

Surveying of road slopes using mobile LiDAR

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Purpose The slope of roads is one of the most important elements to be monitored to prevent landslides and ensure the safety of vehicles. This fact is particularly relevant in areas such as Galicia (Spain), where, due to its orography, slopes always are a relevant factor in road construction projects. **Method** Typically, the slopes of the roads are visually monitored by road inspectors and only in case of important problems do they use measuring equipment (e.g. extensometer, inclinometer). The aim of this work is to introduce the routine use of mobile LiDAR systems for monitoring of slopes. **Results & Discussion** A filter based on the returns of the laser shot is used to remove vegetation of the slope and work only with ground level information. An algorithm that compares the slope surface between two different inspection periods was developed. This algorithm extracts the systematic error due to GPS and can display variations of a few centimeters.

Keywords: *automation, mobile LiDAR, road inspections, slope stability.*

INTRODUCTION

The slopes are common in most roads, especially in high-capacity roads that run through mountainous terrain. The slopes of a region present different behavior, depending the nature of the rocks and geometry. This different behavior sometimes results in landslides, an important problem in the Galician roads, relief quite rugged and varied morphology. Landslides decrease the safety of the existing structures (i.e. bridges, tunnels, overpasses, underpasses) and in some cases directly block the road and become critical to produce car accidents.

Road slopes are typically monitored using geophysics and geodetic measuring methods. Geodetic measuring methods use total stations, levels and static LiDAR. Although these techniques appear accurate and reliable, their productivity is low and the labor costs associated are very important. In the recent years, mobile LiDAR applications have irrupted in the market^{1,2}. These systems combine DGPS positioning and LiDAR measuring. In addition, in the areas with poor satellite coverage, GPS is aided with inertial navigation systems and distance measuring indicators. The combination of DGPS, INS and DMI data is done in post-processing using Kalman filtering algorithms³. Mobile LiDAR systems combine DGPS and LiDAR technology with RGB cameras to provide images of the scenes.

The productivity of mobile LiDAR systems is very high and they allow to measure between 100 – 200 km per journey with two surveyors (one driver and one LiDAR technician). Typically one day more is necessary to post-processing all the information and to obtain a geo-referenced point cloud and images. Mobile LiDAR systems are commonly installed in

cars or vans, although they can also be arranged in boats or trains. The information generated is completely compatible with that obtained from airborne LiDAR or conventional surveying.

One of the main application fields of mobile LiDAR is in road inspections. They provide a complete geo-referenced point cloud of the road that can be used to analyze geometric parameters (i. e. vertical and horizontal clearance, slope geometry, tunnel profiles, road sections).

Although this technology appears very promising, the raw information must be processed and adapted to the normalized parameters required by the road managers. Nowadays, this step is done manually by human operators, increases the labor cost of the process and decrease the operability of the system.

In this work, a semi-automatic procedure to determine the geometric condition of road slopes is developed. The algorithms use the different echoes of the LiDAR to perform automatic vegetation filtering and geo-referenced points to avoid the GPS drifts between different surveying.

METHODOLOGY

Area of study

The slope selected for this study was situated in the Campus of Vigo University, close to the School of Telecommunications Engineering, which is situated on a hilly place at the outskirts of the city of Vigo. Figure 1 shows the situation of the slope (RGB and point cloud image). It presents some vegetation and a height difference of about 4.5 m.



Fig. 1. Area of study (RGB and point cloud images)

Mobile LiDAR and data acquisition

Mobile LiDAR used in this study (Fig. 2) is the Optech Lynx system. The system integrates a navigation GPS/INS system from Applanix (POS 520 - 2 GPS antenna), 2 LiDAR scanners from Optech and 4 digital cameras from Jai (BB 500GE). The metric characteristics of the Lynx system are shown below:

- Maximum range: 200 m
- Range precision: 8 mm (1σ)
- Absolute accuracy: 5 cm (1σ)
- Scan frequency: 80 – 200 Hz
- Scanner field of view: 360°
- Laser measurement rate: 75 – 500 kHz



Fig. 2. Mobile LiDAR Optech Lynx.

