problem consists in the estimation of the probability density related to all possible positions, with the aim of obtaining as much knowledge as possible accurate position. Ideally, this occurs when the “belief” has a single peak at the position of the robot and is zero elsewhere.

Returning to the “Kalman Filter”, recursive algorithm that estimates the state of a linear dynamic system affected by noise, this has access to the measurements of sensors which have a linear dependence with the state of the system. It is shown that the Kalman filter converges to the optimal estimation, the one that minimizes the variance of the error of the estimate, assuming the linearity of the system model and measurement, and the corresponding noise is Gaussian with zero mean. Therefore we can say that the Kalman filter calculates the so-called “belief” (which is supposed to have a gaussian) of the state through two phases: the prediction, which calculates the “a priori belief”, i.e. the conditional probability of being in state x_k known the measures until the time k-1, while in the correction phase calculates the “belief a posteriori”, i.e. the conditional probability of being in state x_k known measures up to the instant k.

We are currently working on “particle filters” that allow to derive the estimate of the state (typically a function of the probability density not Gaussian and multimodal) in a system characterized by a nonlinear model.

The algorithm of the particle filter is recursive and consists of two phases: the prediction and updating. Following each action performed by the robot starts the prediction phase in which each particle is modified according to the existing model with the addition of noise to the variable of interest.

During the upgrade, any weight of each particle is evaluated according to the new measurements from the sensors. The goal yet to be achieved is to get to the implementation of occupancy grid, which involves the construction, starting from the knowledge of the pose of all scans referred to the reference scan, an occupancy grid map.

The last step involves the construction of an occupancy grid of the map, starting from the knowledge of the laying of all scans related to reference scanning.

As known, the “Occupancy Grid Mapping” is a method that addresses the problem of generation of a map of the environment from noisy measurements by the sensors and the knowledge of the robot pose for each instant of time The Occupancy Grid consists of an array of cells all of equal size each of which corresponds to a portion of the environment detected and is characterized by a value of occupancy which corresponds to the probability that the cell to which it refers is busy.

The map can be realized in both 2D and 3D. In the case in which the robot moves on a flat surface is sufficient the 2D map. The main advantages of this type of map are the possibility to convey data from multiple sensors in a simple way and the possibility to model without ambiguity the obstacles present in the environment as well as the blanks.

The negative aspects related to this methodology are related to the granularity, the scalability and extensibility of the map which are mainly due to the fact that the grid that constitutes the map has a fixed size that defines the limit of precision in the localization.

The result of this operation is the partition of the map in a grid in which each element of the grid is associated with a probabilistic value of occupancy.

Using the occupancy grid can be integrated in the same representation of the environment more information from different sensors even if they use different methods of data acquisition.

We used a greyscale reference to the values of occupancy in each cell. In this way, a clearer cell is associated with a higher probability that the cell itself is occupied compared to a darker cell.

3.5 Checks and comparison

The algorithm has allowed us to analyze the first four scans, while the last three we had difficulties due to external phenomena of noise that prevented proper data collection.

In any case, after a “cleaning” of the data from any nuisance parameters (GPS and laser scanner), overlaying the drawing of the survey to cartography is obtained as shown in Fig.14.

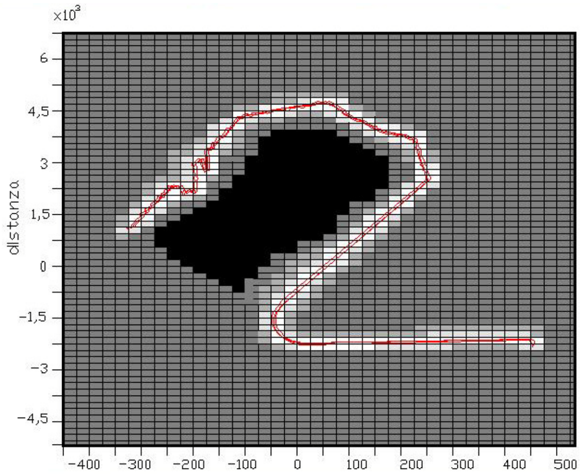

Fig.13: Occupancy grid.

Fig.14: Overlaying result of algorithm on mapping.

Fig.15: Comparison between the two methods.

To check the validity of these results, we do a comparison between the results Laser Scanner and those GPS (red line on maps considered as “certain”), preferring the graphic display able to better show the differences between the two methods (Fig.15) rather than the creation of complex tables and graphs summarizing and/or various statistical parameters on the accuracy of the processing, because the aim of "expeditious" of this proposal.

