Quality Assessment Of Kinematic Airborne Laser Survey

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ABSTRACT

Kinematic positioning is considered as the most important factor in creating a reliable digital terrain model (DTM), by airborne laser scanning. It requires as well, an accurate and consistent base-to-aircraft vector throughout the survey. Different experiments were carried out in Italy and Portugal in collaboration with Auselda ADE group using the TopEye airborne laser scanner. Three main problems encountered in kinematic airborne laser surveys were studied: (1) the radio frequency interference (RFI) with the global positioning system (GPS) signal, (2) the use of more than one reference station when long trajectory surveys are needed and their effects on the GPS results, and finally, (3) the effect of the distance between the reference station and the rover receiver on the GPS solution and consequently on the DTM. Geogenuis and TopEye softwares were used for processing the GPS and laser data. Some recommendations were proposed by the authors to be implemented on the helicopter to improve the reception of the GPS signal, and they proposed as well a limitation for the distance between the reference station and the rover receiver.

KEYWORDS

airborne laser scanning, GPS, DTM, interference, antenna, accuracy

INTRODUCTION

The airborne laser scanning technique is considered as one of the most reliable techniques for DTM generation [Ackermann (1999)]. This technique is based on the collection and determination of the xyz coordinates of a large number of points on the topographic scanned surface. The cloud of collected points is modeled using different algorithms [Vosselman and Dijkman (2001), Axelsson (1999)]. This technique is used for DTM generation [Ackermann (1999); Axelsson (2000); Al-Bayari et al. (2002)], building extraction [Vosselman and Dijkman (2001)], and for many other applications based on the height determination such as trees height detection [Haala and Brenner (1999)]. The airborne laser scanners enable the acquisition of elevation data with an accuracy of 0.1 m [Casella (1999)]. This accuracy depends on many factors [Huisings and Gomes Pereira (1998)], such as the quality of calibration of the group of sensors of the laser scanner [Skaloud and Vallet (2002); Mostafa and Hutton (2003)], the quality of data processing [Ackermann (1999); Axelsson (1999)], topography and vegetation [Kraus and Pfeifer (1998)].
A series of experiments were carried out in Italy and Portugal in collaboration with Auselda ADE group, using the TopEye airborne laser scanner system with the following objectives:

1. To find the system accuracy.
2. To define and overcome the problems encountered in kinematic airborne laser survey (Al-Bayari et al. 2002) to create a reliable DTM.
3. To find the RFI effects on the GPS signal, in order to improve the reception of the GPS signal.
4. And finally, to find the effects on the GPS results when using more than one reference station in case of long trajectories.

DESCRIPTION OF THE AIRBORNE LASER SCANNING SYSTEM

The TopEye system [Axelsson (2000)] is an airborne laser system, which consists of two sensor groups. The first sensor group is a laser range finder, which is used to measure the distance from the laser range finder to the terrain surface. The second sensor group consists of GPS and INS which determine the absolute position and the orientation of the laser range finder at the time of measurement. The system scans the ground across the track of the Helicopter and measures the distance by emitting up to 7000 laser pulses per second. The TopEye system could record four returns for each laser pulse (Fig. 1). The records of different returns within a single laser pulse help to identify the height of the objects on the terrain, such as trees, buildings, power lines, etc. [Al-Bayari et al. (2001)]. At the Bracigliano and Sarno landslides in Italy, the system was set up to record the first and the last returns in order to determine the ground DTM and the vegetation height.

DESCRIPTION OF THE EXPERIMENTS

The first experiment was undertaken at the Bracigliano and Sarno landslides in the south of Italy, where we captured 7 strips at the first landslide and 12 strips at the second one (see Fig. 2). The second experiment was carried out along the Trieste highway in northern Italy. Three receivers were used on board of the helicopter, a Trimble 4000ssi, Trimble 4700 and a Javad (Topcon), as well as, two reference stations at 17km from each other (Fig. 3). The third experiment was performed at the Trieste airport to check the calibration of the new internal Trimble antenna, installed inside the helicopter cabinet (Fig. 4). The fourth experiment was executed in Portugal. An airborne laser survey was carried out for an eighty kilometer (80 km) power line using three reference stations (Fig. 5).

