Microlidar Application for Object Detector to Support The Navigation System in Self-Driving Vehicle

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ABSTRACT

The ability to detect and measure the distance of potential obstacles is importance for navigation system in self-driving vehicles. The measurement process needs to be fast and accurate since the controller requires real-time data to make quick decisions and respond to any potential disturbances on the vehicle's track. This research aims to develop Microlidar for detection system that can accurately measure the distance of a potential obstacle object. The Microlidar utilize Lidar Lite V3 proximity sensor which have range measurement specification of up to 40 meter. Microlidar rapidly rotate 360 degrees by using a stepper motor while in the same time continuously measure the real-time distance. The measurement data are sent to a microcontroller through I2C, and the Processing software plot the 2D image which work like radar visualization. The system is assessed for ranging the various distance object in static and dynamic measurement mode. The results show that the Microlidar has a good level of accuracy with an average error value at the distance of 300 cm is 4.99 cm or 1.7% while the average error value at the distance of 1000 cm is 15.69 cm or 1.6% obtained from 100 data sets collected. The communication from the sensor to Arduino requires a minimum baud rate of 115200 bits/second to minimize data loss and ensure that the measured distance can be processed in real time by the microcontroller. Real-time data with high speed is essential since it will be used on the vehicle in order to quickly decide whether there is a barrier or not on the vehicle's track. The sensor analysis distance expected from this research could be used as a reference to support the navigation system performance of self-driving vehicles.

Keyword: *Self Driving Vehicle, Lidar, Navigation System, Intelligent Transportation System*

1. Introduction

A self-driving vehicle is a vehicle that can operate without human input. Self-driving vehicles use a variety of sensors, including lidar, cameras, and radar, to perceive their surroundings and make decisions about how to navigate safely [1]. Research on self-driving vehicles has been ongoing for decades, but it has accelerated in recent years due to advances in artificial intelligence and sensor technology. Many companies, including Google, Tesla, and Uber, are developing self-driving vehicles, yet security remains a major issue since machines are not fully reliable enough to replace the role of humans in making decisions when driving cars [2], [3]. Sensors are increasingly sophisticated, even the processing speed is improving considering any delay responses can be fatal for an automated car [4]. One of the many sensors developed to support automated cars is a ranging sensor for potential disturbances detection when the car is in motion. This sensor must accurately calculate the distance to an object and send the data to the controller immediately [5], [6]. LiDAR (Light Detection and Ranging) is a widely selected tool for this task since it is a proximity sensor technology that uses scattered light to find the distance and information about an object from the intended target. LiDAR uses laser pulses, similar to radar technology, which uses radio waves to determine the distance to the object by measuring the time between transmission and detection of the transmitted signal [7].

Many related studies use Lidar as an input parameter for self-driving vehicle navigation systems, such as measuring and segmenting highway streets based on lane markers and edges [8]. The sensors used not only utilize Lidar but also combine image processing. Other studies focus on enhancing calibration methods and separating Lidar sensor bias due to noise from the 360-degree rotation (Rotating 2D) using the Levenberg-Marquardt (LM) algorithm [9]. This research successfully reduced the error value to between -15mm to 15mm. Another study focuses on detecting the delimiter edge of a street using Lidar sensors. With Lidar, the limit edge of the street can be detected quickly and accurately and analyzed using a road segmentation method. A lot of data retrieval is done in an off-road manner. The difference with previous research lies in the algorithm calculation of the size of objects that will be detected by the sensor without using image input from a camera. The object located on the lane track will have permanent measurements so that the output decision can be made about whether it is potentially a disturbance or not [10]. Other researchers have proposed a new method for finding the best way to arrange Lidar sensors on a vehicle. The method starts by creating a model of how Lidar sensors work, based on their physical properties. Then, the model is used to develop a general mathematical equation for finding the best arrangement of LiDAR sensors, considering factors such as the angle and position of each sensor based on a new lattice-based approach that converts the problem into a nonlinear optimization problem [11].

