



ANALYSIS OF VEHICLE BEHAVIOR AT UNSIGNALIZED CROSSWALKS USING A NEAR-INFRARED LASER RANGING SENSOR

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Abstract

In Japan, approximately one quarter of pedestrian traffic fatalities occur while pedestrians are crossing at crosswalks. Furthermore, previous studies have pointed out that at unsignalized crosswalks, about 40% of vehicles pass through without stopping for pedestrians, and that drivers' willingness to stop is lower in areas with heavier traffic volumes. Given these circumstances, it is essential to continuously monitor vehicle behavior near crosswalks and evaluate its risk. Many studies have investigated vehicle behavior at crosswalks; however, conventional methods based on visual observation or video cameras suffer from limited measurement accuracy. In addition, such approaches involve operational issues due to installation constraints and concerns regarding privacy protection. Accordingly, this study aims to develop a low-cost and high-accuracy system for observing vehicle behavior using a near-infrared laser ranging sensor, and for automatically determining whether a vehicle comes to a complete stop based on its travel speed. In the proposed method, the distance to vehicles passing near a crosswalk is continuously measured using the ranging sensor, and vehicle behavior is estimated from the time-series variation of the measured distance. After extracting and organizing the acquired data for each vehicle, cases in which the measured distance changes continuously are classified as "no stop," whereas cases in which the change in measured distance becomes extremely small are classified as "stop." Furthermore, the vehicle speed near the crosswalk is calculated from the temporal changes in the measured distance. An observation system was constructed and tested in a pilot operation. The results demonstrated that stable distance measurement near crosswalks can be achieved by setting the near-infrared irradiation angle to 20° and the measurement frequency to approximately 50 Hz. These results indicate that the proposed approach is an effective method for measuring vehicle behavior near crosswalks at low-cost and high-accuracy, while minimizing privacy-related constraints.

Keywords: unsignalized crosswalk, LiDAR, vehicle speed, stopping behavior, traffic safety

1 Introduction

Although the number of traffic accidents in Japan has been declining in recent years, accidents involving pedestrians near crosswalks continue to occur. Particularly at crosswalks without traffic signals, many vehicles fail to stop even when pedestrians are waiting, making safety a major concern. To evaluate the safety of uncontrolled crosswalks, it is crucial to understand vehicle approach speeds and stopping behavior. However, conventional speed measurement relies on speed measurement devices or video analysis, which involves significant burdens in terms of equipment installation and data processing. Therefore, we propose a simple speed measurement method using a near-infrared laser rangefinder.

This method calculates vehicle speed based on the temporal changes in distance data, enabling low-cost and straightforward observation. In this study, we propose an observation method based on this technique that incorporates a stop detection function. Specifically, we calculate vehicle speed from the temporal changes in distance data acquired by LiDAR and determine whether the vehicle has stopped based on intervals of stable distance. We apply this method to uncontrolled crosswalks to quantitatively evaluate vehicle stopping behavior while pedestrians are waiting. Furthermore, we verify the validity of the stop detection by comparing it with actual measurement data obtained through video observation.

2 Previous studies

2.1 Simple method for speed measurement

Vehicle speed is commonly measured using speed guns or video analysis; however, these methods have issues related to equipment costs and data processing efforts. Therefore, a simple speed measurement method using a laser distance sensor has been proposed. Kaneko et al. [1] proposed a method to estimate vehicle speed by applying regression analysis to the temporal variation of distance data obtained from a laser distance sensor. This method enables low-cost and simple speed measurement. Furthermore, temporal changes in distance data can also be used to capture deceleration and stopping behavior. By defining appropriate criteria, this approach can be extended to stop detection.

2.2 Research on vehicle stopping behavior at unsignalized intersections

Research focusing on the interaction between pedestrians and vehicles has been conducted regarding vehicle stopping behavior at crosswalks without traffic signals. Schroeder et al. [2] collected data on vehicle speed and pedestrian behavior using video observation and speed measurement devices and analyzed yielding (stopping) behavior using a logistic regression model. Fujita et al. [3] examined the influence of pedestrian positioning and signaling behavior on driver yielding behavior at uncontrolled crosswalks. Furthermore, Nkurunziza et al. [4] reported that vehicle-related factors and traffic flow conditions affect driver stopping behavior. However, these studies generally rely on video observations, which presents the drawback of requiring a significant amount of time for data collection and analysis.

2.3 The positioning of this study

Previous studies have examined speed measurement using laser distance sensors and analyzed stopping behavior at uncontrolled crosswalks through video observation. However, methods for simultaneously quantifying speed estimation and stopping detection have not been sufficiently explored. Therefore, this study aims to develop a method for quantitatively evaluating vehicle speed and stopping behavior using LiDAR sensors.

3 Principle of measurement

3.1 Monitoring equipment

In this study, we constructed an observation system using a near-infrared laser rangefinder. As shown in figure 1, we used the LiDAR-Lite v3 as the distance sensor and connected it to a small computer (Raspberry Pi) to acquire distance data. Table 1 summarizes the specifications of the LiDAR-Lite v3 [5] used in this study. The LiDAR-Lite v3 has a maximum measurement range of 40 m, making it suitable for observing the approach behavior of vehicles.