![Fig. 1 The TopEye system with four possible echoes](image-url)
**Fig. 2** Laser Scanning experiment at the Sarno Landslide

**Fig. 3** Laser Scanning experiment at the Trieste Highway

**Fig. 4** The new internal geodetic antenna, which has been installed inside the helicopter cabinet under the top window
Experimental Results and Discussion

Influence of the Antenna Position on the GPS Signal

Generally, GPS receivers filter the captured signals and amplify them by a low-noise amplifier. The most important noise of the system comes from this amplification. During the airborne laser survey with the external antenna, we noted that the Signal to Noise Ratio is less than that obtained with the normal antenna which is connected with the receiver on board. This may be due to the separation of the amplifier from the external antenna, which is installed on the tail of the Helicopter. Due to aeronautic regulations, it is forbidden to install large or heavy objects outside the helicopter. Therefore, the antenna is separated into two parts, the first part is installed on the tail of the helicopter and the second part which is the amplifier is installed inside the tail at one meter from the first part. We found that the use of an internal antenna (Fig. 4) showed an improvement in the Signal / Noise ratio, especially in the zones where a loss of lock of the GPS signals was encountered due to interference problems (Fig. 6). These findings were verified at the Trieste Highway, and the Bracigliano and Sarno landslides experiments, as a GPS solution (OTF) was obtained using the data captured by the internal antenna, and no solution was obtained for the data captured by the external antenna. Meanwhile, a DGPS solution was obtained using an external antenna. The TopEye software merges the GPS solution, INS data and laser data using a calibration file. The GPS offset vector from the frame system center of the helicopter body is written in the calibration file. For the use of another antenna, we need to introduce the new vector of the new internal antenna in the calibration file in order to obtain a good laser data. The calibration vector of the internal antenna could be found using a conventional instrument such as a total station or the laser data after processing with the external and internal antennas at the same time. We found that the internal antenna provides a better reception of the GPS signal compared with the external one. We observed as well, that the disturbance during the helicopter maneuver did not affect the final results and this can be verified by comparing the results from both antennas. Therefore, we used an external antenna if a loss of a GPS signal occurs over an area. The external antenna can be replaced easily by connecting the cable of the internal antenna directly on the receiver during the flight.
Signal Interference And GPS Receivers

Radio frequency interference with GPS signal was encountered in many parts of Italy (Fig. 6). This problem may be due to the illegal use of the radio frequencies in Italy. The RFI map of L1 signal, which was produced for navigation purposes could help in the location of the interference problem. Since the cost of the helicopter and laser scanning survey is high, a kinematic survey was carried out along Trieste Highway in order to verify the presence of in-band interference. This procedure gives an indication of the interference situation on the ground but not at the flight level. Three flights were carried out over the Trieste Highway and the same problem of interference was faced in a specific area for the same flight line. This enabled us to isolate the interference zone, but the same method could not, obviously, be applied at the Bracigliano or Sarno landslides. The interference problem has been identified either by loss of lock of L1 and L2 frequencies or just by loss of L2, and in some cases by receiving a low signal / noise ratio (SNR). The use of the most recent generation of receivers, such as JAVAD (Topcon), and Trimble 4700, in these experiments improved the SNR. The quality of kinematic GPS survey will be much better if the SNR is high because the noise will be low in the observations. These receivers demonstrate good capacity to receive the signal in hard conditions [Vorobiev et al. (1998)]. Furthermore, new algorithms are used in these receivers to resolve the in-band interference and jamming signals. All receivers on board have received a good signal / ratio during the first experiment, as compared to the Trimble 4000ssi receiver, which was used by the TopEye system and connected to the external antenna. Consequently we have suggested the installation of a geodetic antenna inside the helicopter cabinet (see Fig. 4) and the use of the new generation of GPS receivers. The company took in consideration these suggestions and adopted the Trimble 4700 receiver on board of the helicopter.

The GPS Solution For A Long Trajectory

During the laser airborne survey of a power line in Portugal, three reference stations were used (Fig. 5). GeoGenius software was used to obtain the OTF solution for the whole helicopter trajectory. The three reference stations were used in the processing of the entire survey session. Normally the OTF solution obtained by the software is not reliable over a long distance, considering the ionospheric problem over a distance greater than 20 km [Cannon et al. (1996)]. The TopEye software merges the GPS data with laser and INS data to calculate the coordinates of laser returns. The file which contains the best GPS solution is elaborated by taking into consideration the nearest reference station. Therefore, the best
solution was obtained using CASC station (from the beginning of the survey at 11:20 AM until 12:00 noon), SERV station (from 12:00 noon till 12:38) (see Fig. 7), and using finally RAMA station (from 12:38 until the end of the survey 13:02) (see Fig. 8). This solution was used in the final GPS file for processing the laser data.

Since the ambiguity resolution is influenced by the ionosphere, the distance between the reference station and the helicopter should be taken into consideration and should not exceed 20 km. This result was also confirmed, on the Portugal experiment (see Fig. 9). Finally, the use of two reference stations with 17 km apart from each other in the Trieste Highway experiment did not show any discrepancy in the kinematic results (see Fig. 10). The use of two reference stations can also confirm the reliability of the airborne GPS data. Recently, new technologies in the GPS data processing softwares appeared such as Bernese 5 (Hugentobler et al. 2005). The elaboration of kinematic GPS data could be done from two reference stations. This software was not available during the survey. Moreover, TopEye is still using Geogenius software for its simplicity.
Accuracy of the obtained DTM

The DTM resulting from an airborne laser survey could be obtained by OTF or smoothed DGPS. GeoGenius software was used to obtain the DTM at Bracigliano landslide using these methods. A kinematic GPS survey was carried out for a specific part of the Bracigliano landslide. Fig. 11 shows the variation in height between this survey and the DTM obtained by OTF.

