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Automatic extraction of highway light poles and towers from mobile LiDAR data

Wai Yeung Yan [a,*], Salem Morsy [a], Ahmed Shaker [a], Mark Tulloch [b]

[a] Department of Civil Engineering, Ryerson University, Toronto, Ontario, Canada
[b] Tulloch Engineering, Huntsville, Ontario, Canada

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ABSTRACT

Mobile LiDAR has been recently demonstrated as a viable technique for pole-like object detection and classification. Despite that a desirable accuracy (around 80%) has been reported in the existing studies, majority of them were presented in the street level with relatively flat ground and very few of them addressed how to extract the entire pole structure from the ground or curb surface. Therefore, this paper attempts to fill the research gap by presenting a workflow for automatic extraction of light poles and towers from mobile LiDAR data point cloud, with a particular focus on municipal highway. The data processing workflow includes (1) an automatic ground filtering mechanism to separate aboveground and ground features, (2) an unsupervised clustering algorithm to cluster the aboveground data point cloud, (3) a set of decision rules to identify and classify potential light poles and towers, and (4) a least-squares circle fitting algorithm to fit the circular pole structure so as to remove the ground points. The workflow was tested with a set of mobile LiDAR data collected for a section of highway 401 located in Toronto, Ontario, Canada. The results showed that the proposed method can achieve an over 91% of detection rate for five types of light poles and towers along the study area.

1. Introduction

One of the challenging tasks for regional and municipal transportation authorities is to maintain and update the latest 3D highway/road inventory. Such a need not only serves the purpose of asset management, but most importantly addresses roadway safety concerns. Existing highway infrastructures are mostly archived with 2D drawings that lack the capability for 3D interpretation and advanced analysis. Various methods, such as field surveying, photo/video log, integrated GPS/GIS mapping system, aerial/satellite remote sensing and mobile LiDAR, are currently being used for highway/road inventory data collection. Jalayer et al. [9] addressed that mobile LiDAR can fulfill the requirement of highway inventory data collection with the highest data quality and completeness among the aforementioned techniques; however, it is recommended to share the data collection and processing tasks by multiple clients so as to reduce the costs. Mobile LiDAR has been introduced for various highway/road inventory data collection tasks, including horizontal alignments [7], road markings [25,6], road edges [10], overpasses [5], manholes and sewer well covers [27], zebra crossings [17], urban objects [24], and lighting system.

Knowing the 3D structure and physical location of lighting utilities can aid in infrastructure impact analysis. For instance, in order to design new location of high voltage transmission lines, it is necessary to provide certain level of horizontal and vertical clearances between the transmission towers and nearby lighting infrastructure. In addition, these utilities might impact the surrounding areas; hence, if an aviation landing is allowed in the nearby areas, an obstruction analysis should be performed in order to assess the potential hazard to the aircrafts [20]. As a result, there emerge a number of researches using mobile LiDAR to extract vertical pole-like features along roads and highways. Lehtomäki et al. [11] proposed a set of segmentation and clustering algorithms to extract vertical pole-like features for a 450-m long straight stretch of road. The proposed method claimed to detect 77.7% of poles with a 81% correctness of detection. El-Halawany and Lichti [3] proposed a five-step processing workflow including structuring data into K-D tree, 2D density based segmentation, vertical region growing, segment merging and pole classification. Yokoyama et al. [26] proposed similar workflow by using both shape and contextual features to detect and classify utility poles, lamp posts and street signs. Both studies achieved an over 80% accuracy in terms of detection and classification rate. Puente et al. [16] presented an interesting study on how to use mobile LiDAR data to detect road tunnel luminaires through putting threshold

* Corresponding author.
E-mail address: waiyeung.yan@ryerson.ca (W.Y. Yan).

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values of LiDAR height and intensity data.

Despite these attempts, there still exist certain limitations that require further research effort. Firstly, several studies reported the use of mobile LiDAR data to extract light poles; however, supplementary data such as trajectory data [28] or road centerline [15] are required in their proposed methods. Secondly, most of the existing studies presented the mobile LiDAR data collected at street level where the road surface is relatively flat [11,26,3]. Municipal highways, such as the one presented in this paper, usually have notable variation in the height profile where existing methods may not be applicable. Lastly, though a variety of road/light poles can be detected and classified as reported in these studies, very few of them addressed how to entirely extract the pole structure from the ground or curb surface. Therefore, this study aims to develop a comprehensive workflow to detect and extract different types of highway light poles/towers from raw mobile LiDAR data, by first performing ground filtering and height normalization, clustering the aboveground data point cloud, building a set of decision rules to classify the clustered point cloud, and extracting the entire pole structure from the base of the point cloud so as to store them into GIS database.

