CYRAX™ 2500 LASER SCANNER AND G.P.S.
OPERATIONAL FLEXIBILITY: FROM DETAILED CLOSE RANGE SURVEYING, TO URBAN SCALE SURVEYING

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ABSTRACT:
The performance of the latest terrestrial laser scanners allows an expanded range of uses of these instruments. Even for laser scanners intended for architectural surveying, the maximum operational ranges reach, or in some cases exceed, 100-150 m. With such ranges, it is possible to utilize the instruments not only for measurements of single architectural elements but also for urban surveying of entire blocks or districts. This has raised the need to define a precise and reliable method to exploit the potential of these scanners.

In this paper, we report the preliminary results of a procedure designed to exploit both laser scanner technology and the Global Positioning System (GPS) for surveying on an urban scale. The GPS was used to determine the three-dimensional coordinates of the homologous points used to merge together the scans. Use of the GPS allowed us to record the scans even if they did not greatly overlap. Moreover, it was possible to conduct the surveying campaign with extreme elasticity; in fact, with the GPS, the scans are georeferenced automatically even if acquired at different times and the data can easily be used for cartographic or cadastral purposes.

1. INTRODUCTION

In previous studies (Balzani et al. 2001; 2002), we demonstrated the potential applications of laser scanner methods in architectural surveying. The instrument used was the Cyrax™ 2400 manufactured by CYRA Technologies. Regarding the problem of recording multiple scans, we studied the applicability and quality of automatic procedures of recognition of the flat reflecting targets suggested by the manufacturer. The results can be summarized as:

- automatic recognition of the flat reflecting targets was performed with good precision and repeatability when the distance from the object was no greater than 50 m and the inclination with respect to the plane of the target was between a frontal scan and a 45° angle;
- for scans at distances over 50 m and inclinations greater than 45°, it was not possible to rely on automatic target recognition. However, it was possible to perform manual recognition of the target centre, with more than satisfactory results;
- even at large distances, measurement and restitution of the object’s natural shapes were carried out with excellent precision.

On the basis of the results of these tests, we decided to conduct new experiments to evaluate the potential of the laser scanner at its maximum range in order to survey large parts of a territory in the least possible time. In addition to surveying speed, one of the problems that must be resolved in an urban application is the need to record a large number of scans without a progressive decrease in precision (effect of error propagation). After some initial tests using a spherical target, we decided to use the GPS to determine the three-dimensional coordinates of a sufficient number of targets for use in the merging of the various scans. The GPS presents numerous advantages: it allows one to quickly obtain the three-dimensional coordinates of points (in the WGS84 geocentric reference system) with centimetric precision; the times of GPS surveying (performed as described later) are comparable to those of the laser scanner and, with suitable "target/GPS" adapters, it can be performed contemporaneously; surveying of a territory (even a very large one) can be carried out in different sessions, spaced in time, all without the need to create and measure a reference network; using a master GPS station of known coordinates, the survey is framed within the WGS84 system and thus, after the appropriate coordinate transformations, can easily be used for cartographic and cadastral purposes.

2. INSTRUMENTATION

The scanner is composed of an impulse EDM and various optical-mechanical apparatuses (rotating mirrors, servomechanisms, etc.). The EDM measures the time each laser impulse takes to go from the source to the measured object and then return to the point of emission. This technology, based on the "flight time" (or LIDAR), can be used with any refracting surface. The laser impulse is guided by small rotating mirrors regulated by servomotors: in this way, a "laser paint" is activated which moves over the object to be measured. The scan appears as a consecutive series of columns of sequential points that quickly form a three-dimensional image. The accuracy of positioning of single points in space depends on the accuracies of the distance measurements and the angular measurements of the small rotating mirrors. The polar coordinate can be easily transformed in 3D Cartesian coordinate in a local frame. For a detailed description of the instrumentation, see the bibliographical references.

In the time between our previous studies and the present one, the Cyrax™ 2400 laser scanner was replaced by the Cyrax™ 2500 model, available in Europe in early 2002. The instrument’s software and preliminary data analysis also changed; the new software is called Cyclone 3.2 and replaces the previous C.G.F. 2.1.

The study is obviously strongly influenced by the characteristics of the instrumentation used: even small operational differences can render the surveying procedures very different. The main differences between the 2500 model and the previous one are:

- the maximum usable range increases to 230-250 m.
the automatic procedures of flat target recognition can be used at distances greater than 50 m (up to 75-80 m);
- the possibility to perform automatic recognition of 6° dedicated spherical targets;
- the possibility to perform a manual search on the point cloud of the desired area (e.g., relative to the position of a flat or spherical target or of any natural point) and to launch a more detailed survey on it (the dimensions of the area and the points density is set by the operator), this possibility was greatly exploited in the present study because it allowed us to position the target/GPS system at distances greater than 75-80 m (even up to 150-200 m).

