STATE OF THE ART IN TERRESTRIAL LASER SCANNING SYSTEMS AT NATIONAL AND INTERNATIONAL LEVEL

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***Abstract**: Mobile terrestrial laser scanning represents nowadays one of the most efficient techniques of collecting spatial data due to its accuracy, its high level of detail, but mostly due to the short time needed to collect large amount of data. The present study tries to point out the state of the art in terrestrial laser scanning systems both at national and international level. The research starts by concisely presenting the historic development of the systems and the principles used in creating such systems. In the second part of the paper, the most relevant systems developed until today are presented, together with their most important applications.*

***Keywords:** GPS/INS, LiDAR, mobile laser scanning, DSM*

1. Introduction

Nowadays, a recent, accurate and detailed Digital Surface Model (DSM) represents a key demand in many of the engineering tasks regarding civil or industrial engineering, hydrotechnics, topography, architecture, telecommunications, land reclamation, etc. In addition to the elements provided by the Digital Terrain Model (DTM), the DSM data includes the natural or artificial elements located on the Earth's surface (buildings, vegetation, etc.).

There are several methods, techniques and technologies used in collecting the data necessary to obtain the DSM. These methods include geodetic surveying using classic instruments or GNSS technologies, photogrammetry, remote sensing, aerial and terrestrial laser scanning, etc. The latter achieved performances which were unimaginable a decade ago, both in terms of accuracy, level of detail and time necessary to collect the data.

2. The historic development of laser scanning systems

The first airborne laser scanning systems were developed in the early 70's, but, due to the lack of solutions for data georeferencing, they were only used in studies regarding the atmosphere, the oceans, the glaciers, etc.. In the early 90's, following the development of GNSS, of inertial navigation systems and of a mathematical model which combines data from all these sensors (the Kalman filter), the use of laser scanning systems in terrain modeling became possible.

During the same period, terrestrial laser scanning systems were developed for topographic and industrial applications, but were used as well in other domains such as architecture, archaeology, etc. Their applicability was, until recently, a static one, by that meaning the system is not moving during a scanning session. The laser beam used to determine the distance to the closest object is oriented on different, well-defined directions by using a servo motor for horizontal movement and by rotating an internal mirror to deflect the laser beam in the vertical plane. The set of points which is defined in a polar coordinate system, obtained using this method is generically named "point cloud". In case of larger objectives, the scanning was done using several base stations and the point clouds were referenced using common points. The newer technologies combine data from the terrestrial laser scanner with data from GNSS/INS systems with the aim of directly referencing the scanned data. These technologies eliminate the static method's lack of efficiency and promote the mobile terrestrial laser scanning systems as leader in collecting spatial data.

3. Principles used in developing mobile terrestrial laser scanning systems

The transition from the static method to the dynamic one is not an easy task to accomplish, since the coordinates of the scanned points are relative to the scanner's geometric centre which is now mobile. Therefore, in order to obtain the point cloud through mobile scanning, the platform's trajectory and inclinations must be determined. In the case of the static method, the high speed rotation of the scanner's internal mirror creates a vertical line of scanned points. By horizontally rotating the scanner using the servo motor, the scanner creates a number of such lines which compose a frame. In the mobile method's case, scanning by frames does not make sense anymore and therefore the only deviation of the laser beam will be the one given by the rotating mirror and due to the platform's movement the point cloud will have a spiral form. A schematic representation of the point cloud may be seen in Fig. 1. – Schematic representation of the point cloud in the case of mobile scanning

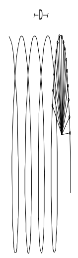

Fig. 1. – Schematic representation of the point cloud in the case of mobile scanning

Thus, the scanned data must be synchronized with the equipments used to determine the system's trajectory. Usually, in order to determine the platform's trajectory and inclinations, a GNSS/INS positioning system is used. The positioning system is composed of an inertial measurement unit (IMU) – used to determine the platform's speed, inclinations and heading, and one or more GNSS receivers – used to reinitialize the IMU and often to improve the determination of the platform's heading.