This research aims to develop Microlidar for real-time localization to achieve precise pose information in dynamic environments that accurately calculates the distance of potential obstructions in the path of a self-driving vehicle. The Microlidar utilize Lidar Lite V3 proximity sensor which have range measurement specification of up to 40 meters. Microlidar is installed above the car which rapidly rotate 360 degrees by using a stepper motor while in the same time continuously measure the real-time distance. The measurement data are sent to a microcontroller through I2C, and the Processing software plot the 2D image which work like radar visualization.

2. Research Method

2.1. Research Stage

The research of Microlidar application involved a systematic stage as follows:

a) Literature review: To formulate and define the objectives of the Microlidar application. This involved a comprehensive examination of existing research and knowledge to establish a solid foundation for the project.
b) System Design and Construction: This stage involved the conceptualization and creation of the hardware and software components necessary for the effective functioning of the Microlidar.
c) Static Mode Measurements: To ensure accuracy and reliability, the Microlidar system underwent a calibration process through measurements in static mode.
d) Dynamic Mode Measurements: Dynamic mode measurements were conducted to assess and determine the accuracy of the Microlidar system in real-world, dynamic scenarios.
e) Observation and Evaluation: The final stage involved a comprehensive observation and evaluation process. This included a thorough analysis of the data collected during both static and dynamic mode measurements. The observed results were critically evaluated to assess the overall effectiveness and efficiency of the Microlidar application in supporting the navigation system of self-driving vehicles.

Through these systematic stages, the Microlidar application was methodically developed, calibrated, and evaluated to ensure its efficacy in enhancing the navigation capabilities of self-driving vehicles.

2.1. Distance Measurement

Lidar works by emitting a laser pulse and then measure the time it takes for the pulse to return to the sensor [12]. The distance to the target R is then calculated using the following equation:

$$R = \left(\frac{c}{2n}\right)\Delta t$$

where c is the speed of light in a vacuum, Δt is the round-trip travel time of the laser light. and n is the refractive index of the medium through which the laser light travels. The refractive index of the medium through which the laser light travels affects the speed of the light. For example, the refractive index of air is slightly less than 1, while the refractive index of water is slightly more than 1. This means that the laser pulse will travel slightly faster through air than it will through water [13].

In this research, microlidar is utilized for localization which is the process of estimating the position and orientation. First, the microlidar data is divided into several point clouds. Each point cloud represents a snapshot of the lidar data at a specific time. The Microlidar system will be installed on a slipring that can rotate 360 degrees at a constant speed to detect objects around the vehicle, not only from the front but also from the sides and back. The schematic of the microlidar system is designed based on the block diagram shown in Figure 1