We now describe the main characteristics of the instrumentation:

<table>
<thead>
<tr>
<th>LASER SCANNER CYRAX 2500™</th>
<th>Company</th>
<th>Country</th>
<th>principle</th>
<th>eye safety class</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYRA technology</td>
<td>U.S.A.</td>
<td>t.o.f.</td>
<td>Class 2</td>
<td></td>
</tr>
</tbody>
</table>

**PERFORMANCES**

<table>
<thead>
<tr>
<th>max. range on natural targets</th>
<th>horizontal scan range</th>
<th>vertical scan range</th>
<th>scan mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 m</td>
<td>44 gon</td>
<td>44 gon</td>
<td>rotating mirror</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>horizontal angle readout accuracy</th>
<th>vertical angle readout accuracy</th>
<th>range accuracy</th>
<th>point accuracy @ 50 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>±3.8 mgon</td>
<td>±3.8 mgon</td>
<td>±4 mm</td>
<td>±6 mm</td>
</tr>
</tbody>
</table>

**OTHER FEATURES**

<table>
<thead>
<tr>
<th>beam divergence</th>
<th>scan rate</th>
<th>dimensions</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤6 mm @ 50m</td>
<td>1 column/sec @ 1000 pts/column</td>
<td>400 x 330 x 430 mm x 60 mm</td>
<td>20.5 kg</td>
</tr>
<tr>
<td>7.6 mgon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. CYRA specifications about Cyrax 2500™

As is known, the GPS is a positioning system based on reception of radio signals emitted by a constellation of artificial satellites in orbit around Earth. For precise positioning, the GPS is used in relative mode, with at least one pair of receivers: a master receiver placed on a vertex of known coordinates in the WGS84 geocentric system and other rover receivers on the points to be measured (Hoffmann – Wellenhof, 1997).

In the present study, we used four Ashtech ZXII double-frequency geodetic receivers in rapid-static mode, with the session duration and sample rate set to allow a centimetric precision of single baselines in normal situations. The baselines were analysed with GeoGenius™ 2000 commercial software.

Figure 1. Laser scanner Cyrax 2500™

Figure 2. Cyclone 3.2

Figure 3. G.P.S. Antenna and receiver
3. AIM OF THE EXPERIMENTS

As mentioned in the introduction, one of the aims of the experiments was to determine, with the GPS, the coordinates of a sufficient number of points to use for the merging of scans performed with the laser scanner.

Merging of the various point clouds is based on a roto-translation in space. This transforms the coordinates of all the points of the cloud (each scan is referred to a "local" frame centred on the laser scanner) into a unique or "global" frame defined by the user, which can coincide with the local frame of a predefined scan.

Therefore, for each scan, six parameters of the transformation must be calculated (the three rotations of the axes and the components of the vector of translation of the origin of the local frame); using three homologous points and a least squares procedure, it is possible to calculate the parameters of the roto-translation with a degree of superabundance of three; thus it is possible to apply the transformation to the entire point cloud. Normally the homologous points allowing an accurate recording between two or more scans are constituted by flat reflecting targets positioned on the object to be measured; the scans to be joined must have a large area of overlap and the position of the target must be analysed from time to time, making the surveying of large territories very difficult (hereafter we use the term territorial scale surveying).

The idea used in these experiments was to successively perform all the scans necessary to cover the survey area and, for each of them, to position at least three GPS antennas able to furnish the coordinates of three homologous points (between the GPS and laser scanner system) to be used to calculate the parameters of the transformation. In this way, the WGS84 geocentric system was used directly as a "global frame" for all the scans. Naturally, the GPS antenna, more precisely its phase centre, could not be used directly as a homologous point (measured by both the GPS and laser scanner); it was necessary to make a suitable device to allow the simultaneous positioning of the GPS antenna and a classical flat reflecting target. In this way, the GPS measurement furnishes the WGS84 coordinates of the antenna's phase centre, while the laser scanner provides the coordinates of the centre of the reflecting target in the local frame of the scan. At this point, the WGS84 coordinates of the antenna's phase centre must be transferred to the target centre, an operation requiring an initial control and calibration of the adapter devices (described later).

The advantages of this solution are obvious:
- contemporaneous measurements; the time component is an important factor in territorial scale surveying;
- flexibility of use of the instrumentation: the proposed method satisfies the requirements of the single instruments without creating annoying overlaps of one on the other;
- areas of overlap reduced to a minimum; with the proposed method, no overlap between the different scans is required for the recording;
- planning of the surveying directly in the field; exploiting the operational elasticity of the GPS antennas, it is possible to decide on the spot which portion of the territory is to be scanned and where to position the reference antennas, without having to plan the session in the laboratory.