In the case of mobile mapping, each scanned line or even each scanned point needs other transform parameters in order to reference it, because the system is permanently changing its position. These parameters may be obtained from the positioning system, the only remaining problem being the synchronization between the scanned data and the GNSS/INS positioning system. For this purpose, the laser scanners incorporate an internal synchronizer which may be reinitialized by an external pulse. This external pulse, represented in our case by a 1 pps pulse provided by the GNSS, reinitializes the synchronizer and increments a counter.

4. State of the art in mobile terrestrial laser scanning at international level

Although this domain is rather new, we cannot talk of a "monopole" from the technological point of view. The first efforts in this domain were made in 2003-2004 in different parts of the world. Initially, these systems were developed for scientific and research purposes, but due to their capabilities and efficiency in less than three years several companies already developed commercial solutions.

Until now, there are no companies which produce all the components of such systems. Usually, companies like Riegl or Topcon which sell mobile terrestrial laser scanning systems, use some of their own components together with other companies' components (Applanix, Sick, etc.). Regularly, the created systems are modular platforms, as they can be easily and continuously upgraded. Therefore, an integrated solution does not make sense for the moment.

4.1 Geomobil – Institut Cartografic de Catalunya (ICC)

This platform may be considered as one of the first steps taken in the field of mobile terrestrial laser scanning. Developed by the ICC in the frame of a research project, at the beginning this system was conceived as an inertial platform which could integrate data from different sensors in order to acquire geographic information [Talaya, J. et. al. – 2004]. Initially, the platform was equipped with video cameras, and starting with the year 2003, it was upgraded by integrating a Riegl LMS Z-210 laser scanner. An image of the platform may be seen in Fig. 2. – The Geomobil platform (with the courtesy of ICC).

Fig. 2. – The Geomobil platform

ICC used the developed system in several application from which we will present two in the following paragraphs.

4.1.1. Using Geomobil in modeling the mountainous area between Ribes de Freser and Santuario de Nuria. The aim of this application was to identify the places were rockslides near the railway may occur. Given the fact that the rack railway is the only terrestrial means of transportation in the respective area, the Geomobil was installed on one of the train's platforms. For a complete zone modeling, several scans took place, with the instrument oriented in different directions. For comparison, the results were overlapped with similar observations obtained from an aerial scanning and the differences between the two sets of data were smaller than 25 cm [Serra, A. et. al. – 2005].

4.1.2. Using Geomobil in urban modeling. This application is common to all mobile terrestrial laser scanning systems. ICC used Geomobil in modeling the buildings’ facades in the centre of Sitges city (Spain). Inside the area of interest, ten points were determined by other methods such as GNSS technologies or classic geodetic measurements, in order to validate the results. The differences between the coordinates obtained by modeling the scanned data and the ones obtained by other methods did not exceed 20 cm [Serra, A. et. al. – 2005].

4.2 StreetMapper – 3D Laser Mapping and IGI mbH

The platform developed by the partnership between the English company 3D Laser Mapping and the German IGI mbH, is the first mobile terrestrial laser scanning system developed with the aim to be commercialized. The first system was assembled in 2005 and went through a 6 months testing phase. StreetMapper is also the first system to have a 360 degrees field of scan around the platform. This performance is realized by integrating up to 4 laser scanners. An image of the platform may be seen in Fig. 3. – The StreetMapper platform (with the courtesy of 3D Laser Mapping).

Fig. 3. – The StreetMapper platform

The systems’ architecture is similar to the one provided by Geomobil, with the difference that StreetMapper is using multiple scanners in order to obtain the 360 degrees field of scan. The scanners are of type Riegl LMS – Q120. For a better data interpretation the platform is equipped with video cameras. In order to improve the positioning accuracy in case of missing GNSS signal, the platform includes an additional distance measurement unit which lowers the IMU error bias. The positioning system is named TERRAcontrol and includes also a GPS/GLONASS/DGNSS NovAtel OEMV-3 receiver and an IMU developed by IGI.

As a commercial system, the StreetMapper was used in several applications from which we will present four in the following paragraphs.

