Suitability Testing of LiDAR Processing Software Aimed at 3-D Sight Distance Estimations

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ABSTRACT

Sight distance estimations are significant components of road safety analyses. Drivers ought to have enough available sight distance (ASD) in order to safely perform basic driving maneuvers. When not performed in situ, estimating ASD on existing roads normally requires up-to-date representations of the roads' geometric properties as well as the execution of roadway design related tasks and geospatial analysis operations; hence, several software products are needed to carry out these calculations throughout their entire workflow. Nowadays, LiDAR based Mobile Mapping Systems (MMS) have been intensively put into use to gather data needed to accomplish many transportation applications. In spite of their many benefits, MMS produce fair volumes of point cloud data which add some complexity to the processing stage in terms of software, computational requirements and interoperability. This paper analyses software capabilities, in terms of suitability and performance, of computer programs capable of LiDAR data processing tasks. The main goal of this evaluation is to gauge their aptness to deliver data needed to perform ASD estimations. To accomplish this, a thorough review of available literature on sight distance analyses was conducted to get a depiction of frequently demanded software tasks and deliverables and based on that, different volumes of point cloud were processed with a variety of software solutions in order to test their appropriateness for the purpose from early stages of the workflow to final calculations. This research highlights how the truly potential of LiDAR data for performing highway safety related analyses relies heavily upon the usage of efficient and powerful software tools.

1. INTRODUCTION

Available sight distance (ASD) is defined as the length of roadway ahead visible to the driver; it is an inherent feature to each point of the road and is reliant on the roadway's design speed. Insufficiency of sight distance can adversely affect the operations of a highway and its overall safety, consequently Departments of Transportations (DOTs) from different countries have defined minimum distance values for distinct maneuvers (AASHTO, 2011; Ministerio de Fomento, 2016); the available sight distance, ought to be checked against these required values. These comparisons are necessary not only during the design stage, where they represent a key factor throughout the overall process, but also on existing roads given the dynamic nature of the road surroundings. Traditionally, sight distance has been evaluated two-dimensionally (considering horizontal and vertical alignment separately), albeit many researchers have pointed out the disadvantages of this approach, especially the fact that it leaves out the effects that certain alignment combinations and external elements might have on the results. When performed on existing roads, and not in situ, estimating ASD initially requires, three-dimensional representations of the road and its environment. Photogrammetry and remote sensing, mainly satellite and aircraft-based, have been customarily used to extract roadway layout information and lately, due to its rapid deployment, decreasing costs and productivity, LiDAR based, and image based Mobile Mapping Systems (MMS). Despite being a powerful 3D surveying and mapping technology, their deliverables add some complexity to the processing stage and product generation due to the great amount of information collected and its characteristics; consequently, most processing workflows comprising LiDAR-derived data require the use of several software packages and fundamental geomatics knowledge (Olsen *et al*. 2013).

The foremost objective of this paper is to evaluate the ability of distinct software suits and applications to provide specific functionalities needed to perform ASD estimations on existing roads utilizing LiDAR data from MMS. This reading is organized as follows: the first section presents a brief overview of some related work and considerations pertaining ASD calculations; the second part shows main criteria for preliminary software selection, subsequently the description of the methodology, study case, and results are presented; finally, conclusions are discussed.