The sensor was mounted on a tripod and fixed at a constant angle relative to the direction of vehicle travel from the roadside. The acquired distance data was recorded along with time information, enabling the continuous capture of vehicle behavior from approach to passage.



Figure 1 Raspberry Pi 4 (left) & assembled equipment (right)

Table 1 Specifications of the laser distance sensor

Sensor	LIDAR-Lite v3
Measuring range	0~40 m
Resolution	1 cm
Accuracy	±0.025 m
Maximum frequency	500 Hz
Manufacturer	Garmin

3.2 Method for observing vehicle behavior data

This vehicle behavior recording method was developed based on the vehicle observation technique using a laser distance sensor proposed in [1]. In this method, a laser is directed at the vehicle from the side of the roadway at a certain angle, and the vehicle's behavior is determined by measuring the temporal variation in the distance to the vehicle. As shown in figures 2 and 3, distance data corresponding to the front or rear of the vehicle is extracted, and the vehicle's behavior is analyzed using the temporal variation in this data. In this study, by applying this observation principle and performing distance correction that accounts for the LiDAR installation angle, we made it possible to estimate changes in distance along the vehicle's direction of travel. This allowed us to continuously track vehicle behavior and utilize it for determining stopping behavior.

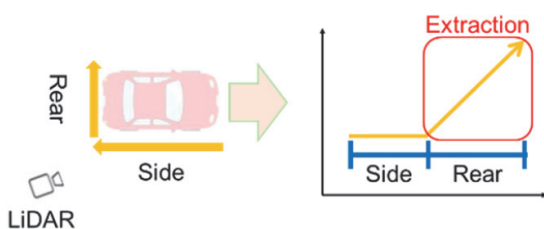


Figure 2 A method of measuring the distance to the vehicle (side and rear)

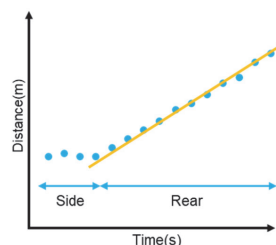


Figure 3 Example of recorded data

4 Development of a stop detection method

4.1 Method for determining the LiDAR installation position

As shown in section 3.2, the LiDAR was installed along the road and fixed at a constant angle relative to the vehicle’s direction of travel. Figure 4 shows the LiDAR layout. Since the relative positional relationship between the vehicle and the sensor varies depending on the observation conditions, we considered two scenarios, measuring the area in front of the vehicle and the area behind it, and adjusted the installation position to ensure stable acquisition of distance data in each case. When measuring the area in front of the vehicle, the LiDAR was positioned to capture the section where the distance to the sensor decreases as the vehicle approaches the observation point. Conversely, when measuring the area behind the vehicle, it was positioned to capture the section where the distance increases as the vehicle moves away from the sensor after passing the observation point.

As described above; by considering the differing trends in distance changes depending on the observation target (front or rear) and adjusting the LiDAR’s installation position and angle, we ensured an environment capable of continuously and stably acquiring distance data corresponding to the vehicle’s front or rear. The LiDAR’s installation position was calculated using equation (1).

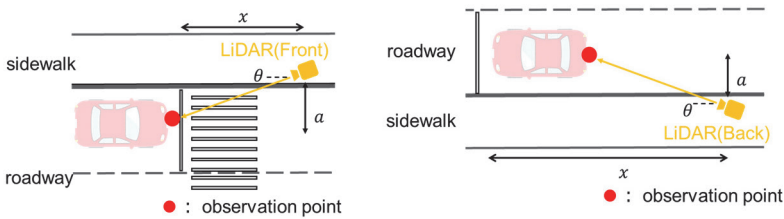


Figure 4 Placement of LiDAR sensor (front and back sides)

$$x = \frac{a - 0.85}{\tan \theta} + \Delta \tag{1}$$

Where:

- x - distance from the stop line to the LiDAR
- a - distance to the center of the target lane
- θ - installation angle
- Δ - correction value according to the measurement target
- 0.85 m is the vehicle center correction value.

4.2 Method for detecting vehicle stops

Vehicle stop detection was determined based on the temporal changes in distance data acquired by LiDAR. While the vehicle is in motion, the relative position between the vehicle and the sensor changes, causing the distance data to fluctuate over time. On the other hand, when the vehicle comes to a stop, the relative position remains nearly constant; consequently, the distance data does not show significant changes over a certain period and tends to maintain a nearly constant value. In this study, we focused on this characteristic of the stopped state and established the determination criteria shown in figure 5. Specifically, we determined that the vehicle was in a stopped state when the change in distance data remained within 20 cm for a continuous period of 0.5 seconds or longer.

By introducing this determination condition, we were able to suppress false detections caused by temporary deceleration, such as when approaching a traffic signal, or by minute errors associated with sensor measurements, thereby enabling more stable detection of the stopped state.

