# Road Marking Survey with Mobile Lidar System

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## ABSTRACT
In this paper, a mobile lidar system for surveying reflective road markings is presented. Aside from inclusion of typical components in many other mobile lidar systems – compact lidars, integrated global positioning and inertial navigation systems, and onboard computers – the road surveying device is designed to maintain scanning resolution while traveling at normal traffic speeds. Occupancy grids are utilized to register the scanned point cloud data, so that outliers and temporarily obstructing objects could be identified and removed. Details about the system design and the filtering techniques are presented. Surveying results from the preliminary road tests are reported.

## Keywords
Lidar, mobile laser scanning, road marking survey, occupancy grid, point cloud, voxelization.

## 1. INTRODUCTION
Light detection and ranging (lidar) technology is a laser application to remote sensing that provides distance estimation by illuminating objects with pulsed laser beams and measuring the reflected laser pulses. Initially implemented for meteorology [1] and atmospheric studies [2], lidar systems have since been utilized in a broad range of applications in research and industry [3]. The lidar systems could rapidly create dense, three-dimensional (3D) point cloud data and survey the surrounding environment with superior accuracy, precision, and flexibility when compared to conventional measurement methods. Particularly, mobile lidar systems on vehicular platforms (often referred to as mobile laser scanning, or MLS) have received an increasing attention in recent research studies, thanks to advancements in scanning speed and accuracy, as well as the integrated global positioning systems (GPS) and inertial navigation system (INS) that offers real-time localization and orientation information [4]. The mobile lidar systems have become an effective solution for rapid environmental mapping and road inventory surveying. A thorough review of these applications could be found in [4, 5].

This paper presents a mobile lidar system for surveying the reflective markings on road surfaces. The system includes typical components similar to other mobile lidar systems; however, a couple of design choices are made to improve performances. First, the lidar sensor is positioned and oriented to minimize the gap between neighboring scanned points while allowing the vehicle to travel at a reasonable speed in traffic. Additionally, the concept of occupancy grids is utilized to register the scanned space as either empty (free) or occupied, such that outliers and temporary obstructions could be easily identified by examining the accumulated registrations. The paper is organized as follows: The design of the mobile lidar system is detailed in Section 2. Section 3 discusses the data processing and filtering techniques. Section 4 summarizes the preliminary surveying tests. Section 5 concludes the paper.

## 2. SYSTEM DESIGN
The mobile lidar system consists of a compact lidar sensor, an integrated GPS receiver, a digital inclinometer, and an onboard computer for data processing and storage. Mounted on top of a vehicle platform, the rear-facing lidar collects point cloud data from the road surfaces. Relative distance together with reflectance of the points on the road are obtained. Real-time 3D point clouds are registered in the world reference frame after coordinate transformations. Subsequently, road surface markings are extracted based on their high reflectance.

### 2.1 Lidar Sensor
In this study, the sensor Velodyne PUCK VLP-16 is a compact direct energy detection lidar device as shown in Figure 1. It has a relatively low power consumption (about 8 W) and a small footprint (a cylinder of about 103 mm diameter and 72 mm height). During operation, the laser pulses switch among 16 evenly spaced elevation angles within a ±15° range as they sweep around 360° azimuthally. As illustrated in Figure 2, every laser beam emitted from the center of the lidar could be described using an azimuth angle $\alpha$ and an elevation angle $\beta$. The elevation angle $\beta$ switches every 2.3 µs during the firing sequence of each set of 16 laser beams, whereas the rotation speed (or rate of change for angle $\alpha$) is adjustable between 5 to 20 rotations per second.

Figure 1. Picture of lidar sensor.

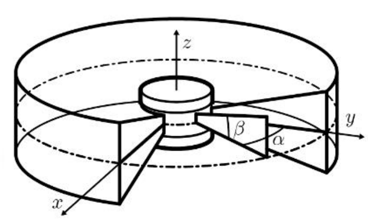

Figure 2. Diagram of lidar scanning field.

Provided that the distance from the scanned object could be inferred based on the amplitude of the returning light, points on the object could be registered with respect to the reference frame that is fixed on the lidar sensor. Data points up to 100 m in range can be detected with measurements of their reflectance.