2. BACKGROUND

Among the authors utilizing LiDAR derived data for ASD estimations, some favor the use of filtered and segmented point clouds to perform ASD calculations directly on them (Campoy Ungria, 2015; González-Jorge, Díaz-Vilariño, Lorenzo, & Arias, 2016) while others utilize LiDAR derived 3D models in both raster and vector formats (Castro, Anta, Iglesias, & Sánchez, 2014; Castro, Iglesias, Sánchez, & Ambrosio, 2011; Gargoum, El-Basyouny, Sabbagh, 2017). These models have to be simplified enough to allow the processing of representative sections of the road, but also their completeness and approximation to reality should allow accurate measurements to be carried out. Typically, Digital Terrain Models (DTM´s) are used to represent part of the road's geometric definition but since they are a bare terrain representation, they leave behind roadside features (de Santos-Berbel, Castro, Medina, & Paréns-González, 2014). Digital Surface Models (DSMs), on the other hand, include information about the vegetation, edifications, and other relevant elements. In this respect, as many authors have documented, utilizing DSM's yields inaccurate results when some elements overhang roadway areas (cantilevered signs, tree branches), in the presence of compound surfaces defined by exterior and interior boundaries, (crash barriers and larger size road signs) among other complex above ground features (Campoy Ungria, 2015; Iglesias Martinez, Castro, Pascual, & de Santos-Berbel, 2016; Jung, Olsen, Hurwitz, Kashani, & Buker, 2018; Khattak & Shamayleh, 2005). The reason is that some data structures used to store these models are mathematically-defined continuous surfaces where only one elevation is allowed for given x & y position. Consequently, Iglesias *et al.* (2016) proposed the use of 3-D objects to represent road obstructions in addition to the DTM's. Other authors overcame this matter dividing the 3D space into voxels, (cubic volume pixels) used to represent the road environment and roadway alignment (Olsen, Hurwitz, Kashani, & Buker, 2016). With respect to specific methods utilized to measure the driver´s sightline, most researchers, utilize viewshed analyses or line-of-sight alike algorithms developed by the authors or exploiting Geographic Information Systems (GIS) tools, and were deployed as standalone applications, or software extensions (Castro, Iglesias, Sanchez & Ambrosio, 2011) each considering a different set of relevant factors.

When it comes to related work on analyzing LiDAR software, latest studies have been mainly focused on proposing solutions aimed at the management of very large LiDAR datasets (Cura & Perret, 2017), overviewing current packages (Fernandez, Singhania, Caceres, Slatton, Starek & Kumar, 2007), comparison and proposal of filtering algorithms for specific applications, among others. Concerning civil engineering applications, Varela-González *et al.* (2013) developed a methodology for the evaluation of different LiDAR software based on their performance; six different suites were selected based on their usefulness to execute civil engineering and surveying related tasks. Their results showed useful insights in terms of performance and capabilities.

3. SOFTWARE CONSIDERATIONS

LiDAR derived point clouds collected using MMS and intended for geospatial representation are normally visualized, manipulated and processed using mapping, geospatial data processing, land surveying, Computer-Aided Design (CAD), and GIS software. Additionally, among the vast amount of software with LiDAR functionalities available in the market, computer programs and applications considered for this research were those aimed at, or useful to carry out civil engineering analyses, more specifically those suitable for transportation applications and those capable of performing basic GIS tasks. Consequently, widespread LiDAR exploitation software together with broadly used geospatial, GIS, and highway design software with wide-ranging LiDAR processing functionalities, were initially taken into account. A preliminary selection process was carried out among those originally considered, pondering the following factors and their possible range of estimates: data-type interoperability, maximum point cloud size that could be handled, Coordinate Reference System (CRS) functionalities and basic spatial analysis capabilities. Taking this into account along with software's purpose and skills required to operate them, the suits selected to be analyzed and compared for this research were: 3DReshaper, AutoCAD Civil 3D, Carlson Point Cloud, Global Mapper, MARS, MDTopX, and Orbit 3DM. A brief description of their main purposes and characteristics are provided in Table 1:

Name	Developer	Category	Main purpose	Version
3DReshaper	Technodigit	Stand-alone desktop	Point Cloud Processing	2017/17.1.24963.0
Carlson Point Cloud	Carlson Software	CAD extension (used in AutoCAD Civil 3D)	Point Cloud Processing	2018
AutoCAD Civil 3D	Autodesk	CAD	Civil engineering projects	2015/ J.141.0.0
Global Mapper	Blue Marble Geographics	GIS	Geospatial data exploitation	2016/ 18.0.0
LAStools	Rapidlasso GmbH	Command line tools	LiDAR processing	170419
MARS	Merrick	Stand-alone desktop	Point Cloud Processing	2017.2
MDTopX	Digi21	Stand-alone desktop	Digital terrain Models Processing	2017/ 7, 31, 07, 0
Orbit Feature Extraction Standard	Orbit Geospatial Technologies	Stand-alone desktop	LiDAR, Imagery and DSM data exploitation	2017/ 18.0.0

Table 1. Software under consideration and their main characteristics.

