



## DEVELOPMENT OF A SPEED-MEASURING DEVICE FOR VEHICLES USING LASER DISTANCE SENSOR

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### Abstract

In Japan, the speed of vehicles on residential roads (roads used mainly by local residents for their daily activities) is in principle limited to 30 km/h. Various measures such as the introduction of Zone 30 have also been taken to limit driving speeds. However, even in areas designated as Zone 30, there is a constant flow of vehicles running in over the speed limit. If driving speeds could be measured accurately and inexpensively, there are many situations where this would be useful, such as speed surveys on residential roads. Therefore, this study attempted to develop an inexpensive speed measurement system by connecting a laser distance sensor with high measurement accuracy to a small PC. The speed measurement method is as follows. A laser is irradiated at an angle to the running vehicle from outside the roadway. The measurement distance is constant while the sides of the vehicle are irradiated and changes while the front or rear of the vehicle is irradiated. The distance to the front or rear of the vehicle, the laser irradiation angle and the three-square theorem are then used to determine the change in distance in the direction of the driving, and a regression analysis is applied in relation to the time of measurement to calculate the driving speed. It was confirmed that the error between the speed obtained by measuring from an angle and the speed measured from the front was small. In addition, it was confirmed that the speed of vehicles running continuously can also be measured. Furthermore, the frequency of the laser irradiation used in this study was about 70 Hz, and it was confirmed that the speed of a vehicle running at about 70 km/h could be observed with high accuracy.

*Keywords: road safety, speed measurement, device development*

### 1 Introduction

In Japan, the speed limit for motor vehicles on residential roads (roads used mainly by local residents in their daily lives) is, in principle, 30 km/h. However, there is no end to the number of vehicles travelling in excess of the regulated speed. In addition to the designation of Zone 30 as a measure to curb speed, measures have also been taken from a physical aspect, such as humps and chicanes. Speed surveys are useful in identifying living roads where speed needs to be controlled and in verifying the effectiveness of the measures taken. As most municipal roads are occupied by residential roads, speed surveys are carried out at a number of locations. If travelling speeds can be measured accurately and inexpensively, they can be used in many situations, such as speed surveys on residential roads. Observations using videography and installed speed guns require specialised techniques for analysis and are expensive, making it difficult to conduct observations at a large number of locations. In addition, when using a simple method, the handheld type speed guns, it is necessary to take measurements on a certain long straight section of road, and it is difficult to take measurements when the vehicle is continuously moving.

Therefore, the aim of this study was to construct an inexpensive and simple speed measurement system that does not require a long straight section of road for observation and that can be used for measurement when vehicles are continuously passing.

## 2 Previous studies

A number of studies have assessed the effects of the road environment on vehicle speed. In most studies, speed guns or video cameras are used to measure speed and observations are made on long straight sections. In many cases, vehicles following a preceding vehicle are not targeted [1, 2].

On the other hand, Onizuka et al [3] are among the studies that have developed and verified inexpensive speed measurement methods. Onizuka et al. have shown that the speed of a vehicle travelling on a domestic road can be measured using stopwatch measurements with an accuracy equivalent to that of video measurements. On the other hand, they state that the issues are that a measurement section of 20 m to 30 m is required and that a large number of personnel are needed for the measurement.

## 3 Principle of measurement

The concept of the measurement method constructed in this study is shown in Figure 1. Determine the point P through which the car passes, and measure the distance  $L_A$  from an angle to P and the distance  $L_B$  from directly across. The distance  $L_C$  between the sensors can be determined as follows, using the fact that  $L_A$ ,  $L_B$  and  $L_C$  form a right-angle triangle.

$$L_C = L_A \cos \theta = L_A \cos \left( \sin^{-1} \frac{L_B}{L_A} \right) \quad (1)$$

From this, the distance data recorded by sensor L1 from an oblique direction can be corrected to a value parallel to the direction of travel of the car by multiplying by  $\cos(\sin^{-1}(L_B/L_A))$ .