4.2.1. Using StreetMapper in modeling the areas where car accidents took place. The traffic police department in Cambridgeshire used the StreetMapper to model the areas where car accidents occurred with the aim to have a better understanding of the causes that lead to the incident and also the conditions in which the accident took place. Moreover, in case of severe accidents, these measurements are necessary for the police and are time consuming if they are done by classic methods. With the help of mobile terrestrial laser scanning, the time spent for these measurements is reduced. Sometimes it's necessary to have a base of comparison, which could be a model of the area before the accident, and thus the platform may be used to scan areas where car accidents often occur.

4.2.2. Using StreetMapper in measuring the position of overhead cables. The objective of such measurements is to precisely identify the minimum distance between the cables and the earth surface [Kramer, J. & Hunter, G. – 2007]. The advantage of using mobile terrestrial laser scanning systems in this case is significant because many of the classic measurements' errors sources are removed. In the traditionally way of checking the wire height, by using a pole, errors such as not finding the exact point where the distance between the wire and the earth's surface is minimum or a small pole inclination, influence measurements so that they always overestimate the distance. Such errors which are biased to determine a larger distance than the real one do not appear in the case of mobile terrestrial laser scanning.

4.2.3. Using StreetMapper to monitor the coastal areas. A model of the coastal areas is a necessity in countries like England in order to evaluate the level of erosion, sediments or other certain extreme phenomena. In order to use the StreetMapper in this type of application, the platform was installed on a 4x4 terrain vehicle, property of the Newcastle University and several scans took place near Scarborough. The StreetMapper was modified to use only one laser scanner Riegl LMS – Q560 and an area of 6.5 km was scanned in 12 minutes, obtaining a point cloud of 20 million points. Similar scans were made for the coastal areas in Felixstowe and its vicinities.

4.2.4. Using StreetMapper for Indivisible Abnormal Load (IAL) routes planning. The transport of IAL often requires a model of the areas which will be used as a route. Although, the main part of the routes is generally known, like highways or European roads, which are monitored and often used for such transports, the final leg of the journey from the highway until the destination needs surveying in order to choose the optimum route. 3D Laser Mapping and IGI used StreetMapper at the request of a UK power utility company to survey an area in Staffordshire to ensure the route was suitable for transporting a large transformer [Hunter, G. et. al. – 2006]. Part of the route was already known, but its last leg, needed surveying. The total length of the route which had to be modeled was 19 km, and the scanning lasted 1 hour, driving at slow speed in order to have a high density of points. The result was a point cloud of 93 million points with a density of 50 points/m^2.

4.3 LYNX Mobile Mapper – Optech Inc.

Created by Optech Inc (Canada), one of the most important companies involved in developing scanning systems, having more than 35 years of experience in LiDAR technologies, LYNX is one of the newest mobile terrestrial laser scanning systems. A picture of this system may be seen in Fig. 4. – LYNX Mobile Mapper

Fig. 4. – LYNX Mobile Mapper

The system's architecture is similar to the ones presented above. Similar to StreetMapper, LYNX offers a 360 degrees scan field as well, by incorporating up to 4 laser scanners designed by Optech. The positioning system was designed by Applanix (POS LV 420) and includes an IMU and two Trible GPS receivers.

From all the applications in which this system was used we present here only the most innovative one: surveying the railway infrastructure. The Aerial Data Service (ADS) in Tulsa, Oklahoma was interested in examining LYNX data for monitoring track conditions, inventory, etc. In order to test the system and its capabilities, ADS arranged to scan a section of railway outside Tulsa, Oklahoma. The scanning system was mounted for this application on a special track-maintenance vehicle called "speeder". The LiDAR sensors were oriented so they would scan the railway and its surrounding area. The scan length was about 5.5 km. The resulting point cloud was used in monitoring the railways, but also in identifying certain areas where vegetation or manmade objects were too close to the rail.

Other applications of the LYNX Mobile Mapper which must be mentioned are: scanning of road infrastructure in Greece (2008) [Ussyshkin, V. – 2009] and mounting the LYNX system on a speedboat in order to scan the inaccessible steep areas on the river bank.