3.1 Planning and calibration of the adapter devices

To achieve the described aims, we designed and built a suitable adapter equipped with a Wild reflector that allowed us to contemporaneously position both the flat reflecting target and the GPS antenna on a topographical tripod and a sideward equipped with a spherical level.

To contemporaneously perform the GPS and laser scanner measurements, we equipped the plane holding the reflecting target with two orthogonal axes of rotation that allowed us to maintain it in a frontal position with respect to the scanner; in this way, automatic target recognition was possible in the scanning phase and manual recognition was facilitated at great distances.

For each adapter, we first performed a control procedure to verify the correctness of its construction. In particular, we measured the planimetric difference in the position of the target centre with respect to the vertical for the station point and the change in position of this centre when the adapter was rotated around the vertical.

In addition, we performed a careful calibration that allowed us to assess the vertical offset between the coordinates of the phase centre of the GPS antenna and the coordinates of the centre of the flat reflecting target positioned on the adapter.
4 EXPERIMENTS

We now describe the organization of the survey and the data collected.

4.1 Organization of the survey

The first part of the survey lasted for 2 days, for a total of about 16 hours of work. We chose to take the scans in a real situation of territorial scale surveying. Thus, we conducted the experiments in an urban area, dealing with problems like traffic, poor visibility of the GPS satellites and the planning of numerous surveying stations.

In accordance with the above-mentioned premises, the surveying session was organized as follows:
- identification of an appropriate station point for the master GPS antenna. The characteristics of this point must ensure a good distance from obstacles, like buildings and vegetation, and from reflecting surfaces (which could produce multipath errors); moreover, it should be in the centre of the area to be surveyed so as to have short baselines and, if one wishes to use the survey for cartographic and cadastral purposes, it should be a vertex of known WGS84 coordinates (if a vertex of known coordinates is not available, one can always carry out a subsequent survey to frame the master station in a pre-existing network or one can use the international IGS network of permanent GPS stations).
- positioning of the laser scanner station on the preset point;
- analysis of the scanner’s field of view and decision about the points on which to position the three adapters with the rover GPS antennas. The laser scanner is equipped with a digital camera that acquires the image of the area to be surveyed; with this image, it is possible to decide on the areas in which to position the adapters;
- positioning of the adapters and acquisition of the GPS data. For each antenna, we set a sample rate of 3 seconds; with a session duration of at least 15 minutes, this provides a sufficient number of epochs for determination (with centimetric precision) of the GPS point in rapid-static mode. To exploit the potential range of the instrument (up to 250 m), we tried to choose station points of the rover GPS antennas that were well distributed (also in depth) within the field of view of the single scan; in this way, we could reduce the hinge effects that can result if they are too close together (even a slight rotation of the model in the junction zone generates a high linear error if multiplied by an arm of 250 m).

- after the adapters were positioned and their effective presence in the scanner’s field of view was checked (e.g. with a rapid wide-grid scan), we began the actual scanning. Assuming that the aim of territorial scale surveying is large-scale reproduction (1:500; 1:1000), it is necessary to have a precision of the measured detail points of 10 cm.

As a first approximation, the precision of surveying performed with the laser scanner can be estimated as the combination of the intrinsic precision of restitution of the single collimated point (± ±6 mm) and the spacing of the projective grid. In fact, due to the nature of the laser scan, the object is defined by a huge mass of indiscernible points; recognition of the characteristics of the object (e.g. restitution of the edges of a building) is performed by interpreting the point cloud and exploiting the level of detail acquired. We chose to survey all the buildings in the field of view with a grid of at least 5 cm. This was achieved by setting the projective grid spacing at 5 cm at the distance of the farthest building;
- execution of automatic recognition of the targets when possible; in fact, for distances less than 80 m, the Cyrax™ 2500 laser scanner can recognize the shape and reflectance of the dedicated flat targets and carry out fine recognition with a millimetric point density;
- manual recognition of the most distant targets; this important innovation of the scanning procedures of the 2500 model (with respect to the previous model) was fundamental for our experiments. In fact, it was possible to manually collimate the target on the point cloud (or the zone in which it was situated) and then perform a fine scan of it with millimetric point density, thus measuring the same level of detail as with the automatic procedure. The same procedure would have been very difficult with the previous instrumentation because collimation of the scanning zone was based only on the low-resolution digital image acquired by the scanner and recognition of a small object (like the target) at great distances was practically impossible.

Figure 7. The three antennas in the scanner’s field of view

Figure 8. Fine scan on the adapter and the antenna
4.2 Surveyed data

We set up 12 scanning stations, for a total of about 12,458,302 measured points. The following table describes the scans.