In this section, we consider the case where the change in distance of a car moving away is observed by a sensor installed at an angle. The distance to the light blue areas in the diagram (side and rear) is measured. The measurement results of the change in distance are shown in the diagram. The following equation is obtained by extracting the data where the measured distance to the rear is longer and expressing the relationship between time T and distance D as a regression line.

$$D = aT + b \quad (2)$$

The slope of straight line a (m/s) is used to determine the speed  $V_p$  of the vehicle passing point P. The multiplier of 3.6 is for unit conversion of speed.

$$V_p = 3.6a \text{ [km/h]} \quad (3)$$

Similarly, when measuring the change in distance of an approaching vehicle, the change in distance at the front is recorded first, followed by the distance to the side. The speed is calculated from the regression line of the time variation of the frontal distance by interchanging the sign of the slope.

$$V_p = -3.6a \text{ [km/h]} \quad (4)$$

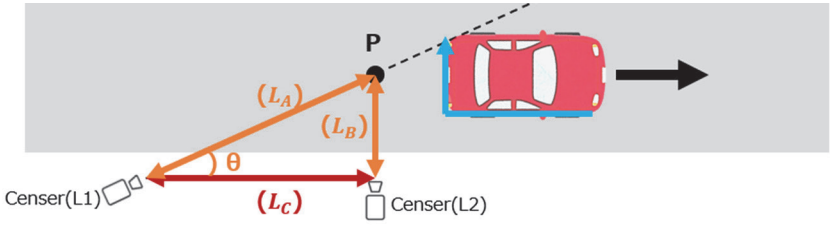


Figure 1 Positioning in measurement

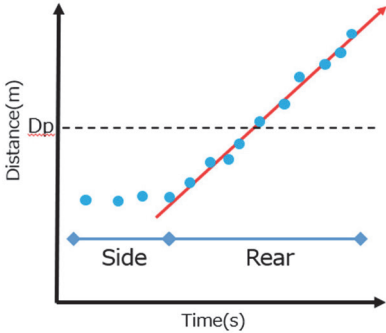


Figure 2 Image of recorded data

## 4 Establishment of observation systems

### 4.1 Equipment overview

Connect the distance sensor to the microcomputer (Raspberry Pi 4) and fix the device to the tripod as shown in Figure 3.

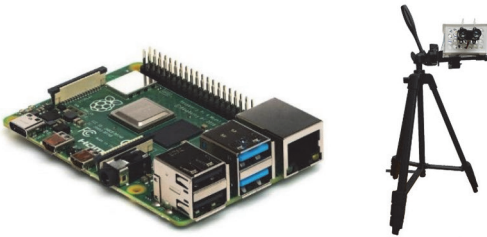


Figure 3 Raspberry Pi 4 (left) & Assembled equipment (right)

### 4.2 Selection of distance sensors

The inexpensive sensor Tfmini [4] and the high-performance LidarLitev3 were used to check whether they could be used for speed measurement; an overview of Tfmini and LidarLitev3 [5] is given in Table 1 and Figure 4.

**Table 1** Distance sensor specifications

Sensor type	Tfmini	LidarLitev3
Measuring range	0.1 m ~ 12 m	0 ~ 40 m
Resolution	1 cm	1 cm
Accuracy	± 0.060 m	± 0.025 m
Maximum frequency	100 Hz	500 Hz
Price	7,600 JPY	28,350 JPY
Manufacturer	Benewake	Germin

