The extraction of urban road inventory from mobile lidar system

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Abstract. Road inventory is an important infrastructure for the intelligent transportation system. The mobile mapping system is an advanced technology to collect high-quality road data efficiently. The objective of this research is to present a procedure to extract the road inventory using the mobile mapping system. The major works of this study include data preprocessing and feature extraction. Data preprocessing is used to improve the accuracy of trajectory using co-registration and 3D similarity transformation. Feature extraction comprises road point selection, road mark extraction, and object measurement. The test data was acquired by Optech Lynx system. The experimental results show the potential for using a lidar-based mobile mapping system in road inventory extraction. The experimental results indicate that the registration error can be reduced to 5cm after co-registration. The automatic filtering is able to select ground point efficiently. Moreover, the mobile lidar system is capable of creating a 3D road inventory wherein the root-mean-square-error of road mark is greater than 20cm. The digitized road marks and road objects can be integrated with geospatial data for analysis and 3D visualization.

1. Introduction
The three-dimensional road model is one of the important infrastructures for Intelligent Transportation Systems (ITSs) and Geospatial Information Systems (GISs). The applications of this road model include transportation management, maintenance, planning, analysis, navigation, etc. Traditionally, collecting road inventory is a labor-intensive process, as it requires on-site surveying, e.g. traverse surveying and leveling surveying. Hence, the development of highly efficient road inventory collection is important for transportation management [1].

Road inventory [2, 3] includes geometric properties and attributes. Geometric property depicts the length, width, lane, direction, surface, road objects (e.g. traffic light, light pole), etc. It requires precise measurements to obtain reliable measurement data. Attribute property is the description of the road; for example, the road name, the road material, the road type, and the road status (e.g., public or privately-owned road). This type of property usually needs field work to obtain the semantic information.

Remote sensing is a useful technology to acquire land cover data efficiently. The platforms of remote sensing can be a space-borne, air-borne, or terrestrial sensor. The increase of platform altitude will reduce the spatial resolution. Therefore, airborne and terrestrial sensors are often applied in road network data acquisition. The active Light Detection and Ranging (LIDAR) and passive optical sensor are the two common sensors in road network data acquisition. The lidar system provides 3D point
clouds for extracting the road model. On the contrary, an optical sensor provides multispectral images instead of laser points in 3D form. Both sensors are beneficial for the interpretation of road information [4].

The idea of Mobile Mapping System (MMS) is to collect and perform the mapping from moving vehicles. Multi-sensors are integrated to obtain 3D points, 2D images, as well as orientation data (i.e. position and attitude of sensors) [5, 6]. That means, MMS system not only collects data, but the object coordinates can also be directly calculated from the orientation data. The acquisition of road inventory using conventional field-work is fairly difficult due to the operational cost and logistical reasons. For the terrestrial sensor, MMS matches the need for road inventory collection [7] while the vehicle mounted with MMS moves on the road.

The aim of this research is to present a procedure for collecting geometric properties of the road using the mobile mapping system. This research uses lidar point clouds for road modeling. The major works include data preprocessing and feature extraction. Data preprocessing is used to improve the accuracy trajectories via co-registration. Feature extraction comprises road point selection, road mark extraction, and object measurement.

2. Methodology
The major works include data preprocessing and feature extraction. The data preprocessing ensures the data quality between trajectories. The major works in data preprocessing include data co-registration and georeferencing. The information extraction from MMS data is an important procedure for establishing road inventory. The feature extraction comprises three major parts: road point selection, road mark extraction, and road object measurement.

2.1. Data processing
A lidar-based mobile mapping system is usually equipped with laser scanners for 3D points, digital cameras for multi-view images, and POS (Position and Orientation System) for platform positioning and attitude information. POS is combined with multiple sensors such as a Global Positioning System (GPS), an Inertial Navigation System (INS) and a Distance Measurement Indicator (DMI) for positioning and orientation determination. All the sensors are integrated to improve the accuracy of georeferencing. Theoretically, direct georeferencing of MMS determinates the geocoded 3D lidar points without using ground control points. However, the accuracy of GPS signal trajectories is frequently degraded in urban areas due to the occlusion. Consequently, the same surface acquired from different trajectories may not be identical. As POS provides position and attitude with high relative accuracy, the number of control entities required for MMS is not as much as traditional mapping. The objective of data preprocessing is to correct the errors between trajectories using the data co-registration technique.

Co-registration is a procedure for transforming a dataset from its own coordinate system to another system. The lidar points acquired by different trajectories on the same road have several overlapping areas. This redundancy is useful for performing accurate registration between two point-clouds of the same overlapping area. The 3D data registration includes three control features: control point, control line, and control surface. The control point is the most popular feature in registration. This study employs Iterative Closest Point (ICP) in data co-registration. ICP utilizes point features to register two point-sets. This algorithm selects the closest points as a conjugate pair and calculates the transformation parameters iteratively until the parameters meet the converge threshold. The transformation in use is 3D similarity transformation. A more detailed discussion of ICP appears in [8].