<table>
<thead>
<tr>
<th>scan</th>
<th>number of surveyed points</th>
<th>max distance on natural point</th>
<th>distance between scan and GPS 1</th>
<th>distance between scan and GPS 2</th>
<th>distance between scan and GPS 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,078,835</td>
<td>258,51m</td>
<td>26,09m</td>
<td>56,47m</td>
<td>29,52m</td>
</tr>
<tr>
<td>2</td>
<td>1,274,512</td>
<td>128,51m</td>
<td>29,49m</td>
<td>36,63m</td>
<td>56,43m</td>
</tr>
<tr>
<td>3</td>
<td>625,892</td>
<td>260,06m</td>
<td>36,61m</td>
<td>45,44m</td>
<td>75,31m</td>
</tr>
<tr>
<td>4</td>
<td>1,106,637</td>
<td>455,69m</td>
<td>48,80m</td>
<td>63,90m</td>
<td>73,28m</td>
</tr>
<tr>
<td>5</td>
<td>1,332,457</td>
<td>204,65m</td>
<td>33,31m</td>
<td>155,91m</td>
<td>13,73m</td>
</tr>
<tr>
<td>6</td>
<td>425,173</td>
<td>149,47m</td>
<td>155,91m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>447,037</td>
<td>118,06m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>973,540</td>
<td>331,38m</td>
<td>106,36m</td>
<td>29,58m</td>
<td>35,67m</td>
</tr>
<tr>
<td>9</td>
<td>648,613</td>
<td>132,37m</td>
<td>26,59m</td>
<td>22,66m</td>
<td>39,79m</td>
</tr>
<tr>
<td>10</td>
<td>1,508,824</td>
<td>235,39m</td>
<td>72,84m</td>
<td>47,32m</td>
<td>28,70m</td>
</tr>
<tr>
<td>11</td>
<td>1,061,557</td>
<td>162,99m</td>
<td>44,85m</td>
<td>89,50m</td>
<td>46,78m</td>
</tr>
<tr>
<td>12</td>
<td>975,225</td>
<td>214,27m</td>
<td>28,55m</td>
<td>47,22m</td>
<td>127,47m</td>
</tr>
</tbody>
</table>

Table 2. Information about the clouds surveyed

Stations 6 and 7 refer to measurements of a terrestrial surface with low satellite visibility. In fact, it consists of a narrow road bordered by tall buildings. In this case, as in similar ones, we decided to use the maximum number of positionable antennas (e.g. only one antenna was positioned at station 6) and the classical recording method (i.e. application of flat targets in a zone of overlap between two scans).

5. RESULTS

5.1 Recording of the scans

All the scans were analysed on the basis of our experience in the previous studies; in particular, before starting to record, it is fundamental to perform a control and possibly a manual adjustment of the recognition of the target centres proposed by the scanner.

It is also appropriate to cancel all the erroneously acquired information due to disturbances (e.g. pedestrians and moving vehicles), so as to make the model as legible and interpretable as possible.

We then used the recording procedures included in the dedicated software and we evaluated the resulting three-dimensional residuals by subsequent application of the calculated transformation.

The coordinates of the phase centres of the GPS antennas were transformed into local topocentric coordinates centred on the master; in this way, we could directly apply the offsets between the target and phase centre of the antenna.

We now report the results in a frequency histogram with 1 mm classes:

As can be seen from the histogram, 67% of the residuals are smaller than 6 mm, which is the manufacturer’s stated precision of the laser scanner for acquisition of a single point.

![Figure 9. Histogram presenting 3D residuals' module](image)

5.2 Data analysis

We now report some visualizations of the point clouds. Visualization in raster format prevents the recognition of much information which instead is perfectly interpretable by direct analysis of the three-dimensional data.

In figure 10 and 11 we show two single scans; the arrows point out the position of G.P.S. antennas and adapter. In figure 12 we show the model after the merging of the two scans. By using this procedure many times we obtained the entire model.

![Figure 10. A single scan. The arrows point out the position of the G.P.S. antennas](image)

![Figure 11. A single scan. The arrows point out the position of the G.P.S. antennas](image)
6. CONCLUSIONS

Preliminary tests of the potential advantages of combining laser scanner and GPS surveying fully justify the use of this method. The precision obtained in the recording procedures and the direct analysis of the complete model have demonstrated its good reliability.

At the moment, we are conducting a study to evaluate the precision of the model and to assess the applicability of the method to larger portions of a territory. Use of the survey for cartographic or cadastral purposes can be hypothesized on the basis of the results of the restitution tests.

7. BIBLIOGRAPHY


KEY WORDS

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