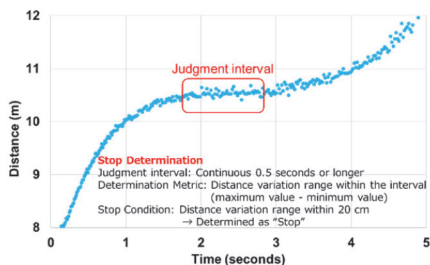


Figure 5 Example of stop detection using actual distance data

5 Study site and overview

Figure 6 shows the study site. The study site is a crosswalk located at 3-11 Umeda, Adachi Ward, Tokyo; the speed limit for this section is 40 km/h.

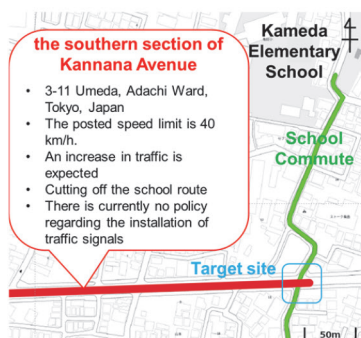


Figure 6 Observation point

6 Verification

6.1 Validation of vehicle behavior recording

In this study, to confirm that the vehicle behavior estimated from the distance data was accurately recorded, we calculated vehicle speed based on the temporal changes in the distance data and verified the validity of the observed data by comparing it with measured speed from back. Figure 7 shows the results of the comparison between the calculated vehicle speed and the measured speed from back. A generally linear relationship was observed between the two, demonstrating that the vehicle speed estimation using LiDAR possesses a certain degree of validity. Figure 8 shows the distribution of speed differences. Although some variation in the speed differences was observed, most data points fell within the acceptable range, suggesting that the vehicle speed calculations using this method possess sufficient accuracy.

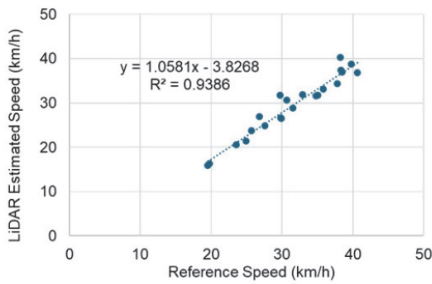


Figure 7 Comparison of measured speed from back and LiDAR estimated speed

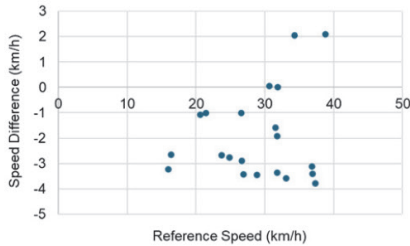


Figure 8 Distribution of speed difference between LiDAR and measured speed from an angle

6.2 Verification of stop detection results

Figure 9 shows the breakdown of the stop detection results. In this study, to confirm the validity of the proposed stop detection method, we conducted verification by comparing it with actual data obtained from video observations. The results confirmed that the method can accurately detect vehicle stopping behavior in most cases, demonstrating its effectiveness. On the other hand, depending on the LiDAR installation conditions and the surrounding environment, distance measurements were sometimes obstructed when pedestrians or bicycles passed between the vehicle and the sensor, resulting in temporary gaps in the distance data. When such data gaps occur, the necessary changes in distance required for stopping detection cannot be fully captured, which may reduce detection accuracy. Additionally, in some cases, it was confirmed that vehicles that should have been detected as stopped could not be detected because the necessary data was not acquired. In summary, while this method generally enables high-precision stop detection, it was demonstrated that it may be susceptible to the effects of data loss caused by the observation environment.

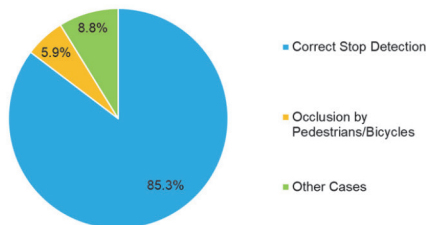


Figure 9 Classification of stop judgment results

7 Observation results

Table 2 shows the observation results for the study site. The stop rate varied from observation to observation, and it was confirmed that results fluctuated even at the same location due to differences in observation conditions.

Table 2 Observed stop rates

	Number of observation units (units)		
	1 st	2 nd	3 rd
Total vehicles	14	22	42
Parked vehicles	5	14	26
Stop rate	35.7%	63.6%	61.9%

8 Conclusion

In this study, we developed an observation method using LiDAR and proposed a technique for quantitatively evaluating vehicle behavior. By calculating stop detection and driving speed based on time-series changes in distance data, and comparing these results with video observation data, we confirmed that stop behavior can be determined with reasonable accuracy. This method is a simple and low-cost approach that enables the quantitative evaluation of vehicle behavior without the use of video recordings. In the future, we aim to develop a pedestrian detection method and combine it with this approach to apply it to the safety assessment of crosswalks. Furthermore, it is necessary to verify its general applicability by testing it at multiple locations.

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