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An algorithm for automatic detection of pole-like street furniture objects from Mobile Laser Scanner point clouds

C. Cabo [a,*], C. Ordoñez [a], S. García-Cortés [a], J. Martínez [b]

[a] Department of Mining Exploitation, University of Oviedo, 33004 Oviedo, Spain
[b] Department of Natural Resources and Environmental Engineering, University of Vigo, 36310 Vigo, Spain

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ABSTRACT

An algorithm for automatic extraction of pole-like street furniture objects using Mobile Laser Scanner data was developed and tested. The method consists in an initial simplification of the point cloud based on the regular voxelization of the space. The original point cloud is spatially discretized and a version of the point cloud whose amount of data represents 20–30% of the total is created. All the processes are carried out with the reduced version of the data, but the original point cloud is always accessible without any information loss, as each point is linked to its voxel. All the horizontal sections of the voxelized point cloud are analyzed and segmented separately. The two-dimensional fragments compatible with a section of a target pole are selected and grouped. Finally, the three-dimensional voxel representation of the detected pole-like objects is identified and the points from the original point cloud belonging to each pole-like object are extracted.

The algorithm can be used with data from any Mobile Laser Scanning system, as it transforms the original point cloud and fits it into a regular grid, thus avoiding irregularities produced due to point density differences within the point cloud.

The algorithm was tested in four test sites with different slopes and street shapes and features. All the target pole-like objects were detected, with the only exception of those severely occluded by large objects and some others which were either attached or too close to certain features.

1. Introduction

Accurate urban cartography is being increasingly demanded for several purposes in city management (Sahin et al., 2012; Gröger and Plümer, 2012; Shi et al., 2008). Three-dimensional models are now widely used for street and traffic control (Buch et al., 2008; Ranzinger and Gleixner, 1997), where the identification and accurate determination of the location and shape of certain street furniture elements is crucial. The presence of elements such as traffic lights, traffic signs, lampposts, utility poles or street trees has a huge impact on street and road planning, safety and maintenance, as they have a critical role in the general city management and in the road and street visibility studies for traffic management purposes (Escalera et al., 2010). In addition, the presence of aforementioned objects is used and needed for vehicle and pedestrian navigation and for driver assistance (Zin et al., 2007). Most of these street furniture objects either contain a pole or are entirely shaped like a pole. For instance, lampposts are often pole-like objects (i.e. shaped like a pole), traffic lights are usually placed in a pole-like structure and street trees often have a pole-like trunk.

Three-dimensional city mapping has been carried out in the last two decades using several methods in order to achieve accurate spatial models of the volumetric elements present in urban environments (Frueh and Zakhor, 2003; Haala and Brenner, 1999; Holopainen et al., 2011; Zhou and Neumann, 2013). Surveying, photogrammetry and remote sensing have been widely used, but the emergence and popularization of LiDAR technologies have produced a wide range of new techniques and applications (Gonzalez-Aguilera et al., 2013). The LiDAR technologies most commonly used for urban mapping can be divided in: (i) Airborne Laser Scanning (ALS), (ii) Terrestrial Laser Scanner Systems (TLS) and (iii) Mobile Laser Scanning (MLS) Systems.

Airborne Laser Scanning (ALS) has been used since the early 1990s. This method produces an adequate point density for the extraction of large urban features (i.e. building footprints or vehicles), but is often not enough for smaller or vertical elements. Moreover, the scanning angle does not allow the adequate measurement of points on vertical surfaces (Boulaassal et al., 2007). Terrestrial Laser Scanner Systems (TLS) are able to provide a much higher point density and do not have the angle limitation for

* Corresponding author. Tel.: +34 696333979.
E-mail addresses: carloscabo.uniovi@gmail.com, carloscabogomez@hotmail.com (C. Cabo).

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vertical objects detection that the ALS has. However, measurements from TLS are usually affected by occlusions in urban environments, and time-consuming scanning from different locations is needed (Dold and Brenner, 2006).

Mobile Laser Scanning (MLS) systems operate with the same principles as ALS, but are usually deployed in a vehicle, such as a van or a car. However, MLS systems produce a denser 3D point cloud than ALS and they use more adequate scanning angles for the measurement of vertical features. Furthermore, MLS systems avoid some of the occlusions that affect TLS, due to the movement of the scanning device and the fact that MLS systems usually use more than one sensor that operate in different scanning planes (Puente et al., 2012; Tao, 2000; Vaaja et al., 2011).

The distribution of the points from laser scanning systems (especially MLS) is usually heterogeneous and the amount of data is generally extraordinarily large. Therefore, and in order to reduce the processing times and the complexity of the datasets, the point clouds are often simplified before the use of an algorithm for feature extraction. In some cases (Yokoyama et al., 2011), the largest features present in the point cloud (i.e. ground points and/or buildings) are removed manually. Alternatively, a segmentation technique based on a surface growing algorithm, which groups points according to their connectivity and coplanarity, can be used (Pu et al., 2011; Vosselman et al., 2004). Another option is to apply a segmentation to the sweeps of the MLS, eliminating groups of points that are not compatible with the section of the target elements (i.e. pole-like objects) (Lehtomäki et al., 2010). More recently, (Puttonen et al., 2013) applied different distance-sensitive sampling methods to the original point cloud and tested them for pole-like objects detection using the algorithm from (Lehtomäki et al., 2011).