4. MATERIALS AND METHODS

Two road sections were used for testing purposes, both positioned in rural settings. The first section is part of the M-607 highway (Madrid) located between the kilometers twenty-seven and thirty-one. This segment was considered mainly due to its horizontal alignment and roadside features. The mobile LiDAR system utilized to cover this section was the IPS-3 from Topcon Positioning (Topcon Positioning Systems, 2015). The second segment is part of the two-lane rural road M-633 between the first and third kilometer markers. The section was mapped with the IPS-2 MMS also from Topcon Positioning (Topcon Positioning Systems, 2010). This point cloud contained 4 million points. The preprocessing steps, required to generate the point clouds after the data collection process, were carried out using software provided by the Mobile LiDAR System (MLS) vendor and both point clouds were derived without gross errors, holding traffic noise and without CRS information.

In order to compare software, three evaluations were carried out:

- Suitability test, comparing the number of tasks required to those completed and their main characteristics.
- Efficiency test, focusing on software behavior and capacity.

- Statistical analysis of the results obtained from the execution of ASD calculations utilizing these programs' outputs.

With regards to the suitability testing, the required tasks along with their evaluation criteria are itemized as follows:

1. Data import and export: In addition to assess their capability to read and write LiDAR in widespread formats, the capability of combining dissimilar formats and allow the import of reference or auxiliary information was gauged.
2. Point cloud decimation options: Reduction of redundant points, point decimation, thinning and down sampling are processes intended to reduce the point size following a determined criterion. The capability of performing these operations were verified along with the criteria offered to perform it.
3. Noise Removal: The removal of unwanted points and surface regeneration is frequently performed manually or semi-automatically, hence a tool to perform these functions with higher levels of automation were sought.
4. Filtering and classification: This study evaluated two aspects related to classification functionalities; first, variety of classification/filtering tools provided, and second key parameters required from the user to adapt/improve the performance of the algorithm.
5. Modelling: Modelling functionalities and output formats were evaluated.
6. Feature extraction: As it has been stressed, given that DTMs do not account for elements in the roadside, it is of great use to be able to automatically extract roadside features and store them in a separate file either to perform ASD analyses or to evaluate the possible impact that their removal could have in the overall road visibility.

Regarding the efficiency testing, in addition to data loading and task execution timing, the time behavior when utilizing these programs simultaneously with other software in distinct setups was verified. For this purpose, three scenarios have been predefined, scenario zero where the action is performed loading only the considered software; scenario one, where a text editor program is being run simultaneously, and scenario two where a CAD software is being used concurrently. It was also assessed whether the user received messages of excessive memory consumption or unresponsiveness in a tolerable time. The capacity was measured testing whether a 240 million point cloud, could be loaded.

The computer utilized during the testing was a Toshiba SATELLITE P850, with the following specifications:

- Control processing unit Intel Core TM i7–3610 QMCPU@ 2.3 GHz.
- Installed memory (RAM): 16GB.
- Graphic card: Intel HD Graphics 4000
- Disk Drive: Standard disk drive TOSHIBA MQ01ABD100 with 1Terabyte storage capacity of which 368 were available.

