ABSTRACT
The behavior of vehicles at intersections is complex, spatially distributed, and ever-changing, yet there are few tools to track vehicles through intersections. This is particularly true for intersections that lack overhead views for mounting cameras. This paper proposes the use of a Light Detection and Ranging (LIDAR) sensor to accurately track a vehicle as it passes through an intersection. The LIDAR sensor is interfaced to a computer which runs a tracking algorithm to provide real-time estimates for the stopping distance, position, and velocity of a vehicle travelling through a single lane. The data collection process is automated to save human labor, reduce measurement errors and increase reliability. The LIDAR sensor and the computer were integrated into a portable measurement system that contains rechargeable batteries and power electronics. Tests on 2-way, 3-way and 4-way intersections during peak hours with considerable pedestrian were conducted. The results verify that the system has robust and precise tracking capability.

INTRODUCTION
Knowledge of vehicle behavior at roadway intersections has a number of different applications: roadway design engineers can acquire traffic statistics to determine the appropriate location for installing a stop sign. Law enforcement can monitor adherence to traffic laws. Driver warning systems can increase vehicle safety, especially near accident-prone intersections.

However, measurement of vehicle behavior through intersections is not easy. Manual measurement of stopping distances at intersections can be difficult, unreliable, and inaccurate. To obtain manual measurements, markings are placed on the curb or painted on the road. The vehicle’s stopping point is recorded by an observer. This method requires a considerable amount of manual labor, and the results may be biased as drivers may behave differently when they see a person observing their stopping behavior.

There are many alternatives to manual traffic measurement in intersections including the use of inductive loops, video cameras, LIDAR, or RADAR (Radio Detection and Ranging) and magnetic sensors. Inductive and magnetic sensors [1] are currently the most commonly used system to detect vehicle and measure velocities at a fixed site. The accuracy of speed depends on how close sensors are laid out. Video camera systems are less common but are increasingly being used both for intersection surveillance and measurement. Video systems can measure vehicle speed based on Motion Estimation (ME) technology, including Block-Matching method, Phase Correlation method, Optical Flow Equation method, Bayesians method and so on [2]. RADAR and LIDAR are two common research-grade velocity and position sensors, and most systems in present use are based on a single line of emission that is from a hand-held “gun” device aimed by the researcher. While both devices have similar operating characteristics, a RADAR speed sensor is based on the Doppler Effect which computes speed of a moving object by frequency shift, whereas LIDAR sensors use the time-of-flight of a laser to compute an object’s range [3].

In contrast to the hand-held single-beam LIDAR, there is increasing availability of LIDAR units that utilize a spinning mirror to spread the detection beam along a large range of angles. The scanning frequency is adjustable, but generally quite high (10 to 100 scans/second). This work focuses on the use of this multi-angle LIDAR system to derive real-time velocities from vehicle positions measured from adjacent scanning frames, and hereafter the reference to LIDAR sensing refers to the multi-angle rather than single-beam measurement systems.
In this paper, a LIDAR-based automatic measurement system is presented to identify, count, and track vehicles. The key tracking information includes the total number of vehicles, pedestrians, and cyclists passing through the measurement area, each object’s time-changing position (path), the object’s velocity along that path, and specific vehicle stopping locations relative to signage. The system is designed to be portable and automated such that the unit can be set up and left unattended or at least with researchers out of view. And unlike camera systems, the LIDAR sensor is particularly robust to lighting conditions. In this implementation, the data processing is done offline, but the algorithm is sufficiently fast that it can be integrated into real-time applications. Intersection tests were performed in State College, Pennsylvania, USA.

The remainder of the paper is organized as follows: The second section of this paper will provide a brief overview of the previous work on vehicle detection and tracking. The third part describes the test setup and the data processing algorithm. The results are presented in the fourth section. Conclusions and future work are then presented in the last section.

PREVIOUS WORK

Vehicle Detection

As described in the introduction, both inductive and magnetic sensors are widely used for vehicle detection, but there is interest in more accurate intersection data using more advanced sensors. For example, Yoneyama et.al [4] utilizes both single camera and multiple camera systems to extract traffic data. The cameras are placed on top of the lane in an almost horizontal direction, and then a robust algorithm extracts traffic feature including vehicle size, position and motion even in situations where there are shadows, occlusions, and poor illumination. Bevilacqua and Vaccari present a video tracking system in [5] that utilizes background subtraction to detect stopped vehicles at intersections. The output of the system is vehicle trajectories, vehicle behavior (does the vehicle stop or not) and stopping time.

Vehicle Tracking

Of particular note in Bevilacqua et al’s work [5] is their use of pyramidal Kanade-Lucas-Tomasi (KLT) algorithms to track vehicles. In this method, the “corner point” of each blob is extracted from the video image. A Self-Organizing Map neural network is then applied to deal with object occlusions. Image processing algorithms that can adapt to changes in road condition and lighting were also implemented in this work as well as others [2].