Although there is the same precision of the GPS data in terms of return, however, is highlighted as the algorithm proposed for the processing of the given laser scanner is able to provide by itself discrete results, as evidenced by the partial planimetric correspondence of the two tracks GPS and Laser Scanner shown in Fig.15.

This is a good omen for the continuation of the trial.

4 Integration of GPS and Laser Scanner for connecting subsequent scans

As known, the main problem for laser scanner data is the assembly of the scans in order to determine a unique reference system in which "immerse" the obtained model. The acquisition of the scans results in an immediate point cloud ordered in the plane, whose coordinates are known with respect to the center of "taking".

The scan is then locally oriented with respect to a reference system that derives from the arbitrary choice of the pickup point, which will be taken as the origin of the reference system of the scan. The assembly of multiple scans thus requires the knowledge of the parameters of rototranslation: these parameters can be calculated if the position of the origin of the reference system of each scan with respect to a single system is known through the measurement of the external "target". Such a problem for geo - topographic applications is solved by having remarkable points (targets), of which the coordinates are known, in all the scans: in this way each scan can be oriented independently of the other. Their georeferencing can be done by using the techniques of GPS tracking.

From the above considerations, the idea of experimenting with a rudimentary expeditious survey able to repeat what has already been experienced with the vehicle fully equipped (equipment includes two GPS, a laser scanner and a target all mounted on a vehicle in motion) that, by combining the two receivers GPS with the sensor laser scanner and a target audience, can overcome the issues raised; the whole mounted on a moving body that allows easy movement between the measurement sessions.

By performing measurements laser scanner and GPS simultaneously with stationary body is thus ensured a high quality of fit and positioning into a single reference system.

The system is to mount on movable equipped trolley (rigidly and coaxially) the laser scanner surmounted by a GPS and connect the trolley through a rigid arm (adjustable in length) to a "target" coaxially surmounted by other GPS reference (which will serve as the orientation of the scan), left free to rotate anyway so as to guide the laser target to the sensor. In this way, the problem of defining the coordinates of the acquisition point (Laser Scanner) and target orientation is overcome by fitting precisely coaxially two GPS receivers, respectively, the Laser Scanner and the target .

The receivers, while the laser sensor scans, acquire measurements from GNSS satellite constellations providing coordinates, both geographic both local coordinates of the laser sensor and the target orientation into a single reference system.

Once we have defined the ideal location for the first scan, we must place and stop the mobile equipped trolley at the point defined by performing both those measures GPS and Laser Scanner with the characteristics of density required by the survey. After a few minutes we must close the measures and shall move the trolley equipped cabinet in the next position chosen for the second major station, operating as before and repeating the process until completion of the survey. The processing of GPS data will allow to obtain homogeneous coordinates for all points of outlet (station laser scanner) and for all orientation target with sub-centimeter accuracy. These coordinates are assigned to stations and targets thereby allowing the software used for the management of the scans to unite and georeference all the scans made even in the absence of homologous points or targets positioned on the ground.

In this way, in addition to speed up and facilitate the steps of the survey in the field by eliminating the need of affixed targets and the necessity of their internal visibility between a measurement session and the other, will be easier georeferencing also individual scans with no points in common, decreasing processing time of "point clouds" resulting from the scans.

Taking into account what was said above, namely we have tried to make an initial experimentation in order to achieve "coarse" and "expeditious" what has already been experimented on equipped machine (cf. Leica experiment reported in bibliography).

Specifically, it was built by placing a measuring system on the mobile trolley equipped (rigidly and coaxially) the laser scanner superimposed by a GPS and connecting the trolley through a rigid arm (simulating the modulation length through the ability to extend and contract) to a “target” coaxially superimposed by other GPS reference.

In particular, measures have been simulated with arms of 3 meters, 2 meters, 1.50 meters, 1 meter, 0.5 meters (Fig. 16)

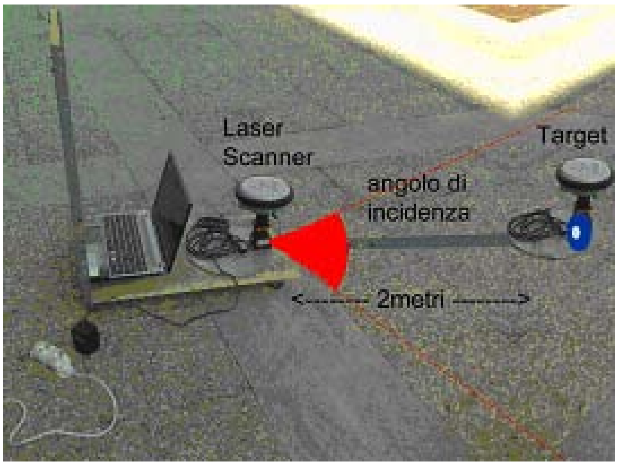

Fig.16: System with target and dual GPS.