## 2.2 Scanning Resolution

Since the lidar system is to be mounted onboard a vehicle platform moving in traffic, a reasonable choice would be on the front or the back of the vehicle where the road surfaces are exposed for scanning. Assuming the lidar is mounted on the back without loss of generality, the geometry for the lidar scanning field could be depicted as in Figure 3. As the vehicle traveling forward along the $x$ axis, the set of 16 laser beams within ±15° separation from the center line (dash-dot line in Figure 3) forms a circular sector, which in turn sweeps along a helix curve. Spacings between the neighboring laser beams could be reduced when they hit the ground, if the lidar is mounted lower in height and/or pitched further down. However, this does not necessarily result in higher scanning resolution because it may also increase the gap between consecutive sweep (full rotation).

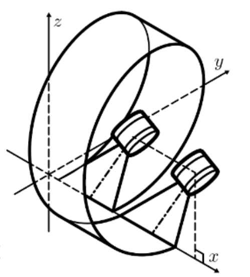


Figure 3. Lidar scanning coverage.

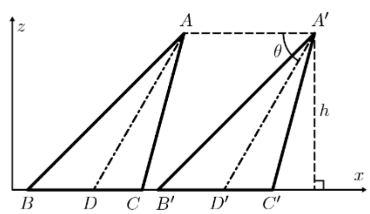


Figure 4. Illustration of two consecutive sweeps.

To further investigate the scanning geometry, an approximation is made that all 16 laser beams are fired simultaneously and reach the ground along $x$ axis on every rotation.[1] The approximated scanning model is illustrated in Figure 4, in which the laser beams make contact to ground along line segment $BC$ and subsequently $B'C'$ on the next sweep, while the lidar center travels from point $A$ to $A'$. As a result, the lidar pitch angle $\theta$ and height $h$ constitute a minimization problem:

$$\underset{\theta\in[15°,\,75°]\subseteq\mathbb{R},\,h\in\mathbb{R}^{+}}{\arg\min}\; h[\cot(\theta-15°)-\cot(\theta-13°)],$$

subject to:

$$u_{\max}T_{\text{rot}} \le h[2\cot(\theta-15°)-\cot(\theta+15°)-\cot(\theta-13°)],$$

where $u_{\max}$ denotes the maximum survey speed and $T_{\text{rot}}$ represents the azimuthal rotation time period.

It is difficult to find the optimal solution analytically. However, the trigonometric functions could be replaced with their estimates at $\theta = 75°$, since the expressions in both brackets are monotonically decreasing functions. Subsequently, the minimal value for lidar height $h$ is obtained based on the maximum surveying speed $u_{\max}$.

For example, defining maximum speed $u_{\max}$ to be 50 mph yields a minimal height $h$ of around 1.8 m or 6 feet. In simulation, positions of the resulting laser points reaching the ground are illustrated in Figure 5. Consequently, the scanning sweeps will continuously cover the road surface if the vehicle is moving no faster than the maximum speed. In addition, the lidar may also provide decent measurements on the neighboring lanes when there are no obstructions.

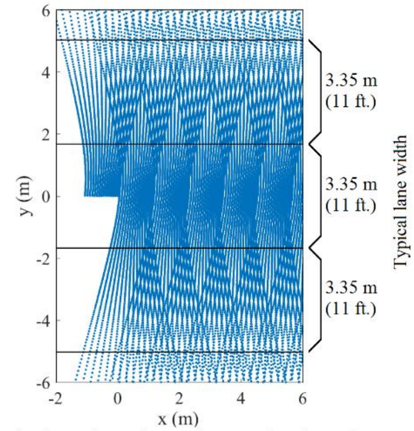


Figure 5. Simulated scanning points on the ground at the maximum surveying speed.

# 3. FILTERING TECHNIQUES

As visually demonstrated by Figure 5, the lidar system can produce a large number of data points (almost 200,000 points per second for this particular model), all of which are stored as a 3D point cloud with an additional variable as reflectance. To reduce data size and computation load, the point cloud data is converted into discrete voxel space where data points are collected in separate cubes. Thus, the geometry of the scanned scene can be represented by voxels that contain one or more data points. Outliers can be readily eliminated by setting a threshold for the number of points in the voxels. Undesired points registered due to temporary obstruction by traffic can be identified by utilizing the concept of occupancy grids to register scanned points.