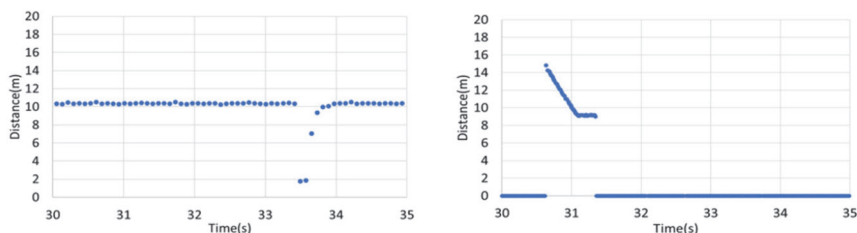


**Figure 4** Tfmini (left) & LidarLitev3 (right)

The actual measured frequencies of the acquired data are shown in the Table2 and the results from the observation of an actually running vehicle are shown in the Figure5. The period (frequency) of data recording was smaller than the nominal value for all sensors. In some cases, the frequency of Tfmini was less than 10, and the number of observation points of the distance change recorded at the moment the vehicle passes is insufficient for the calculation of speed. Furthermore, the measurable range is less than 12 m, which is not considered possible in some locations, such as when there is a wide shoulder or multiple lanes. Therefore, it was decided to use LidarLitev3 for the measurements.

**Table 2** Frequency of data recording

Sensor type	Frequency [Hz]		
	Max	Min	Average
Tfmini	22.2	2.5	13.9
LidarLitev3	100	55	81



**Figure 5** Examples of Tfmini (left) & LidarLitev3 (right) data

## 5 Construction of speed calculation methods

As shown in the Figure 6, instrument L1 was placed on an extension of the vehicle's driving position and L2 was placed at an angle. Six round trips were made to the observation point, with data recorded six times each from the front and rear, to compare the speeds calculated from the measurements made by L1 and L2. The data range used to calculate the speed is compared between 1 m and 2 m before and after the observation point.

First, a comparison was made according to the direction of observation. Both observations from behind and in front of the vehicle in the direction of travel showed a high correlation, but the former resulted in a higher correlation accuracy. This is presumably due to the shape of the vehicle. The rear of the vehicle used for verification is flat, and the higher accuracy of distance measurement compared to the curved front surface is considered to have been reflected in the difference in speed error. In addition, although only one vehicle type was measured in this study, it was decided to adopt measurement from the rear surface, as many vehicles have flat rear surfaces and are considered suitable for measurement when considering actual on-road operation.

Next, a comparison is made with regard to the data extraction range: due to the characteristics of LidarLitev3, a value of 0 m is recorded, as shown in Figure 5, if it is outside the measurement range or if there is not enough reflection. If the other side of the road is a wall or a house, the distance to it is recorded. The data when a vehicle passes is obtained by extracting the front and rear of the distance to the observation point P. While both speeds calculated by extracting 1 m from the front and rear and 2 m from the front and rear showed a high correlation, the former resulted in a higher accuracy. This is thought to be due to the fact that at 1 m, the side sections were not measured. However, considering the actual operation on the road, there may be a case where a vehicle travelling at a faster speed than this time is observed, and the number of measurement points within 1 m is too small to calculate the speed, so it was decided to remove the side data from the data 2 m before and after the observation point and use it to calculate the speed.

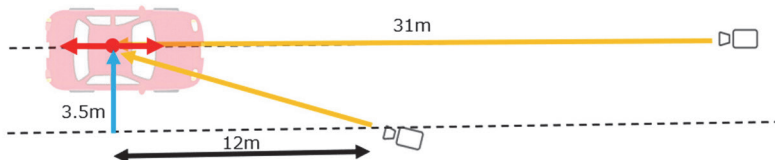


Figure 6 Tfmini (left) & LidarLitev3 (right)

Table 3 Period (frequency) of data recording

Data extraction range	Direction of measurement	
	From the front	From the rear
P ± 1m	0.997	0.999
P ± 2m	0.981	0.99