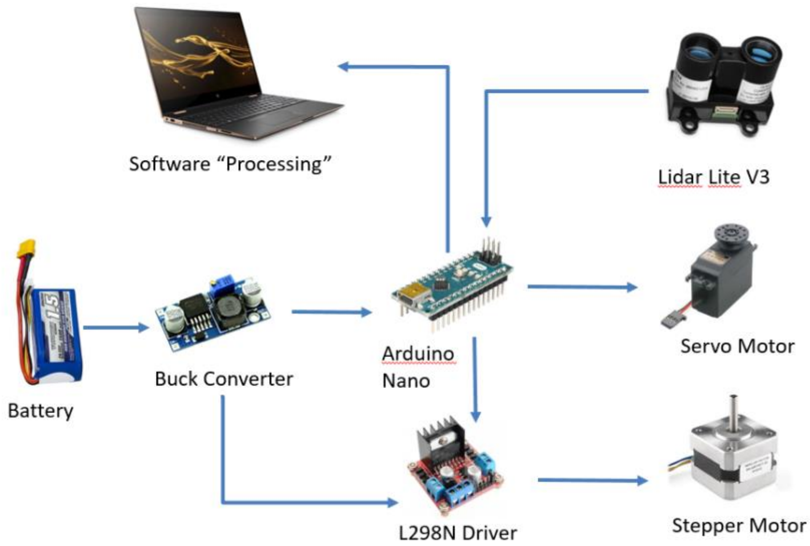

Figure 1. Block diagram microlidar system

The measurement procedure begins by calibrating the receiver bias to its maximum light sensitivity. The transmitter then sends a signal to the receiver to establish a "Zero Distance" time delay. The sensor then performs several measurements to collect periodic data. The transmitter emits a laser signal and waits for the reflected signal to return to the receiver. If a match is found, the data is automatically saved to memory. The measured data is then sent to a computer via Arduino to create a 2D visualization plot. The Microlidar system was assessed in both static and dynamic conditions. In static conditions, the sensor and the measured object were stationary. Objects were placed at 300 cm and 1000 cm from the sensor. Measurement in static condition allows for more accurate measurement of the sensor's range and resolution and for more repeatable measurements. This is because the sensor and object are not moving, so the same data points can be collected multiple times. Static mode assessment can also be used to calibrate the sensor. This is because known distances can be used to verify the sensor's accuracy. In dynamic conditions, the sensor rotated to localize objects around it. Dynamic mode assessment allows for the evaluation of the sensor's performance in real-world conditions or in different environmental conditions. By assessing microlidar in both static and dynamic modes, we can get a more complete picture of the sensor's performance and identify any areas where improvement is needed. In this research, we developed a Microlidar system which is mainly consist of Lidar Lite V3 and Processing software for 2-dimension visualization. The Lidar Lite V3 is utilized in this research because of lower price and its comparable functionality to the lidar used in real autonomous vehicle production, despite having limited range. The system was assembled at the Laboratory of Instrumentation in the Electrical and Informatics Engineering Department at the Vocational School Universitas Gadjah Mada. The detailed materials used in the system are listed in Table 1.

Figure 2 shows the prototype of Microlidar system which consist of Lidar Lite V3 and Processing software for visualization.

Table 1. Utilized materials for microlidar

No.	Materials	No.	Materials
1.	LidarLite V3	6.	Processing Software
2.	Computer	7.	Stepper Motor
3.	Arduino	8.	Slipring 8 wire
4.	Servo Motor	9.	Stepper and Servo Driver
5.	Buck Converter	10.	Battery

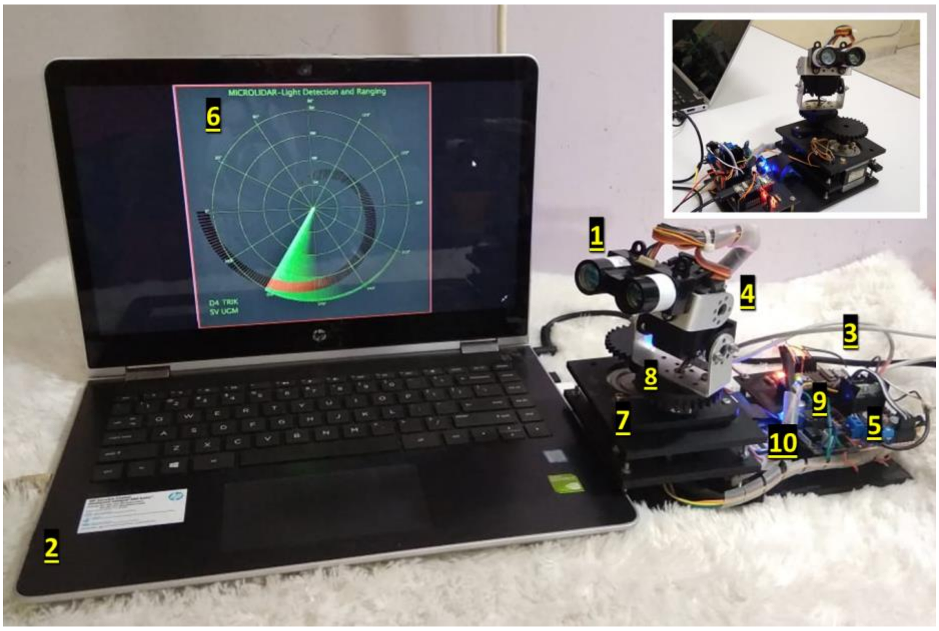

Figure 2. Prototype of microlidar system

3. Result and Analysis

The research includes two categories of measurement analysis which are static and dynamic condition.