- File system: NTFS;
- Operative system: Windows 7 Home Premium 64 bit

5. RESULTS AND DISCUSSION

The main findings of the suitability testing are presented in the same order tasks were listed. To start with, relating to the import/export capabilities, Global Mapper resulted the one allowing a larger number of I/O LiDAR file formats. Other programs not evaluated but initially considered and with an impressive number of supported formats were Cloud Compare and FME. Despite the fact that most available point cloud files are stored in the *.las format, it is of great use to be able to import LiDAR data from plain text and other widespread formats as well as export them, hence it was also evaluated their capability to load ASCII formats. All software tested were able to read or write plain text formats. It was also assessed whether they could import reference information from distinct sources; connect to Web Map Services (WMS), add aerial imagery or download georeferenced online imagery. All software tested were able to import georeferenced imagery in commonly available formats, except from 3DReshaper; WMS were supported by Global Mapper, AutoCAD Civil 3D, OrbitGT, MARS and MDTopX; download online imagery or maps was supported by Global Mapper and AutoCAD Civil 3D. The addition of polylines was supported by all software tested either stored in plain text, GIS or CAD formats. Given that LAStools was used directly on the command line, its integration capabilities were not verified.

Point decimation capabilities are mainly intended to speed-up the functionalities of the software and enhance performance by providing a way of reducing the total amount of points from the cloud. This can be accomplished utilizing a wide range of options, either making use of clever and standard down-sampling options, tiling the data or selecting an area of interest (AOI). 3DReshaper, MARS, Carlson Point Cloud, MDTopX, Global Mapper and LAStools offered standard down sampling options, either based on a stated number of points to maintain, selecting the n^{th} element to be kept or specifying a maximum distance from points to be kept, each showing different levels of straightforwardness; MARS, Carlson Point Cloud, LAStools and Global Mapper provided the easiest AOI selection. Tailored decimation functionalities were partially provided by LAStools, Carlson Point Cloud and the initially considered software FUSION.

Concerning noise removal, MDTopX, Global Mapper, Carlson Point Cloud, LAStools and 3DReshaper were the ones offering noise-aimed tools and showed the most automated and straightforward options. Most of these options sought isolated points within a specified distance. Respecting the removal of vehicles, MDTopX and Orbit showed the easiest workflows, but none had specific traffic removal tools.

Manual and automated filtering and classification tasks were analyzed and resumed in Table 2. Only noise and ground automatic classifications were carried out. Global Mapper, MDTopX, Carlson Point Cloud, LAStools, and 3DReshaper required the less interaction from the user while performing their automatic ground filtering tools. MARS topped the number of algorithms offered with 31 each considering distinct criteria, but their level of automation was very low provided that they do not yet have a single-filter ground extraction. Following a higher number of algorithms offered is MDTopX with eleven; its distinct tools exploited the geometry information in combination with other parameters, providing a wide range of options to choose from. Results from 3DReshaper had important omission errors, where ground points were classified as non-ground points, while using the default options, but inspecting the elevation range of the data and selecting a more appropriate slope parameter, reduced the errors considerably. Global Mapper uses statistical curvature bin sizes and minimum height above local mean as threshold values; in their selection it is of great use the elevation histogram showed in the LiDAR file metadata tool. Selecting appropriate values for the considered dataset resulted in a ground cloud with mostly commission errors, where non-ground points were considered as ground. Software considered but not showed in Table 2, lacked classification capabilities. In addition to their parameters and performance, their scripting options were checked as well, given that some processing and analysis operations exceed the functionalities offered, and require custom programmed functions or pipelines.

Software	Parameters required	Scripting options
3DReshaper	Terrain Type	✓
Carlson Point Cloud	Varies depending on the method selected (Grid or Profile)	-
FUSION	Cell size	✓
Global Mapper	Curvature deviations, Height departure from local mean, distinctive parameter information and extern files	✓
LAStools	Terrain Type, granularity	✓
MARS	Varies depending on the algorithm selected	✓
MDTopX	Terrain Type, distinct parameter information and extern files	✓

Table 2. Ground filtering algorithms assessed and their key parameters.

Modeling options were assessed generating a DTM after the classification with those points considered to be ground. Models were generated using 3DReshaper, Global Mapper, LAStools, Carlson Point Cloud and MDTopX. These software suits are capable of generating DTM’s in widespread CAD and GIS formats.