4.4 Other mobile terrestrial laser scanning systems.

There are several other systems like the ones presented above, most of them developed for commercial use. We will not insist in presenting them as they have the same architecture as the others. We will only mention two other such systems: VMX 250 developed by Riegl and IP-S2 developed by Topcon. In the figure below a view of the IP-S2 is presented (Fig. 5. – The IP-S2 platform)

Fig. 5. – The IP-S2 platform

5. State of the art in mobile terrestrial laser scanning systems at national level.

In Romania there is only one such system created or used. This system was developed through a research project financed in the frame of PNCDI II, which is still on going. The architecture of the system developed by the S.C. C-TECH S.R.L. is not different from the ones developed at international level. A view of the platform may be seen in Fig. 6. – Mobile terrestrial laser scanning platform developed by S.C. C-TECH S.R.L. (courtesy of S.C. C-TECH. S.R.L.)

Fig. 6. – Mobile terrestrial laser scanning platform developed by S.C. C-TECH S.R.L.

The system can be supervised during the survey by using the navigation system's software (POSView) or the laser scanner's software (RiScan Pro). One can monitor in this way parameters such as: the real time position (N, E and H) and its standard deviation, the way the solution is computed (GNSS/INS based or only INS), GPS time, speed (N, E and D) and its standard deviation, platform inclinations (pitch, roll) and their standard deviations, platform heading, other problems, etc.

Since its developing, in 2008, the system was used in different static and mobile applications studies and projects from multiple fields such as: topography, architecture, archaeology, civil engineering, etc. We will only mention here some of its mobile applications: creating the DTM (Digital Terrain Model) and the DSM (Digital Surface Model), road monitoring, identifying electrical networks, updating the geospatial database necessary to evaluate the level of erosion in coastal regions, etc.

6. Software used in post-processing the point clouds

At this time, there is no commercial software dedicated to process the point clouds obtained from mobile terrestrial laser scanning. Usually, the companies use either own created software (Geomobil) or software created to process point clouds regardless of the way these point clouds were obtained. Regularly, these products have a hard time processing point clouds obtained through mobile scanning due to the large number of points (up to several hundred million points). The software generally breaks the point cloud in several blocks, which implies a lack of efficiency. Moreover, up to now, there are no dedicated algorithms for processing this type of point clouds; by that meaning there should be algorithms which dynamically modify the point cloud.

The most used software solutions are: RiScan Pro (Riegl), TerraScan, Pointools, PolyWorks, Metris, ClearEdge 3D, PointCloud Kubits, LFM Server (Z+F).

7. Conclusions

The development of mobile terrestrial laser scanning systems improved the spatial data collection. Although the static terrestrial scanning represents an important step in the field of spatial data collection, it still has a lack of efficiency in the case of large objectives which need to be scanned. In these cases, the objectives must be scanned from several stations and the individual point clouds must be referenced with the aid of special targets mounted on the scanned objective. Moreover, in the case of objectives where it's difficult to place the instrument in certain areas (highways, high cliffs, coastal areas, etc) static scanning does not provide an easy to use solution. The mobile terrestrial laser scanning systems currently represent a very efficient technology in these cases. A temporary shortcoming of the systems is their acquisitioning or developing costs.

It must be mentioned that mobile scanning technologies for airborne platforms were developed before the terrestrial ones, but due to their high operating costs were feasible only for projects and operations regarding wide areas. Besides their costs and the flight restrictions, the point cloud obtained through airborne scanning has a low spatial density. Therefore, these systems are regularly used in generating DTM's or DSM's for wide areas or for applications where high precision or high detail level are not required. For rigorous and fast modeling, mobile terrestrial laser scanning systems are the most efficient, having also the advantage of surveying areas which are hidden for airborne scanning (tunnels, areas shadowed by vegetation, etc).

Mobile terrestrial scanning still represents a new field of research at international level. The research is generally oriented on improving the positioning accuracy, reducing the system's size and portability, improving the algorithms for post-processing the point clouds obtained through mobile terrestrial scanning, etc. It should also be studied the impact of future global satellite systems (Galileo, Compass) and the development of present ones (GPS, GLONASS) over the positioning accuracy.

8. References

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