A particular advantage of LIDAR systems is their robustness to lighting conditions. The long detection range for LIDAR makes them highly effective in collecting certain types of traffic information including vehicle/pedestrian yielding, stopping and motion behavior. Typically, LIDAR sensors have a greater angular resolution than RADAR and this make it particularly suitable for vehicle tracking applications [6]. For research use and specialized measurements, the LIDAR systems are reasonably priced ($5000) and the cost of operation is low [7].

METHOD

System Description

The instruments listed in Table 1 are shown in Figure 1 and were used to construct the system.

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Major Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>SICK LMS 291</td>
<td>Up to 75Hz scan rate, 180° angular range,</td>
</tr>
<tr>
<td>LIDAR</td>
<td>30 meter sensing range</td>
</tr>
<tr>
<td>Device Master</td>
<td>4-port device server</td>
</tr>
<tr>
<td>Csi/SPECO</td>
<td>115VAC input, 24VDC 2 Amp output</td>
</tr>
<tr>
<td>Regulated Power</td>
<td></td>
</tr>
<tr>
<td>Supply</td>
<td></td>
</tr>
<tr>
<td>410 W Power</td>
<td>Invert DC power to AC power</td>
</tr>
<tr>
<td>Inverter</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>Deep cycle marine batteries</td>
</tr>
</tbody>
</table>

FIGURE 1. THE PORTABLE LIDAR SCANNING UNIT

The LIDAR unit is a SICK LMS 291 model, which has an angular range of 180 degrees and a resolution of 0.25 degrees. The scanning frequency, e.g. how long it takes to perform a 180-degree scan, is user-adjustable depending on resolution that is
selected, with a maximum frequency of 75 Hz. The sensing range is 30 meters, with a resolution of 10 mm. It operates on a 24VDC supply.

Two deep-cycle marine batteries were used to supply power to all the instruments and the laptop. The DC voltage from the battery powers a 410W Power Inverter for the Laptop, two Csi/SPECO power regulators, a 50-watt power supply for the LIDAR, and an Ethernet device server. The LIDAR transmits measurements via a high speed RS 422 serial cable to the device server which converts the LIDAR data stream to a TCP/IP data packet. The computer communicates with the server via a TCP/IP connection to store the resulting LIDAR data.

**Test Procedure**

The original goal of the LIDAR-based system was to measure the distance at which a vehicle stops in front of a given stop sign. The distribution of these distances will help civil engineers determine the best place to install a stop sign. The type of intersection and traffic situation determines the driver behavior at a stop sign. For example, at a blind intersection, drivers tend to stop at a conservative distance and then yield. In this case, the stop sign is expected to be placed further ahead of the intersection. In order to obtain an accurate model of vehicle behavior at a stop sign, a large dataset of vehicle stopping distances is required.

Tests were done at Pennsylvania State University, University Park campus. Figure 2 shows one test site: a 3-way intersection which has a traffic flow of about 700 vehicles per hour during weekday peak hours. The intersection is also near a student residential area and thus has a large amount of pedestrian traffic.

Figure 2 shows the location at which the test was done and the LIDAR placement relative to the stop-sign. The height of the LIDAR was set so that the LIDAR beam detects the body of the vehicle, rather than the tires, e.g. at a height of approximately 0.75 meters.

**Data Processing**

The LIDAR data consists of range information corresponding to each angular position and was stored as a text file. This file was utilized for post processing the data. An example of one single scan is shown in the blue line in Figure 3. From the playback of the measured data, the objects and their actions at the intersection can be inferred from visual inspection, such as vehicle yielding, stopping and passing, and pedestrians walking by.

In order to get the stopping distance of every vehicle, the following four-step algorithm is utilized. 1) Object Identification, 2) Feature Point Extraction, 3) Tracking and 4) Computation of the Stopping Distance. Details on each step are as follows:

1) **Object Identification:** An initial frame without vehicles is first captured as the background. All non-background objects are extracted by subtracting the background frame from the current frame. Once the difference between background and foreground exceeds a fixed threshold (13 cm in this study, which is 3 standard deviations beyond the noise in the sensor), the set of points is identified as belonging to an object. Figure 3 shows a typical
range plot of LIDAR, in which a pedestrian, a vehicle and the noise due to abnormal surface reflections can be observed. In contrast with video analysis, a fixed background and a simple fixed thresholding scheme are sufficient for LIDAR data because its output is not affected by illumination conditions [9].

![FIGURE 3. LIDAR RANGE PLOT](image)

To represent individual scan points as objects, points that are close to each other are grouped together while ignoring any noise artifacts (such as sudden peaks due to non-reflection). The difference in size of the LIDAR signature of pedestrian and a vehicle can be utilized to distinguish between these objects as shown in Figure 4. Based on a threshold of 9 cm on allowable group size variation, the vehicles in the LIDAR scan are identified for further processing.