Storage and compression of a vast and dense point cloud from TLS is performed in (Elseberg et al., 2013) using octree structures, where the point clouds are stored in a volumetric hierarchical space (Meagher, 1982). Nevertheless, in many cases, it is not necessary to build categorized structures (Elseberg et al., 2013) and a grid of volumetric units (i.e. voxels) is used (Aijazi et al., 2013; Hosoi and Omasa, 2006; Moskal and Zheng, 2012; Truong-Hong et al., 2013; Wu et al., 2013). In some of these voxel spaces, the topologic relations are not initially established, so conditions of neighborhood/proximity that would represent one third of the total processing time (Vanderhyde and Szymczak, 2008) can be analyzed in subsequent stages within the regions or groups of voxels of special interest.

It is only very recently that a few studies have started to address pole-like object extraction from MLS in urban environments. In 2010 (Lehtomäki et al., 2010) used a method which looked for pole sections within each sweep of the MLS. The selected features from different scan lines were linked together and their isolation was checked using two cylinders (see (Brenner, 2009)).

In 2011, (Yokoyama et al., 2011) used iterative smoothing in order to obtain skeleton structures and a subsequent identification of the pole-like objects using principal component analysis. (Pu et al., 2011) used both a shape-based method, and a process based on the identification of horizontal sections of the pole-like features avoiding their extreme segments.

Golovinskiy et al. (2009) propose methods for urban features recognition (including poles) developed from an initial selection of potential objects based on point densities. The candidate objects are separated from the background, and they are characterized according to their spatial context and configuration. Finally, the features are classified comparing their characterization with labeled data from a training dataset.

More recently, (Wu et al., 2013) developed a method that uses an orthogonal, but non regular voxel space for tree detection in urban environments. The algorithm is based in the detection of the sections of trees that match with the expected diameter at breast height (DBH) (i.e. 1.2–1.4 m from the ground). A neighborhood search is applied to the sections that fulfill the requirements at DBH in order to extract the tree trunk and the estimation of other morphological parameters.

The aim of this work is to develop a new methodology for identification of pole-like street furniture objects from MLS data, which is more general and able to improve the performance of the existent methods: (i) able to detect pole-like objects with independence of the structures attached to them. It is a frequent situation that poles are joined together through tree branches or other features. Some methods like (Pu et al., 2011) or (Yokoyama et al., 2011) use 3D connected components labeling before the pole extraction, so they are not able to detect connected poles separately. (ii) Does not require training data. Machine learning based methods, such as (Golovinskiy et al., 2009) imply the time-consuming collection of training data, in addition, the fact that a model works with a training dataset, does not necessarily guaranty that adequate results could be obtained with other data, and they can suffer from overfitting problems (Ling, 1995; Zhang, 2000). (iii) No initial assumptions are taken about the position of the poles. In (Wu et al., 2013) it is assumed that all the targets (i.e. trees) are placed at the same height from the ground, and that they have a pole-like section at breast height (i.e. 1.2–1.4 m). (iv) The algorithm has to be independent of the scanning geometry (i.e. scanning angles and scanning frequency) and structure of the data (i.e. only the *XYZ* coordinates of the points are needed). The method from (Lehtomäki et al., 2010) fulfills the previous requirements, but is dependent of the scanning geometry, as it is based in the use of sections of the poles, which imply a limit in the tilt angle of the sweeps. An indexation of the points (i.e. sweep id. and point index within the sweep) is also needed as input for this algorithm.

The proposed methodology is based on very simple geometric principles and consists in the initial creation of a simplified version of the original point cloud through voxelization, the subsequent analysis of its horizontal sections, and the final identification of the poles and the structures attached to them in the voxel space.

Four test sites from different environments are used in order to test the algorithm. Three of them are from a narrow street in the city center, and they contain different common features in urban environments (i.e. large buildings, junctions, roundabouts, small parks, parked vehicles or bins). The fourth test site is a long street which contains many peri-urban structures, such as commercial centers, large parks, bridges and some road elements).

2. Methodology

The method proposed for the detection of street furniture pole-like objects from MLS data consists of three consecutive steps:

1. Voxelization of the point cloud space through codification. This stage allows to simplify the analysis and to reduce the computing cost of the subsequent operations.
2. Two-dimensional analysis of horizontal sections of the voxelized point cloud. At this stage, the candidates are identified by the properties of their sections.
3. Tridimensional reconstruction of the selected features from the previous 2D analysis.

2.1. Voxelization

Point clouds from MLS measurements are habitually very large and the distribution of the points is usually extremely heterogeneous. For that reason a simplification is often necessary. Consequently, we developed a voxelization method that allows the