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An automated algorithm for extracting road edges from terrestrial mobile LiDAR data

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ABSTRACT

Terrestrial mobile laser scanning systems provide rapid and cost effective 3D point cloud data which can be used for extracting features such as the road edge along a route corridor. This information can assist road authorities in carrying out safety risk assessment studies along road networks. The knowledge of the road edge is also a prerequisite for the automatic estimation of most other road features. In this paper, we present an algorithm which has been developed for extracting left and right road edges from terrestrial mobile LiDAR data. The algorithm is based on a novel combination of two modified versions of the parametric active contour or snake model. The parameters involved in the algorithm are selected empirically and are fixed for all the road sections. We have developed a novel way of initialising the snake model based on the navigation information obtained from the mobile mapping vehicle. We tested our algorithm on different types of road sections representing rural, urban and national primary road sections. The successful extraction of road edges from these multiple road section environments validates our algorithm. These findings and knowledge provide valuable insights as well as a prototype road edge extraction toolset, for both national road authorities and survey companies.

1. Introduction

Light Detection And Ranging (LiDAR) is a relatively recent technology, enabling 3D surveying of real world environments by measuring the time of return of emitted light pulses. Laser scanning systems make use of this technology to acquire accurately georeferenced sets of dense 3D LiDAR point cloud data. They provide several benefits over conventional sources of data acquisition in terms of accuracy, resolution, attributes and automation. The information obtained through laser scanning systems have applications ranging from monitoring urban development to evaluating natural environments (Darnel, 2012).

Laser scanning systems are used to acquire LiDAR data from aerial and terrestrial platforms. The data acquired from these systems differs in terms of its intrinsic accuracy and resolution for a variety of reasons but primarily due to the distance of the scanner to the target objects (Rutzinger et al., 2009). In recent years, the use of laser scanners onboard terrestrial based moving vehicles has led to an increase in the collection of high quality 3D data. The applicability of these terrestrial Mobile Mapping Systems (MMSs) continue to prove their worth in route corridor, urban and utility mapping due to the rapid, continuous and cost effective 3D data acquisition capability compared with static terrestrial laser scanning systems (Haala et al., 2008; Barber et al., 2008).

The concept of terrestrial MMS dates back to 1990s and since then has been primarily driven by the advances in kinematic positioning, imaging, laser scanning, data fusion and spatial information technologies. Mobile mapping refers to a means of collecting geospatial data using mapping and navigation sensors that are mounted rigidly onboard a mobile platform (Tao and Li, 2007). Mapping sensors can consist of imaging and laser scanning system while the navigation system is based on integrated Global Navigation Satellite System (GNSS) and Inertial Navigation System (INS). In their initial development phase, terrestrial MMSs were developed based on GNSS/INS integration and digital cameras. Later, several MMSs integrated with laser scanners were reported over subsequent years. The development of various terrestrial MMSs has been thoroughly reviewed in Ellum and El-Sheimy (2002) and Barber et al. (2008). Over the last 20 years, terrestrial MMSs have slowly developed from research projects in the academic sector to becoming commercially viable activities (Petrie, 2010). There are a number of companies which provide rapid and cost effective capturing of 3D LiDAR data for larger areas. According to a market research study conducted by ARC advisory group, the 3D laser scanning market is expected to double in size from 2010 to 2015 (Rio, 2011).

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Terrestrial MMSs present a reliable and rapid tool for capturing 3D spatially referenced information about road infrastructure and surrounding route corridor environment. This information can assist road authorities in effective management of road networks and to ensure maximum safe driving condition for road users. The volume of data produced by a terrestrial mobile laser scanning system such as the Riegl VQ-250 is large, generating 300,000 points per second resulting in approximately 20 GB of data per hour. Manual processing of such data is time consuming and has led to the development of automated algorithms. To estimate road geometry and physical road objects along the route corridor, road edges are needed to be correctly identified and extracted. The road edge is a fundamental feature and its efficient extraction is a topic which has not been extensively explored by the research community. In this paper we present an algorithm which has been developed for extracting road edges in multiple road environments from terrestrial mobile LiDAR data. The algorithm is based on the novel combination of two modified versions of the parametric active contour or snake model that, in turn, provides a more precise extraction of the road edges. In Section 2, we review various methods developed for extracting the road and its boundaries from LiDAR data. In Section 3, we discuss the parametric active contour models and investigate associated methods that have been developed for segmentation from LiDAR data. Following the review, we list the research limitations in current approaches which are addressed in our research work. In Section 4, we provide a step wise description of our road edge extraction algorithm. In Section 5, we describe the process for validating the extracted road edges. We test our road edge extraction algorithm on different types of road sections in Section 6. In Section 7, we validate and discuss the road edge extraction test results. Finally, we draw a number of conclusions in Section 8.