The overall reconstruction of the data, although simulated, is very interesting in particular for the test carried out with the arms of 3 meters and 2 meters (note in this regard the result of the perimeter displayed in color and overlaid on the map as reported in Fig. 18). Instead, less accurate appear the results obtained with simulated arm of 1.5 meters, while it was not possible to make reliable reconstructions with simulated arm of 1 meter or less. (Fig. 17).

Arm (distance between the coaxial position of the laser scanner and that of the target) of:	Deviations "average" positioning expressed in percentage
3 meters	11%
2 meters	19%
1.5 meters	37%
1 meters	Determinabile only occasionally with higher % than 65%
0.5 meters	Location not determined

Fig.17: Variation of the percent error compared to GPS method (in test simulated) by varying the arm.

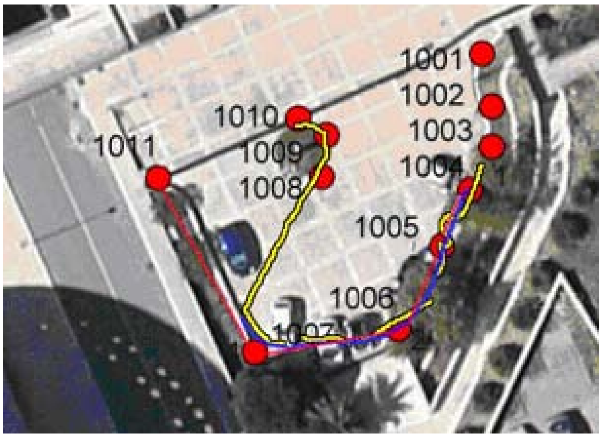

Fig.18: Integrating the two different methodological approaches.

With this method it is possible to combine and georeference all the scans carried out even in the absence of homologous points or targets positioned on the ground. This will speed up and facilitate the steps of importance in the field by eliminating the need for affixing targets and the internal visibility of the same between a measurement session and the other; allow georeferencing easily (with the immediate integrability into a GIS) and with great accuracy even individual scans that have not between their points in common dramatically decreasing the processing time of the "point clouds" resulting from the scans.

The choice of interesting details in the construction of the mathematical model of the survey is shifted to the management of point clouds in post processing and no longer delegated to the surveyor in the field, allowing :

- Survey non-invasive (there is no need to physically reach the objects to be measured);
- Completeness of absolute information (instrumentation detects everything is visible);
- Three-dimensional modeling of reality (if possible);
- Absolute freedom of choice of interesting points during the graphic rendering of the survey;
- Fast survey extremely reduced and executed by one person;
- Time to return extremely low thanks to the automatic georeferencing point clouds through integration with GNSS sensors;
- Mobility fast and easy because the system is mounted on a trolley.

5 Conclusions

The future application will allow a Three-dimensional modeling of the reality when hopefully we will use a 3d laser scanner for rendering. Now it worked planimetrically, only in 2D because the laser scanner used had those features, while the future application will concern 3D.

Of course, although we must emphasize that the results obtained from the integration are to now only been achieved in a “simulated” way and the automation of the procedure is still under study and implementation (having now moved to the cart only by hand), yet the results seem encouraging in view of the realization of a “expeditious” process for the auto positioning and perimetering by using mobile and automated tools. The results certainly push to further study both in terms of actual full realization of the experiment, both in terms of optimization of the algorithms used for the compensation of the integrated data.

References:

[1] G. Weiß, C. Wetzler, E. von Puttkamer, Keeping track of position and orientation of moving indoor systems by correlation of range-finder scans, *Proceedings of the International Conference on Intelligent Robots and Systems*, 1994, pp. 595–601.

[2] F. Lu, E. Milios, Robot Pose Estimation in Unknown Environments by Matching 2D Range Scans, *Journal of Intelligent and Robotic Systems*, Vol. 18, No. 3, 1997, pp. 249-275.

[3] S. Thrun, Robotic Mapping: A Survey, *Exploring artificial intelligence in the new millennium*. Pittsburgh: Morgan Kaufmann, 2002.