## 3.1 Occupancy Filter

Application of the occupancy grid concept in lidar scan is proposed in [6], where the scanned scene is categorized as free, occupied, or hidden along the direction of every laser beam and a probabilistic model is derived to facilitate feature detection. A non-parametric solution for occupancy probability estimation is presented in [7] to improve the computation performance.

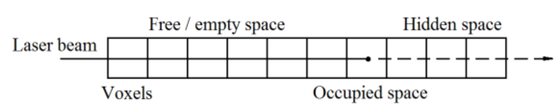


Figure 6. Information about the scanned scene along a single returning laser beam.

The idea behind the filtering technique can be illustrated in Figure 6. As each data point on an object gets registered by the lidar, the corresponding laser beam passes through empty space between the lidar center and the object. The information about the scanned scene suggests that not only is the data point occupied, but the space before the point is empty and the space behind the point is hidden. Therefore, by registering the voxels along the laser ray as empty or occupied and comparing the accumulated registration after multiple

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[1] The approximation is valid because the time period (55 µs) for 16 laser firing sequence is considerably smaller than that of the azimuthal rotation (adjustable between 0.05 to 0.2 s).

scans, temporary obstructions can be identified by the voxels that are registered as both occupied and empty.

As an example, the lidar system is set stationary in a road and captures point cloud data as two vehicles passes by on neighboring lanes. Figure 7 shows the point cloud from two different time intervals. One depicts the road being empty and the other shows one of the vehicle. As demonstrated in Figure 8, directly voxelizing the accumulated point cloud data gives a 3D scene that contains the traces of both of the pass-by vehicles while the voxels representing the road surface are hidden underneath. Applying the occupancy filter removes the obstruction with little residue.

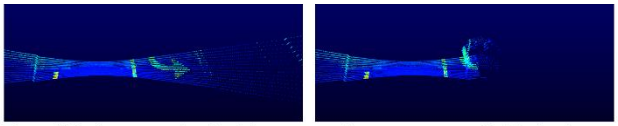

Figure 7. Reflectance point cloud from two stationary scans as traffic blocks view.

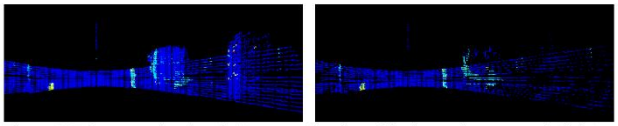

Figure 8. Direct voxelization (left) versus filtering with obstruction removal (right).

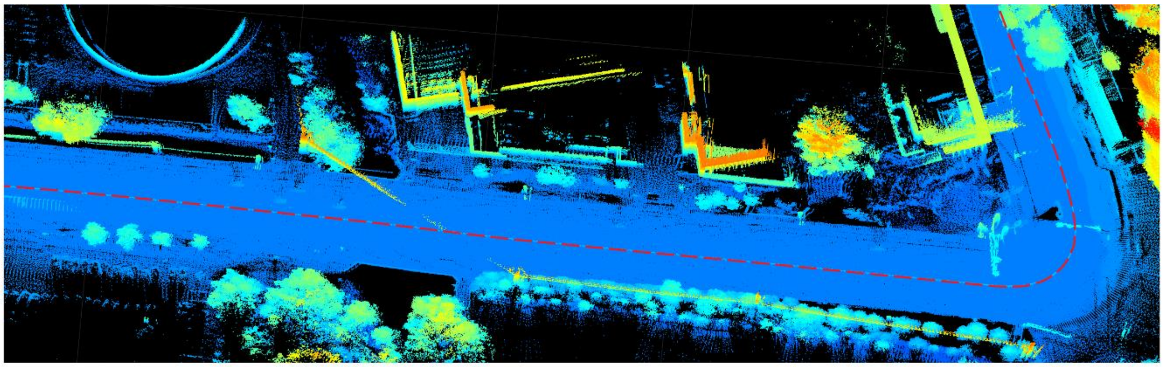

Figure 9. Voxelized lidar scanning result from road survey tests. Color indicates elevation. Vehicle trajectory is illustrated as red dashed lines.