2. Previous work on road extraction

The use of LiDAR technology for mapping route corridors provides accurate and dense 3D point cloud data which can be used for reliable and precise extraction of road features. The methods developed for segmenting LiDAR data are mostly based on the identification of planar or smooth surfaces and the classification of point cloud data based on its attributes (Vosselman, 2009). Based on these methods, several attempts have been made to extract the road and associated features from LiDAR data. Clode et al. (2004) segmented airborne LiDAR point cloud data into road and non-road objects using a hierarchical classification technique based on elevation and intensity information. The accuracy of their road segmentation approach was reduced due to the presence of car parks and private roads in their survey area. Goulette et al. (2006) presented a method for segmenting road, trees and facades from terrestrial mobile LiDAR data. The road was segmented as horizontal plane with high density of points in the histogram and then the segmented information was used to compute road width and curvature. The trees and facades were identified as vertical planes and disconnected elements in the histogram. Yuan et al. (2008) proposed an algorithm for extracting road surface from terrestrial LiDAR data. The algorithm used a fuzzy clustering method to cluster LiDAR points. Straight lines were then fitted to the linearly clustered data using slope information for extracting the road surface area. Elberink and Vosselman (2009) developed an automated method for 3D modelling of highway infrastructure using airborne LiDAR and 2D topographic map data. The road polygons were extracted from the topographic map data using a map based seed-growing algorithm combined with a Hough transformation. The LiDAR points were added to the corresponding road polygons using a LiDAR based seed-growing algorithm. Subsequently, 3D reconstruction was achieved by assigning the LiDAR elevation values to the map polygons. Lam et al. (2010) extracted roads from terrestrial mobile LiDAR data by fitting RANdom SAmple Consensus (RANSAC) planes to small sections and then interconnected these fitted planes using Kalman filtering. The extracted road information was further used to segment urban objects such as lamp posts, power line posts and power lines based on dimensional constraint and fitting RANSAC lines to 3D points.

Few research attempts have been focused on precisely extracting the road edges. Jaakkola et al. (2008) developed a method for classifying kerbstones, road surface model and road markings from terrestrial mobile LiDAR data. The kerbstones were delineated by filtering the gradient image of height attribute to find the pixels which were neither horizontal nor vertical. The extracted kerbstone information was used to estimate the points that belong to the road surface area. These points were used to create a triangulated irregular network and then it was shaped into smooth surface by applying slope and edge length constraints. The road markings were extracted by first normalising the intensity attribute and then applying threshold approach. Yoon et al. (2009) presented an approach for evaluating the terrain surface for autonomous vehicles in an urban environment from LiDAR point cloud data. They calculated the slope and standard deviation from LiDAR points and used these values to estimate the edges of the road. Vosselman and Liang (2009) developed a method for detecting kerbstones from airborne LiDAR data. The approach was based on the detection of small height jumps caused by the kerbstones in the LiDAR point cloud data. However, their extraction accuracy was affected by parked cars occluding the kerbstones. Smadja et al. (2010) developed an algorithm for extracting roads from LiDAR data based on the detection of slope break points coupled with the RANSAC algorithm. The extracted road boundaries were further processed to compute road curvature and road width information. Zhang (2010) proposed a method for detecting road edges in an urban environment using terrestrial LiDAR data. In their method, road edge points were identified based on elevation information. The identified 3D road edge points were then projected on a ground plane to estimate the road kerbs. McElhinney et al. (2010) developed an algorithm for extracting road edges from terrestrial mobile LiDAR data. In the first stage of their algorithm, a set of lines were fitted to the road cross sections based on the navigation data and then LiDAR points within the vicinity of the lines were determined. In the second stage, these points were analysed based on information such as the slope, intensity, pulse width and proximity to vehicle information in order to extract the road edges. Ibrahim and Lichti (2012) developed an approach to extract street kerb and its surface from terrestrial mobile LiDAR point cloud data. In their approach, the point cloud data was segmented into ground and non-ground based on varying point density with respect to the distance from mobile vehicle's trajectory. The segmented ground data was further refined by analysing the morphological characteristics of the neighbourhood of each point in the segment. The kerb edges were finally extracted from the refined ground segment by applying the derivative of the Gaussian function to 3D points.

The majority of these road extraction methods attempt to delineate roads by distinguishing them from non-road objects but do not make attempt to extract the road edges. Approaches which have been developed for extracting road edges to date fail to provide an efficient and robust solution. Most of these approaches have been developed for urban road environments where algorithms rely on the existence of a sufficient height or slope difference between the road and kerb points for detecting road edges. Little or no research has been carried out to extract rural roads, where the non-road surface comprises grass-soil and the edges are not as easily defined by slope changes alone. The intensity and pulse width attributes from LiDAR data can be a useful source