![FIGURE 4. LIDAR RANGE PLOT](image)

In experimentation, we found that vehicles which were black in color were particularly difficult to identify because the LIDAR reflectivity of black paint is very low. As a result of the intermittent return, the LIDAR scan of such a vehicle may sometimes resemble a group of pedestrians. To minimize this negative effect, the observation window where data was processed for an incoming vehicle was constrained to be the road surface of the entry to the intersection, represented by parallelogram in Figure 5. In this area, large groups of pedestrians seldom walk in the middle of the road far away from the stop sign, and therefore any large objects identified in this particular area moving in unison were labeled as being vehicles. Not only does this approach greatly reduce the amount of computation, but also it eliminates the accidental tracking of oncoming vehicles in the other lane as being possible vehicles ignoring the stop sign.

2) **Feature Point Extraction:** For each identified point group, a feature point is extracted to represent the vehicle and to track its velocity. Due to our LIDAR placement, the LIDAR beams were only able to reach one or two sides of a vehicle, depending on its position relative to the LIDAR. Thus, the silhouette of the vehicle takes the shape of the alphabet “L” or straight line on LIDAR range plot. Examples LIDAR scans showing both profiles are seen in Figure 5.

![FIGURE 5. DIFFERENT SHAPES OF VEHICLES AND DIFFERENT FEATURE POINTS](image)

To represent an entire cluster of points with a single position or “feature point”, the corner point of the “L” and first point of a line are two potential candidates. The corner point of an “L” shaped signature on the LIDAR plot can be seen in Figure 5, and is obtained by fitting the front and side profiles of the vehicle with lines, and finding the intersection of these two lines. The first point of either “L” group or line group can also be a potential feature point as it is very easy to identify; however, the first point in a line scan may change depending on the vehicle orientation. Through experimentation, the first point in a vehicle scan does not change significantly for most vehicles traveling through intersections, and thus is chosen as the feature point for line-shaped objects hereafter.

3) **Tracking:** The goal of tracking is to associate feature points in one scan with features in subsequent scans. First, small gaps of the sequence of feature points are filled. These gaps are predominantly in black-colored vehicles. Because the LIDAR scans vary quickly relative to the distance a vehicle can move, and because vehicles maintain spacing between each other, a simple metric can be used for tracking: the closest feature points in adjacent frames are assigned the same vehicle ID number. Using the
time sequence of feature points, we are able to track the position of each vehicle.

**4) Computation of the Stopping Distance:** The original goal of this work was to calculate the stopping distance and minimum velocity during a stop for typical intersections. To do this, a successive difference method is used to compute the vehicle velocity. The stop distance is computed at the point where the velocity becomes zero. A positive stopping distance means the vehicle stops before the stop sign line, and a negative distance implies that the vehicle comes to a stop after the sign.

**TEST RESULTS**

**FIGURE 6. THE DISTANCE PROFILE OF VEHICLES DETECTED AT AN INTERSECTION DURING 5 MINUTES**

**FIGURE 7. A VEHICLE STOPPING 2 METERS BEFORE THE STOP SIGN**

Figure 6 shows 19 vehicles passing through the intersection in a period of 5 minutes (negative position means beyond the stop sign). The lines in the plot indicate the vehicles that were tracked. It can be seen that in some cases the lines are dotted and this pertains to situations in which the reflectivity of the vehicle was inadequate for continuous tracking.

Figure 7 shows the distance profile of a single vehicle which stops 2 meters beyond the stop sign for about two seconds.
Figure 8 shows the distribution of stopping distances from a sample of 113 vehicles at the intersection shown in Figure 2. It can be concluded that most of the vehicles never fully stop at the intersection. For the stopped vehicles, most vehicles stopped within 1 meter in front of the stop sign. Figure 9 and Figure 10 are from a 4-way intersection and a 2-way intersection respectively.

CONCLUSION AND FUTURE WORK

This work demonstrates the use of a LIDAR-based system for stopping distance measurement. The algorithm proves to be effective in extracting vehicle objects, using a static background and a static threshold. It was seen that a "first point" feature point was most effective in tracking the vehicles.

Currently, a successive difference method is proposed to calculate the vehicle velocity and can correctly reveal the vehicle action approaching intersections. Subsequent work will include applying Kalman Filter to improve velocity accuracy and calibrating velocity using a probe vehicle equipped with a GPS.

Besides stopping distance measurement, this system can be used in: (1) triggering traffic hazard alarm, such as vehicles passing a stop sign without stopping; (2) stop delay measurement on highway, a popular topic proposed by Institute of Transport Engineers [5]; (3) Vehicle size identification and counting.

REFERENCES