Mobile LiDAR survey began and finished with the acquisition of 5 min of GPS data in an area with small PDOP (high GPS precision). The complete time of the survey was 12 min. Scanner and photographic data are only taken while the van is moving to avoid the excess of data. The synchronization of the data from the different sensors of the mobile unit is achieved using the time stamp and the PPS of the GPS/INS system. A total of 120 million of geometric points were acquired during the survey. The survey was repeated one week after to establish a comparison between the two surveying of the slope. The aim of this work is to develop a methodology for exact slope inspection, so we prefer to adopt a slope without any appreciable geometric change.

The data processing is performed using Applanix POSpac and Dashmap software. The first one corrects the GPS information using a RINEX file from a base station. In addition, combines, using a Kalman filter, the data from the GPS with those obtained from the inertial navigation system (INS) and distance measurement indicator (DMI). The corrected trajectory file exhibits a precision higher than 2 cm in X Y and higher than 4 cm in Z.

Dashmap combines the range and angle information obtained from the Optech scanners with the trajectory information from PosPAC. The point cloud obtained will be managed using the QT Modeler software⁴ in addition to Matlab and AutoCAD software.

Point cloud classification and filtering

QT Modeler software (Applied Imagery) is used to the classification of the point cloud in function of the

number of returns, the light echoes that achieve the scanner detector (Figure 3). Optech system allows the detection of four echoes per geometric point.

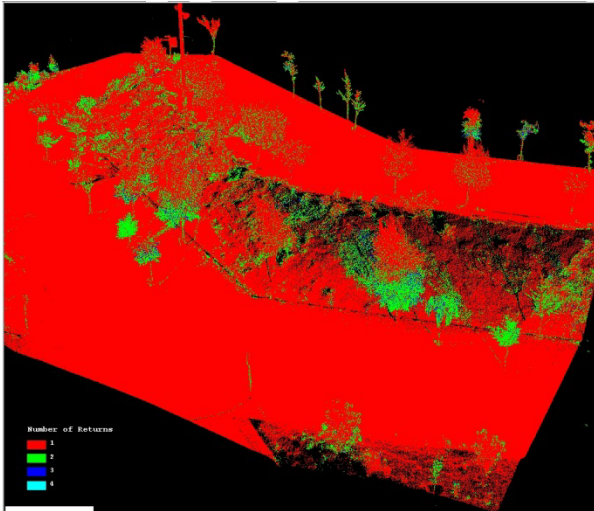


Fig.3. Point cloud classification by laser returns.

Results show that vegetation areas depict typically two echoes (green points in Figure 3). The filter applied to automatically remove the vegetation consists on saving only the last return from the laser and remove the other returns. Figure 4 depicts the point cloud after the vegetation filtering. All the vegetation was perfectly removed. In addition, it was also necessary the removal of the tree trunks. This removal process was manually performed using the selection and cut toolbox of QT Modeler.

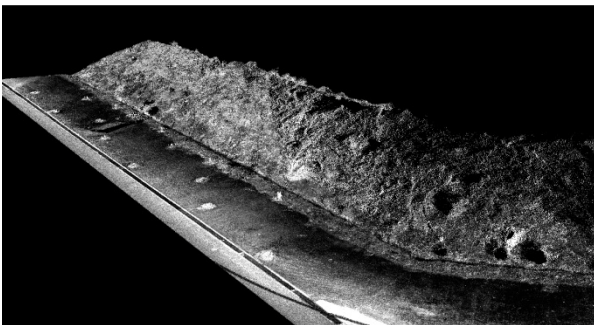


Fig.4. Point cloud after vegetation filtering.

Although the DGPS provides accurate positioning of the geo-referenced point cloud it is important to avoid possible GPS drifts to guarantee accurate measurements. In this work, some control points were used in both surveying to geo-reference both measurements in the same coordinate system (Figure 5). QT Modeler is used for the geo-referencing of the two surveying. Natural landmarks were used as control points to make the procedure more productive and easy to implement. Horizontal signage is very adequate for this purpose because the different light reflective provide clear marking points for the QT Modeler software.