3.1. Static Measurement

Static measurement is a way to test the accuracy of a lidar sensor by measuring its distance to an object in a fixed position and comparing that measurement to the actual distance. This is conducted in order to obtain a calibration factor, which can be used to correct the sensor's measurements and improve its accuracy. To perform a static measurement, the lidar sensor is placed in a fixed position and pointed at an object that is at least 3 meters away. This research performed static measurements on a lidar sensor at distances of 300 cm and 1000 cm. We collected 100 data sets at each distance and calculated the average error value. The sensor is then fired multiple times, and the average distance to the object is calculated. This average distance is then compared to the actual distance to the object to obtain the calibration factor. The percentage of average error value $\langle E \rangle$ is determined as the absolute difference between the measured distance D_m and the actual distance D_a, divided by the maximum measured distance D_{max}, as expressed by following equation [14],

$$\langle E \rangle [\%] = \frac{|D_m - D_a|}{D_{max}}$$

Figure 3 shows the measurement result of static condition. The results of the static measurements showed that the lidar sensor had an average error value of 4.99 cm (1.7%) at a distance of 300 cm and an average error value of 15.69 cm (1.6%) at a distance of 1000 cm. These results indicate that the lidar sensor is very accurate, even at long distances.

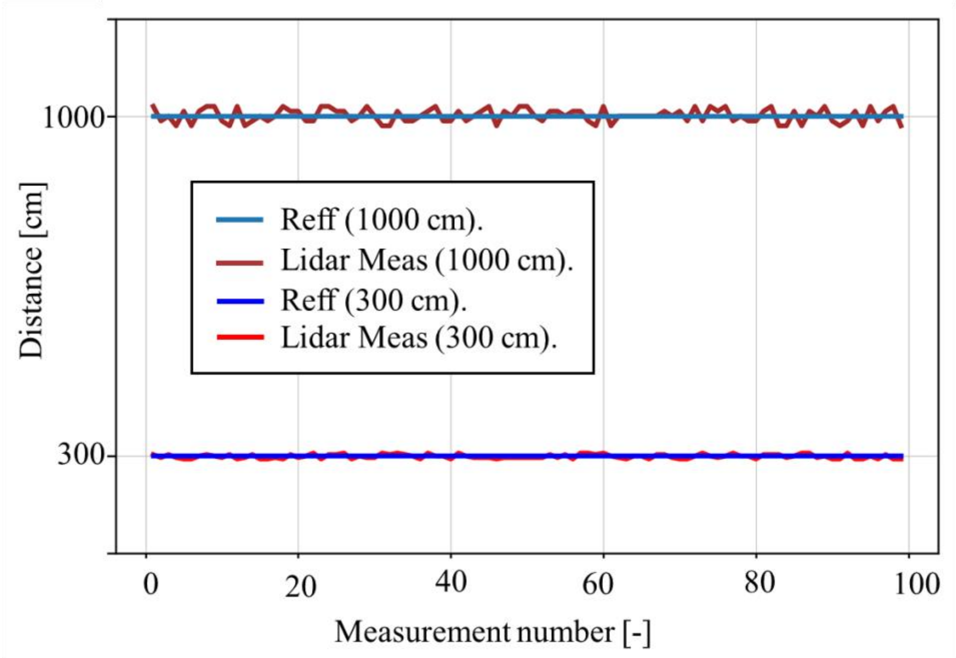

Figure 3. Static measurement at 300 cm and 1000 cm.

3.2. Dynamic Measurement

Dynamic measurement is a way to test the performance of a lidar sensor in real-world conditions by rotating it continuously and measuring the distance to objects around it. This is done to determine if the sensor can accurately detect and report the distance to objects in real time. To perform a dynamic measurement, the lidar sensor is mounted on a stepper motor and rotated at a constant speed. The sensor is then fired multiple times as it rotates, and the distance to objects is measured. The position angle of the stepper motor is used to correlate the distance data to the sensor's orientation. This allows us to create a 2D plot of the sensor's surroundings. The distance data is then plotted on a 2D plot using processing software which is designed to filter out noise and improve the accuracy of the plot. This research performed dynamic measurements on the microlidar at baud rates of 9600 and 115200. The baud rate is the speed at which data is transmitted between the sensor and the computer. A higher baud rate means that data can be transmitted more