In addition to road and roadside modelling, the automatic extraction of a wide variety of data from both, ground (road boundaries, pavement conditions, road markings, sidewalks, curbs) and above ground features (poles, traffic signs, urban furniture, vegetation) have been for some time, an area of active research. In this evaluation, Global Mapper, Carlson Point Cloud, Orbit 3DM and MDTopX were the ones capable of exporting possible visual obstructions as 3D features in the desired formats. Orbit 3DM excelled with their automatic ridge, corner and surface recognition and its automatic pole and traffic sign detection and extraction functionalities. MDTopX also allowed the automatic export of roadside features to 3D files with associated attributes.

On the point of efficiency, loading timing was measured and showed in figures 1 to 3. Initial loadings were performed three times for each point cloud size, and for each scenario, and their mean values were the ones displayed. As seen, MARS showed the best performance with AutoCAD civil 3D taking the longest to load the datasets.

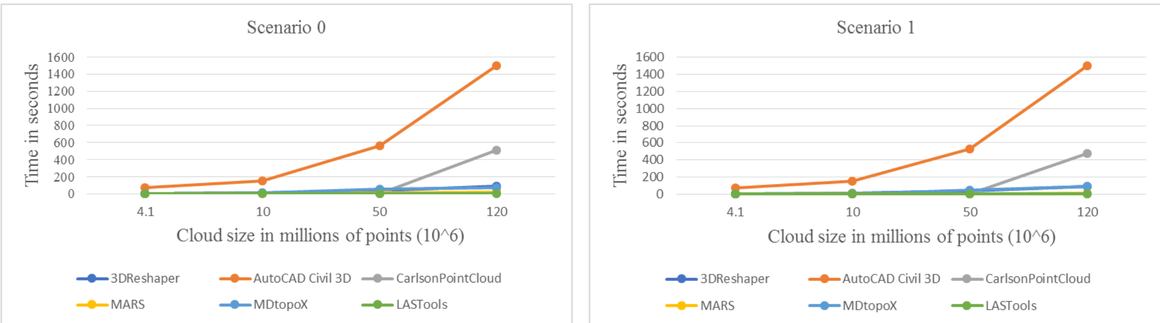

Fig. 1 –Loading time for scenarios 0 and 1.

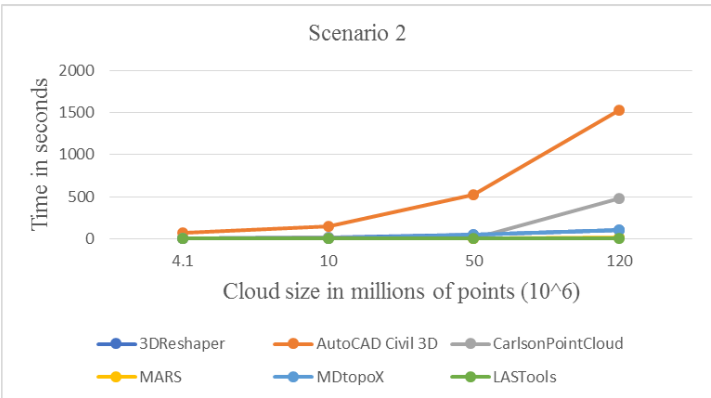

Fig. 2 –Loading time for scenario 2.

As shown, distinct scenarios did not show remarkable differences among themselves. The importance of this assessment relies on the fact that hardly ever working stations are committed to one software or task, in this sense is important to know by how much the final goal could be elongated due to the performance of concurrent tasks. Only the suites presented were considered for the performance test. 3DReshaper resulted the most informative in terms of memory consumption messages, followed by Global Mapper. Task timing is presented and compared in figure 3. As shown, the task that comprised more time was the ground filtering with a mean among software of 3.24 minutes. The noise removal mean was found to be of 8 minutes nonetheless this was due to the 40 MDTopX lasted. Considering the size of the point cloud and road section length these results would not necessarily allow a relatively fast processing of entire road networks. 3DReshaper and Global Mapper were the ones informing the user about the memory consumption while executing these tasks. All software were able to load the 240 million point cloud except from MDTopX who closed unexpectedly in the attempts.