[4] J. S. Liu, R. Chen, T. Logvinenko, A theoretical framework for sequential importance sampling and resampling, *Sequential Monte Carlo in Practice*. New York: Springer-Verlag, January 2001.

[5] P. Pirjanian, N. Karlsson, L. Goncalves, E. Di Bernardo, Low-cost visual localization and mapping for consumer robotics, *Industrial Robot*: *An International Journal*, Vol. 30, No. 2, 2003, pp. 139 – 144.

[6] I. M. Rekleitis, A particle filter tutorial for mobile robot localization, *Technical Report TR-CIM-04-02*, February 2004.

[7] G. Bekey, *Autonomous Robots*: *From Biological Inspiration to Implementation and Control*. The MIT Press, Cambridge, MA, 2005.

[8] K. Lingemann, A. Nüchter, J. Hertzberg and H. Surmann, High-Speed Laser Localization for Mobile Robots, *Journal Robotics and Autonomous Systems (JRAS)*, Elsevier Science, Vol. 51, No. 4, 2005, pp. 275-296.

[9] A. Garulli, A. Giannitrapani, A. Rossi, A. Vicino, Simultaneous localization and map building using linear features, *Proceedings of the 2nd European Conference on Mobile Robots*, Ancona (Italy), September 7-10, 2005.

[10] A. Garulli, A. Giannitrapani, A. Rossi, A. Vicino, Mobile robot SLAM for line-based environment representation, Decision and Control, 2005 and 2005 European Control Conference. CDC-ECC '05. *44th IEEE Conference on, 2005*, pp. 2041 – 2046.

[11] A. A. Aghamohammadi, H. D. Taghirad, A. H. Tamjidi, E. Mihankhah, Feature-Based Laser Scan Matching For Accurate and High Speed Mobile Robot Localization, *European Conference on Mobile Robots* (ECMR 2007).

[12] A. A. Aghamohammadi, A. H. Tamjidi, H. D. Taghirad, SLAM Using Single Laser Range Finder, *Proceedings of the 17th World Congress, The International Federation of Automatic Control*, Seoul, Korea, 2008.

[13] M. Secchia, F. Uccelli, *Laser Scanner e GPS - Stop&Go* FIG Working Week, *Knowing to manage the territory, protect the environment, evaluate the cultural heritage,* Rome, 2012.

[14] M. Wahde, *Introduction to autonomous robots*. Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden 2012.

[15] V. Barrile, G. M. Meduri, G. Bilotta, Laser scanner surveying techniques aiming to the study and the spreading of recent architectural structures, in *Recent advances in signals and systems, Proceedings of the 9th WSEAS International Conference on Signal, speech and image processing* 2009, pp. 92-95.

[16] V. Barrile, G. M. Meduri, G. Bilotta, Laser scanner technology for complex surveying structures, *WSEAS transactions on signal processing*, Vol. 7, No. 3, July 2011, pp. 65-74.

[17] V. Barrile, G. Bilotta, G. M. Meduri, Least Squares 3D Algorithm for the Study of Deformations with Terrestrial Laser Scanner, in *Recent Advances in Electronics, Signal Processing and Communication Systems, Proceedings EUROPMENT 2013 International Conference on Electronics, Signal Processing and Communication Systems*, ESPCO 2013, Venice, Italy, Sept. 28-30, 2013, pp. 162-165.

[18] T. Bailey, E. Nebot, Localisation in large-scale environments, *Robotics and Autonomous Systems*, Vol 37, No. 4, December 2001, pp,

261–281.
[19] R. Siegwart, I. R. Nourbakhsh. *Introduction to Autonomous Mobile Robots.* A Bradford Book, The MIT Press, Cambridge, MA, London, England, 2004.
[20] J. Borenstein, H.R. Everett, L. Feng, D. Wehe, Mobile Robot Positioning - Sensors and Techniques, *Journal of Robotic Systems*, Mobile Robots. Vol. 14, No. 4, 1997, pp. 231-249.
[21] V. Barrile, M. Cacciola, F. Cotroneo, F. C. Morabito, M. Versaci, TEC Measurements through GPS and Artificial Intelligence, *Journal of electromagnetic waves and applications*, No. 20, 2006, pp. 1211-1220.
[22] M. N. Postorino, V. Barrile, An integrated GPS-GIS surface movement ground control system, *Management of Information Systems*, WIT Press (GBR), 2004, pp. 3-12.