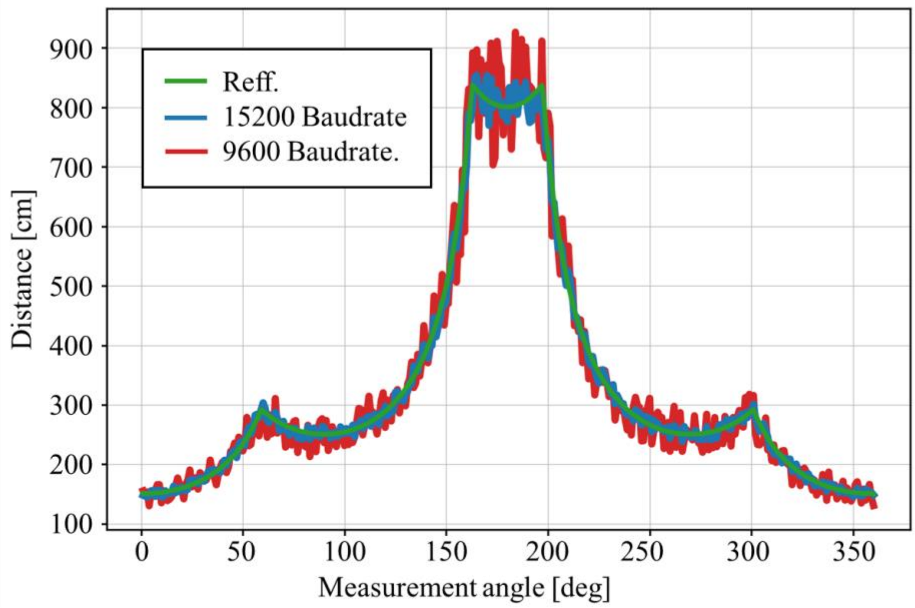

Figure 4. Dynamic measurement result

quickly. The comparison results of the dynamic measurements at two different baud rates allows us to evaluate the effect of baud rate on the sensor's performance. Figure 4 shows the measurement result of dynamic condition.

The results of the dynamic measurements showed that using a baud rate of 9600 resulted in less maximum data transmission and delays in data transmission compared to the rotation of the stepper motor. This is because the sensor could not transmit data quickly enough at the baud rate of 9600. Using a baud rate of 115200 resulted in smoother data, but there were still some fluctuations in the data. This is because the sensor is still under development and is not perfect. Figure 5 shows the microlidar 2-Dimensional plot for visualization which work like radar.

Based on microlidar 2-Dimensional plot, it is visible that using a baud rate of 9600 results in less maximum data transmission due to delays in data distance compared to the rotation of the stepper motor. However, using a baud rate of 115200 shows smoother data even though there are still fluctuations in the data.