Fig. 11  Difference in height between kinematic GPS survey and DTM created by laser survey using the OTF solution
The accuracy of a DTM depends on many factors, such as the quality of GPS solution, synchronization of INS and GPS sensors [Skaloud and Vallet (2002)], flight height [Kilian (1994); Hofton et al. (2000)], angle of scanning, topography and vegetation [Kraus and Pfeifer (1998)]. The DTM could be obtained by OTF or smoothed DGPS solutions. The accuracy is estimated at 0.1 m for OTF solution and 2.5m for DGPS using GeoGenius software. Table 1 gives the difference in height between rapid static GPS and airborne laser scanning measurements obtained with a flying height of 195 m over a flat terrain. The effect of flight height on the DTM was found by comparing the results of two strips over a flat terrain at two different heights 195m and 750m. This effect is found to be around 0.1 m.

The standard error is estimated at 0.03 m and 0.08 m for the heights 195 m and 750m respectively. The error variation is due to the variation of laser footprint diameter and number of laser points/m² at different heights. The effect of topography and vegetation have been tested on different types of terrain: (1) a flat terrain without vegetation, (2) a steep terrain without vegetation with a slope ranging from 20 to 45 degrees, and finally, (3) a steep terrain of the same slope, covered by vegetation. Table 2 gives the results obtained by the airborne laser system and rapid static GPS technique over the three types of terrain. The effect is found to be 0.11, 0.18, and 0.33 m for the first, second and third type of terrain respectively.

**Table 1  Difference in height between the rapid static GPS and the airborne laser scanning measurements obtained with a flying height of 195 m and 750m over a flat terrain**

<table>
<thead>
<tr>
<th>Point No.</th>
<th>Coordinates Obtained by Rapid Static GPS Technique</th>
<th>Coordinates Obtained by the Airborne Laser Scanner at 195m</th>
<th>Difference in Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northing  Easting  Height</td>
<td>Northing  Easting  Height  195m  750m</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4922247.406 498824.960 102.776</td>
<td>492247.29 498825.00 102.76</td>
<td>0.02 0.09</td>
</tr>
<tr>
<td></td>
<td>4922247.30 498824.82 102.81</td>
<td>4922247.43 498824.80 102.80</td>
<td>-0.03 0.05</td>
</tr>
<tr>
<td>2</td>
<td>4922214.584 498782.637 103.702</td>
<td>4922214.63 498782.86 103.74</td>
<td>-0.04 -0.04</td>
</tr>
<tr>
<td></td>
<td>4922214.43 498782.86 103.73</td>
<td>4922214.52 498782.19 103.73</td>
<td>-0.03 -0.09</td>
</tr>
</tbody>
</table>

**Table 2  Difference in height between the rapid static GPS and airborne laser scanning measurements due to different types of terrain**

<table>
<thead>
<tr>
<th>Terrain Type No.</th>
<th>Terrain Type</th>
<th>Difference in Height Between GPS and Laser Measurements for Three Points (m)</th>
<th>Standard Error (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flat</td>
<td>0.130 0.060 0.048</td>
<td>0.106</td>
</tr>
<tr>
<td>2</td>
<td>Steep without Vegetation</td>
<td>0.115 0.110 0.198</td>
<td>0.180</td>
</tr>
<tr>
<td>3</td>
<td>Steep with Vegetation</td>
<td>0.216 0.375 0.175</td>
<td>0.330</td>
</tr>
</tbody>
</table>
CONCLUSIONS

Throughout this study, the following points are concluded:

1. The accuracy of airborne laser scanning depends on many factors such as the GPS solution, flying height, topography and vegetation as demonstrated in our experiments. The accuracy of a DTM obtained by an airborne laser scanner could reach 0.1 m. This accuracy of 0.1 m is acceptable for many engineering projects and applications.

2. The Radio Frequency Interference problem could be decreased by using the last generation of GPS receivers, which have an efficient interference/jamming suppression system integrated into the GPS chip. The Trimble 4000s receiver was replaced by the Trimble 4700 after these experiments and the performance of the TopEye system was improved.

3. The installation of an internal Geodetic antenna inside the helicopter improved the reception of the GPS signal, especially when an interference problem with the GPS signal is encountered. The internal antenna is used now inside the helicopter cabinet after the validation of these experiments.

4. The usage of more than one reference station in processing the data is recommended for any survey mission, the distance between the rover and reference station should not exceed 20 km. The use of new softwares such as Bernese 5 helps much in processing the data from two stations simultaneously.

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