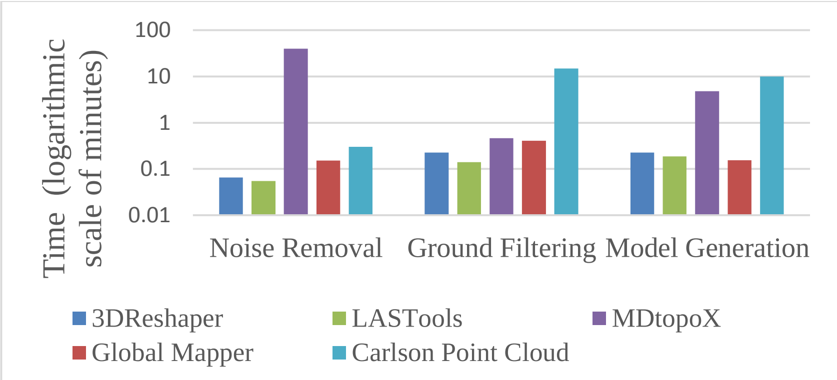

Fig. 3 –Task timing. Global Mapper tasks were carried out in a different workstation hence its information has a representative purpose rather than comparative.

On the subject of sight distance results' comparison, only the DTM´S generated with data from MDTopX, Carlson Point Cloud, 3DReshaper, Global Mapper and LAStools were used to perform calculations, given that the other software either did not export their models in GIS formats or did not perform modelling tasks. The estimations were carried out using specific software in the ArcGIS environment developed by the authors (Castro *et al.* 2014). The height of the driver's eye above its virtual trajectory was chosen to be 1.1 m, whilst the height of the target object on the roadway was 0.5 m, as stipulated in the Spanish geometric design standards (Ministerio de Fomento, 2016). After performing the calculations, a comparative analysis was carried out to verify whether it was a significant difference among them. The test performed was a Mann–Whitney–Wilcoxon in pairs of two. This test evaluates the differences between observations taking into account their sign and magnitude. Most tests returned P-values higher than 0.05, hence was concluded that significant differences do not exist between the obtained results, except from the comparison between MDTopX and Global Mapper and Carlson Point Cloud and 3DReshaper.

6. CONCLUSIONS

The suitability testing highlighted that most of the set of common tasks required to deliver useful data to estimate ASD are provided by current software solutions. The main reason is that several uses of point clouds require the same preliminary steps. Additionally, given that MMS are being importantly utilized for transportation applications, which traditionally store in-service road assets in GIS and CAD formats, most LiDAR outputs can be integrated with or exported in widespread formats. The import and export revision underlined how the majority of programs available in the market utilize the public format *.las as their native working format, and cases where other formats are held, the export to *.las option is a must in order to ensure interoperability. The many options provided so as to add reference information also emphasized how overlaying reference information into the point cloud allows a better inspection of the AOI, permits to gain a better understanding of the data and facilitates a quick assessment of their quality properties. The noise removal, filtering and classification tasks evidenced Global Mapper, 3DReshaper and MDTopX as the programs requiring less interaction from the user. This enables operators with limited LiDAR knowledge to be able to efficiently complete distinct workflows with their datasets. MARS on the other hand, despite showing a wide range of filtering and inspection options required more interaction and knowledge from the users. Regarding the extraction functionalities, Orbit 3DM outdid having amazing asset inventory functionalities, however since is not intended for modelling GIS objects it could not be used through the entire workflow. On the subject of their performance and loading times it was evidenced the great improvement in all programs in terms of the maximum amount of points that could be loaded, as well as the loading time compared to their functioning in previous years. On this regard, AutoCAD civil 3D reflected the worst loading and executing times. Lastly, the sight distance analysis performed utilizing their delivered 3D data did not evidenced significant differences among four suits utilized. As future lines of research, authors plan to apply this software evaluation to road sections with potential visual hindrances overhanging the roadway. Additionally, it could be useful to assess these software deliverables accuracy and compare their resulting classifications with a ground truth classified dataset.

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