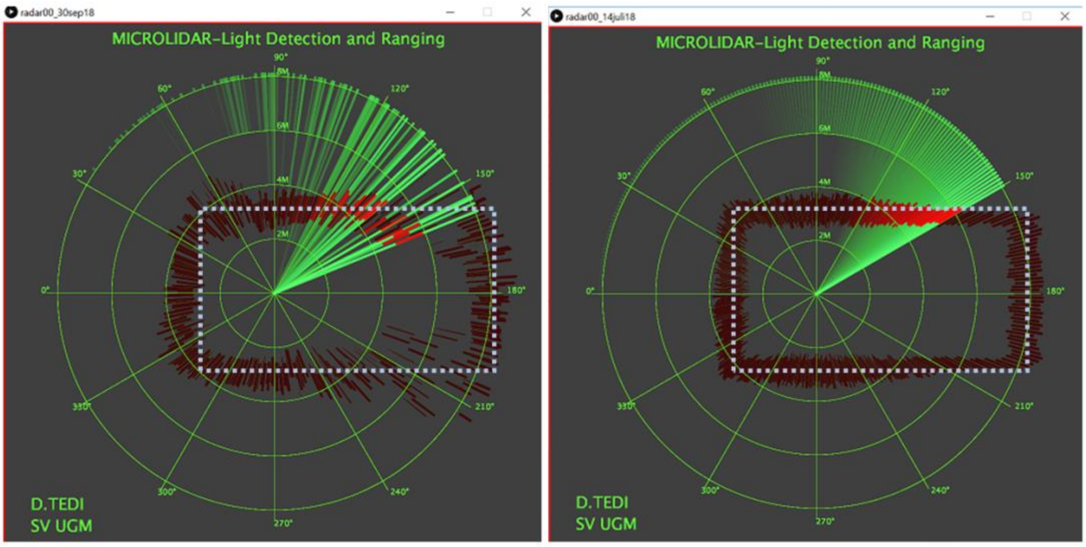

Figure 5. Microlidar 2-Dimensional plot

3.2. Discussion

This research focuses on the measurement analysis of a Lidar Lite V3 sensor that is used as a proximity sensor. The analysis includes two categories, static and dynamic measurement. In static measurement, the sensor is tested by measuring data in a fixed position and comparing it with actual data to obtain the calibration factor. The measurement is done at different distances, and the error values obtained from the data sets collected are within an acceptable range. These error values provide an insight into the accuracy of the sensor and its ability to provide reliable data.

In dynamic measurement, the sensor is rotated continuously at a constant speed while measuring the distance to detect objects around it. The success parameter of this trial is the sensor's ability to detect and transmit the distance of objects around it in real-time. The results of the distance data obtained from the measurement are plotted on a 2-dimensional plot using customized processing software with the position angle of the stepper motor. The obtained data from the measurement provides a comprehensive insight into the functionality of the sensor in a dynamic environment.

Microlidar can provide reliable data at different distances and can accurately detect objects around it in a dynamic environment. The comparison of the results obtained from different baud rates indicates that using a higher baud rate results in smoother data even though there are still fluctuations in the data. This research provides useful information for the development of proximity sensors that can be used in various applications such as automotive, robotics, and industrial automation.

The results of the static measurements showed that the microlidar has an average error value of 15.69 cm (1.6%) at a distance of 1000 cm. Also for data communication from the sensor to the processor, a baud rate of at least 115200 bits per second is recommended, as this results in an average error of 1.7%. In comparison to other lidar application research, Ikhsan, *et al.*, reported an average error of 1.109%, but specifically for distance measurements up to 2 meters [15]. While, Senanjung, *et al.*, report an lower average error of 0.87%, but again, this is limited to distance measurements only up to 2.44 meters [16]. Despite the slightly lower average errors reported in research [15] and [16], it's crucial to recognize the limited range of their measurements that only up to max 2.44 meters. This research with a 1.7% average error up to 10 meters, offers a more extensive operational range without compromising significantly on accuracy. Therefore, it is relatively better when considering broader range of distance measurements it covers. This broader operational range makes it more suitable for applications requiring accurate distance measurements over longer distances, such as those encountered in the context of self-driving vehicles.

3.2. Future Work

There are a number of factors that can affect the accuracy of lidar sensors, including environmental conditions, target reflectivity, and sensor noise. Lidar sensors can be affected by environmental conditions such as dust, fog, and rain [17]. This is because these particles can scatter the laser light, making it more difficult for the sensor to detect objects. The reflectivity of the target can also affect the accuracy of lidar sensors. Dark or non-reflective objects can be more difficult for the sensor to detect. All lidar sensors have some level of noise, which can also affect their accuracy [18].

Therefore, future work to improve the accuracy of lidar sensors is needed. This could involve using multiple sensors, data fusion, and deep learning. By using multiple lidar sensors from different locations on the vehicle, it is possible to create a more complete and accurate map of the surrounding environment. Data fusion algorithms can be used to combine data from lidar sensors with data from other sensors, such as cameras and radar, to improve the overall accuracy of the system. Deep learning algorithms can be used to train lidar sensors to better detect and classify objects, even in challenging environmental conditions.

4. Conclusion

Overall, this research indicates that the microlidar sensor is reliable and accurate for measuring distance and detecting objects in both static and dynamic conditions. The results of the static measurements showed that the lidar sensor had an average error value of 15.69 cm (1.6%) at a distance of 1000 cm. The study also highlights the importance of choosing the appropriate baud rate for transmitting data in dynamic measurement. For data communication from the sensor to the processor, a baud rate of at least 115200 bits per second is recommended, as this results in an average error of 1.7%. This research provides valuable information for improving the design and functionality of proximity sensors, which can have practical applications in various fields such as automotive, robotics, and industrial automation.