2.2. Road point selection
The along-track and across-track slope of a road may influence the safety of driving. An accurate road-surface model is able to provide the profile, surface deformation, and continuity of a road, which are important for road maintenance. As lidar point clouds include three-dimensional coordinates for
ground points and non-ground points, this study selects the ground points for road modeling. The ground points are processed with an automated filtering technique. This study uses the slope-based filtering algorithm [9] in road point selection. This method is able to handle planar roads and highway ramps. The first step is to generate a coarse ground model from the lowest points on a designed grid. The idea of the slope-based filtering algorithm is to progressively include potential ground points. This method examines the slope and distance of a point and coarse ground model. If the slope and point-to-plane distance are less than the predefined thresholds, the candidate point is labeled as a ground point and updates the coarse ground model. Figure 1 shows an example of road point selection. Figures 1(a) and 1(b) are top-view and front-view of MMS’s lidar points before filtering. Many non-ground points like trees and vehicles are located on the road. Figures 1(c) and 1(d) show the road point in top-view and front-view. The non-ground points are removed from the road point selection.

![Figure 1. An example of road point selection](image)

2.3. Road mark extraction
The objective of road mark extraction is to obtain the road mark on the road surface. Road mark information is extensively used to determine the road networks [10]. Such information can be used to derive road parameters like road boundaries, road lanes, and road directions. The lidar system not only provides 3D points but also the intensity of the return signals. This is an important characteristic in road mark extraction. The intensity of asphalt roads is usually lower than those roads marked with white paints. Therefore, the separation of road marks can be done by manual measurement or semi-automatic measurement.

![Figure 2. An example of road mark extraction](image)

In order to extract reliable information from complex scenarios, this study manually digitizes the road mark from MMS data. The road marks include lanes, directions, boundaries, traffic islands and parking lots. Figure 2 shows an example of road marks extraction. Figure 2(a) shows the lidar intensity
of a road segment. The road marks such as arrows, lanes, and parking lots are digitized and shown in Figure 2(b).

2.4. Object measurement
Road marks indicate the information on the road surface while road objects are the on-ground objects like traffic objects, trees and temporary objects [11]. Lidar-based MMS collect road surface points and object points along the road. The advantage of MMS is to collect the data efficiently. These collected point clouds and images can be used to build a road inventory off-the-field. In other words, the combination of a field mobile mapping system and in-door measurement is more efficient than the traditional field survey. Moreover, MMS data serves as evidence for verifying the quality of the measurement.

This study uses a CAD system to conduct the object measurement from 3D point clouds. The CAD environment is able to measure the coordinate of a point of interest, the distance between two targets, an object’s height, etc. These objects include trees, light poles, and traffic lights. Figure 3 shows an example of traffic light measurement in a CAD system.

![Figure 3. An example of object measurement](image)

3. Experimental results
The test site, located at Kuang-Fu Road in Taipei city, has a length of 1.2km. The lidar point clouds were acquired on July 10, 2011, using Optech Lynx M1; they had an average point spacing of 3cm. The acquired data includes not only a road but also the building walls facing the road. The GPS quality in the urban area caused a difference of 0.3m to 0.5m between lidar points in different trajectories. This study used ICP to co-register lidar points from different trajectories automatically. The discrepancy between the paths was less than 0.05m after the ICP co-registration. Then, four control points were used to calculate the 3D similarity transformation parameters. Finally, all the lidar points were geocoded.

As the collected points contain ground and non-ground points, a slope-based filtering algorithm was applied to remove the non-ground points. The elevation ranged from 31m to 80m before filtering and 31m to 34m after filtering. Note that the total road length is 1200m. The along-track slope is less than 3/1200 in this area. Moreover, some of the ground points are distributed on the sidewalk. The elevation of the sidewalk is higher than the road for about 0.2m. Figure 4 compares the lidar data before and after filtering. The traffic island in the center area is also removed as it is higher than the road surface.
This study uses the 3D points with intensity in road marks digitization. The road marks are separated into different layers to accommodate the GIS analysis. These layers include lanes, parking lots, arrows, and traffic islands. In the object measurement phase, this study measured the light poles, traffic lights, and locations of trees. Figure 5(a) integrated the digitized road information and existing GIS layers. The closed polygon indicates different properties. The points are the location of trees and light poles. Finally, the entire extracted road inventory is imported into a 3D browser for visualization. Figures 5(b) and 5(c) show the results of visualization. The scenario includes road inventory, orthoimage, and building models.

**Figure 5. An example of road point selection**

Ground survey reference data are selected to verify the accuracy of the road marks. There are 33 independent checkpoints in use. The mean errors in X and Y directions are 0.97cm and 1.27cm, respectively. The root-mean-square-errors are 11.35cm and 18.86cm in two directions, respectively. Hence, the extracted road inventory can be used in many applications. The distribution of errors is shown in Figure 6. The maximum error is less than 35cm. The errors are caused by measurement error and insufficient point density.

**4. Conclusions**

In this study, a lidar-based mobile mapping system is employed to extract the road inventory in an urban environment. The major works include data preprocessing and feature extraction. Co-registration and 3D similarity transformation are the two major steps in data preprocessing. Feature extraction consists of road point selection, road mark extraction, and object measurement. The experiment shows the potential of using MMS in road inventory extraction. The experimental results also indicate that the registration error can be reduced to 5cm after co-registration. The automatic filtering is able to select ground points accurately. Moreover, the digitized road marks can be integrated with another GIS layer for further processing.
Figure 6. Accuracy analysis

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