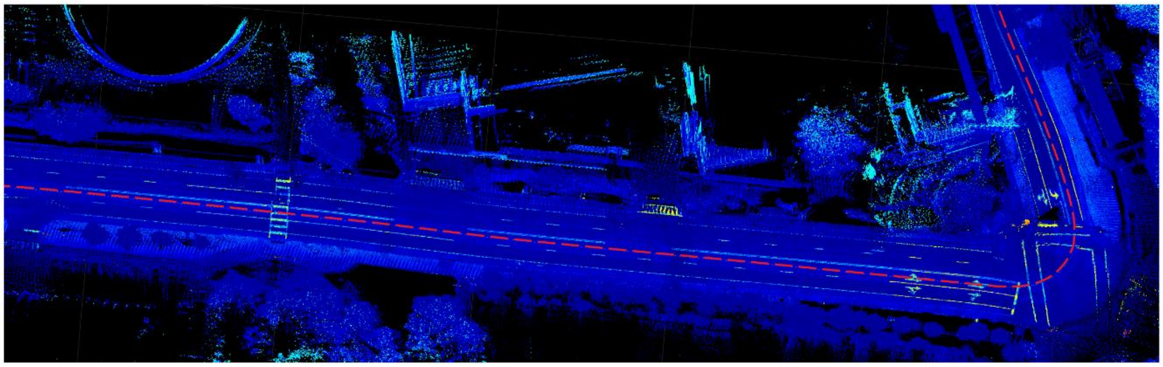

Figure 10. Voxelized lidar scanning result reveals reflective road markings, including solid and broken lines, arrows, and crosswalks. Color represents reflectance.

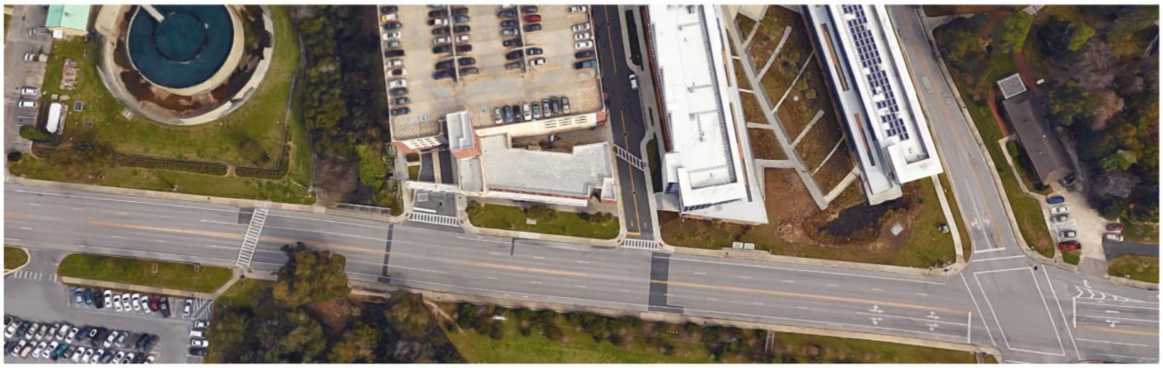

Figure 11. Latest available satellite map from Google. Roadworks have been taken since this picture, especially the crosswalk on left has become perpendicular to road.

## 4. SURVEY TESTS

A series of road survey tests were conducted to validate the design of the mobile lidar system and the filtering techniques. The system is mounted on a vehicle that traverses the campus area in traffic. Voxelized lidar scanning results are shown in Figure 9 and 10, where vehicle trajectory is indicated by red, dashed lines. A satellite map from Google of the same area is provided in Figure 11 for reference. Geometric features of the scene – including trees, buildings, power lines, etc. – can be easily recognized in the elevation map (Figure 9); whereas in the reflectance map (Figure 10), road surface markings, such as the solid and broken lines, arrows, and crosswalks, can be identified and matched with the satellite image.

## 5. CONCLUSION

This paper presents a mobile lidar system for road marking survey. The system design and the filtering techniques are detailed and tested. Results from preliminary road survey tests are satisfactory. Although the system is capable of collecting and registering point cloud data, efficiency and reliability of the data storage and filtering techniques remains to be verified. Future work will also be aimed towards automatic extraction and recognition of road markings.

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