2. Study area and dataset

The study area (43°45′56″N and 79°22′03″W) is located along the highway 401, which is one of the busiest express highways in terms of traffic volume in Toronto, Ontario, Canada. The survey extent is bounded by the exit of Bayview Avenue to the west and the exit of Don Mills Road to the east. Data collection was conducted by the surveying team of Tulloch Engineering on September 11th, 2014 between 10:45 p.m. and 2:40 a.m., where the Ministry of Transportation – Ontario (MTO) approved the highway closure to facilitate the surveying mission. The exact survey extent is shown in Fig. 1, where the south part of the highway 401 with two corridors (in total of seven lanes) was surveyed by the Tulloch's mobile mapping system (MMS), resulting in a longitudinal distance of 1.94 km. Part of the circular ramp connecting to the exit of Leslie Street was also covered by the LiDAR scans.

The mobile LiDAR data was collected by Tulloch's MMS that equips with a RIEGL VMX-250 mounted on a 2011 Nissan Pathfinder. The study area was surveyed with a driving speed at approximately 80 km/h with at least two passes in each lane, where these two sets of data are completely overlapped in the study area with an average point density of 3000 pts/m^2. A primary control station was set up with a Sokkia GRX1 GNSS receiver (see Fig. 1 for the location), and a minimum of 7 GPS satellites and a PDOP less than 3 were recorded during LiDAR data survey. A total of 18 points stamped with a PK nail and washer at the point of a painted chevron were placed at an approximately 250-m interval on the paved shoulder across the project area and tied to the primary control for use as validation checks and registration points (see Fig. 2). Table 1 summarizes the overall registration error (in vertical direction) of mobile LiDAR data with reference to these registration points.

The entire LiDAR dataset includes 36 files: 18 files were collected by the first scan and the rest were collected by the second scan. The LiDAR data files were stored in *las* file format version 1.3. The data were collected with reference to the coordinate system of MTM NAD83 Zone 10, which is commonly used by the MTO for the Greater Toronto Area. All the 36 *las* files occupy a file size of 4.09 GB resulting in a total number of 156 million points. The elevation change found in the LiDAR data ranges from 124.245 m to 202.762 m.

3. Methodology

3.1. Overall workflow

Fig. 3 illustrates the overall workflow for extracting highway light towers and poles from mobile LiDAR data. All the 36 *las* files were combined and then splitted into 28 regular square grids for structured data processing. A ground filtering algorithm was first implemented to separate the aboveground and ground features based on the measurement of slope changes in each LiDAR point with respect to its neighboring points. The separated point cloud data were used to generate a digital elevation model (DEM) so that the height value of all the aboveground features can be normalized with reference to the DEM. These height-normalized point cloud data underwent an unsupervised clustering algorithm, named density-based spatial clustering of applications with noise (DBSCAN) [4], to group the point cloud data into clusters.

With reference to the existing highway lighting specification/manual [1], a set of decision rules can be built and these rules were used to classify the clusters as light towers, poles or other road features. Though the ground filtering algorithm was implemented in the early stage, the extracted towers and poles were inevitably associated with certain ground surface data points. Thus, the final stage included a data cleaning process that utilized a least-squares circle fitting mechanism to identify the circular pole and to remove the ground points from the pole structure. Finally, the extracted and cleaned light poles and towers were stored in ArcGIS file geodatabase for manipulation and visualization.

3.2. Data processing

The entire data processing was implemented based on several software tools and open source libraries. The *lastools* was used to convert the *las* data files into ASCII data file format. Although we

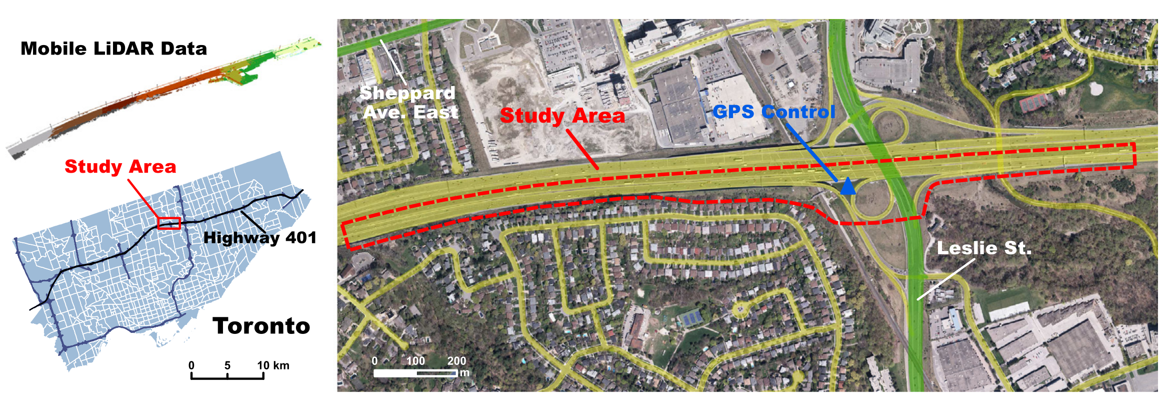

Fig. 1. The study area and the extent of the mobile LiDAR survey.