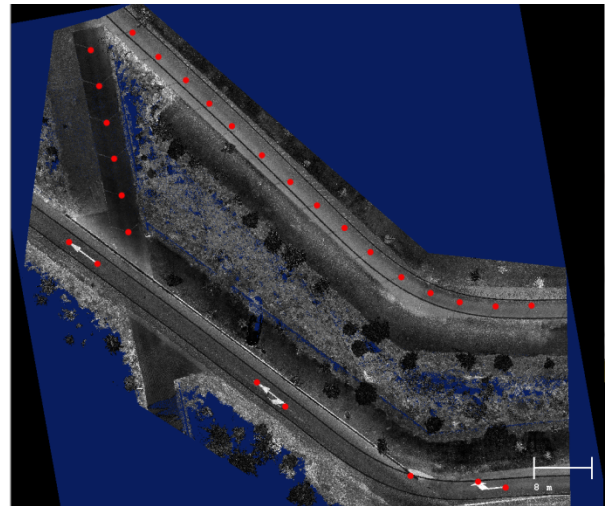


Fig.5. Control points used for the geo-referencing of the surveying.

RESULTS AND DISCUSSION

Figure 6 shows the slope point cloud visualized using Matlab software. Previously, the LiDAR point cloud in las format is exported to ascii - xyz code and imported in Matlab.

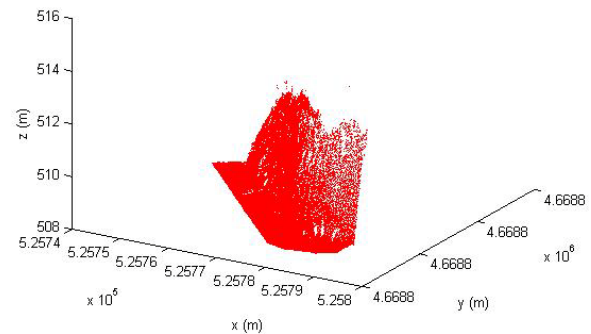


Fig.6. Point cloud visualization in Matlab software.

The point clouds of both surveying were extracted one from each other to estimate the geometric differences between them and prevent the detection of possible landslides. In this case, there is no evidence of any damage in the slope (Figure 7). The result is quantified using a Normal distribution (Figure 8). The average of the Normal distribution is related with the accuracy of the method and the standard deviation with the precision, because the slope geometry remains stable during the both surveying⁵. Accuracy of the procedure is 6.4 mm and precision (1σ) is 34 mm, which seems enough to study landslides in future researches. In addition the good fitting of the data to a Normal distribution also confirms the good quality of the results

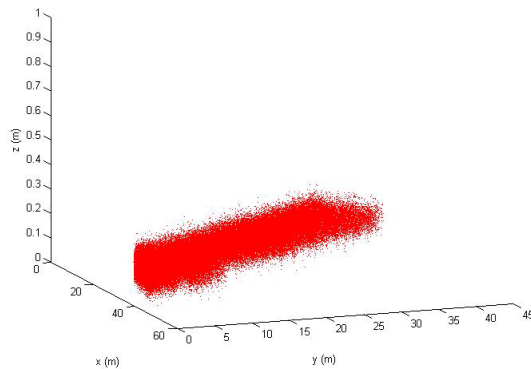


Fig.7. Subtraction of point from surveying one to surveying two.

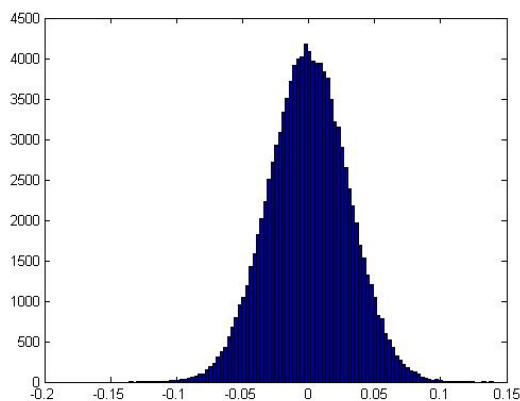


Fig.8. Normal distribution fitting.

CONCLUSIONS

LiDAR mobile appears a productive surveying technology to obtain geometric characteristics in road inspection programs.

Filtering using LiDAR returns can automate the removal of vegetation and accelerate the processing of the point cloud.

Geo-referencing of point clouds from different surveying allows the comparison of the condition state of road slopes to determinate the risks associated to their stability. Horizontal signage is used as landmarks and simplify the data acquisition process.

Acknowledgements

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