## 6 Accuracy verification

Using the constructed speed measurement system, the accuracy of the system was verified by measuring the speed of vehicles travelling on the road. As shown in Figure 7, L0, which observes vehicles moving away from it in a straight line, and L1 and L2, which observe them from an angle, were installed to measure their speed. The speed measured in a straight line was then compared with the speeds measured from an oblique angle. Figure 8 shows a plot of the measured speeds, with  $S_{st}$  on the horizontal axis and  $S_{ob}$  on the vertical axis. The coefficient of determination is also shown: for both  $S_{ob1}$  and  $S_{ob2}$ , indicating high measurement accuracy. The Figure 9 also shows the frequency distribution of the error  $E(\%)$  calculated as in Equation 5, where it can be seen that both  $S_{ob1}$  and  $S_{ob2}$  have errors in the 4 and 5 % range. In addition, the median deviates slightly from 0 % in both cases. This may be due to inaccuracies in the right-angled triangles caused by the location and angle of the equipment. The fact that  $S_{ob2}$ , which has a large oblique angle, gives similar results to  $S_{ob1}$  indicates that this method can measure shorter straight sections than existing methods.

$$E = \frac{S_{ob} - S_{st}}{S_{st}} \cdot 100 \tag{5}$$

The validity of the speed measurements for vehicles travelling continuously is confirmed in Figure 10, which shows time on the horizontal axis and distance on the vertical axis. It can be seen that the speeds of consecutive vehicles with intervals of about 1 second can also be measured.



Figure 7 Location of equipment

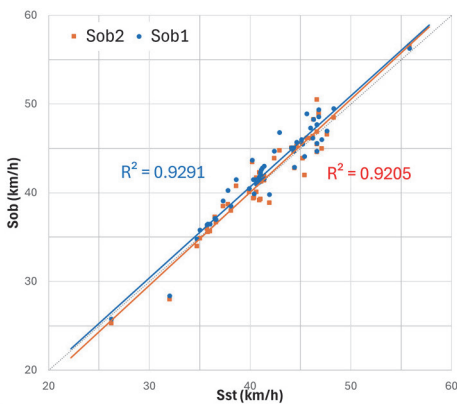


Figure 8 Correlation between  $S_{st}$  and  $S_{ob1}$  &  $S_{ob2}$

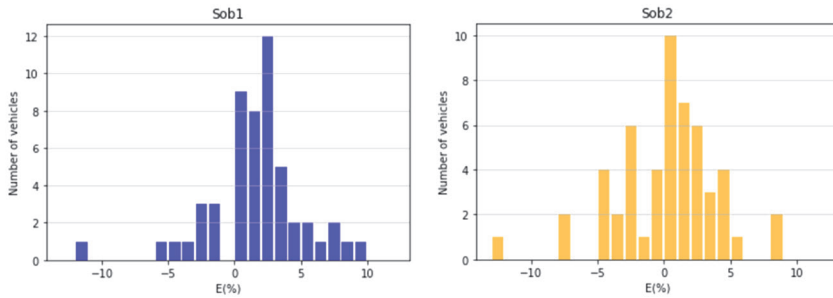


Figure 9  $S_{ob1}$  &  $S_{ob2}$  error with (%)

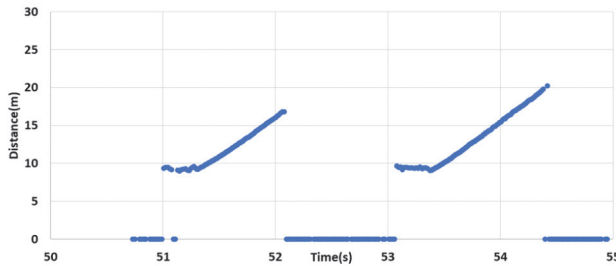


Figure 10 Examples of continuous vehicle measurements

## 7 Conclusion

In this study, an inexpensive and simple speed measurement system was constructed that does not require long straight sections for observation and can be used to measure the speed of vehicles as they pass continuously. A device connected to a small PC with a laser distance sensor with high accuracy in distance measurement was used. The laser is irradiated at an angle to the travelling vehicle from outside the carriageway. Using the distance to the rear, the laser irradiation angle and the three-square theorem, the distance change in the direction of travel was determined and the travel speed was calculated by regression analysis in relation to the time of measurement. It was confirmed that the error between the speed corrected by measuring from an angle and the speed measured from the front was small, and that vehicles travelling in succession could also be measured. It was also shown that this method has the potential to enable measurements on shorter straight sections than existing methods.

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