References

[1] A. Gazis, E. Ioannou, and E. Katsiri, "Examining the Sensors That Enable Self-Driving Vehicles," *IEEE Potentials*, vol. 39, no. 1, pp. 46–51, 2020, doi: 10.1109/MPOT.2019.2941243.

[2] N. F. Mustamin, I. Indrabayu, and I. S. Areni, "Optimasi Perhitungan Jarak antara Kendaraan," *J. Penelit. Enj.*, vol. 22, no. 2, pp. 105–112, 2018, doi: 10.25042/jpe.112018.02.

[3] N. Jayaweera, N. Rajatheva, and M. Latva-aho, "Autonomous Driving without a Burden: View from Outside with Elevated LiDAR," in *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, 2019, pp. 1–7, doi: 10.1109/VTCSpring.2019.8746507.

[4] X. Du, M. H. Ang, and D. Rus, "Car detection for autonomous vehicle: LIDAR and vision fusion approach through deep learning framework," *IEEE Int. Conf. Intell. Robot. Syst.*, vol. 2017-Septe, pp. 749–754, 2017, doi: 10.1109/IROS.2017.8202234.

[5] Z. Rozsa and T. Sziranyi, "Obstacle prediction for automated guided vehicles based on point clouds measured by a tilted lidar sensor," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 8, pp. 2708–2720, 2018, doi: 10.1109/TITS.2018.2790264.

[6] S. H. Kim, S. J. Lee, and S. W. Kim, "Weaving Laser Vision System for Navigation of Mobile Robots in Pipeline Structures," *IEEE Sens. J.*, vol. 18, no. 6, pp. 2585–2591, 2018, doi: 10.1109/JSEN.2018.2795043.

[7] J. Park, J. Cho, S. Lee, S. Bak, and Y. Kim, "An Automotive LiDAR Performance Test Method in Dynamic Driving Conditions," *Sensors*, vol. 23, no. 8, pp. 1–17, 2023, doi: 10.3390/s23083892.

[8] K. L. Lim, T. Drage, and T. Bra, "Implementation of semantic segmentation for road and lane detection on an autonomous ground vehicle with LIDAR," *IEEE Int. Conf. Multisens. Fusion Integr. Intell. Syst.*, vol. 2017-Novem, no. Mfi, pp. 429–434, 2017, doi: 10.1109/MFI.2017.8170358.

[9] Y. Zeng *et al.*, "An improved calibration method for a rotating 2D LIDAR system," *Sensors*, vol. 18, p. 497, 2018, doi: 10.3390/s18020497.

[10] C. Premebida, O. Ludwig, and U. Nunes, "LIDAR and vision-based pedestrian detection system," *J. F. Robot.*, vol. 26, pp. 696–711, 2009, doi: 10.1002/rob.20312.

[11] S. Mou, Y. Chang, W. Wang, and D. Zhao, "An Optimal LiDAR Configuration Approach for Self-Driving Cars," *J. Comput. Sci. Robot.*, 2018, [Online]. Available: http://arxiv.org/abs/1805.07843.

[12] Fardiansyah Nur Aziz and Masduki Zakarijah, "Analisis Kinerja Sensor TF-Mini LiDAR untuk Pengukuran Jarak," *J. Nas. Tek. Elektro dan Teknol. Inf.*, vol. 11, no. 3, pp. 192–198, 2022, doi: 10.22146/jnteti.v11i3.3814.

[13] T. Hieta, M. Merimaa, M. Vainio, J. Seppä, and A. Lassila, "High-precision diode-laser-based temperature

measurement for air refractive index compensation," *Appl. Opt.*, vol. 50, no. 31, pp. 5990–5998, Nov. 2011, doi: 10.1364/AO.50.005990.

[14] A. M. Handayani and I. N. Rifa'i, "Sistem Ground Control Station Berbasis Mobile Untuk Pengamatan Dan Pengendalian Uav," *J. Nas. Teknol. Terap.*, vol. 2, no. 1, p. 121, 2018, doi: 10.22146/jntt.39204.

[15] I. Maulana, A. Rusdinar, and R. A. Priramadhi, "Lidar Aplication for Mapping and Navigating on Clossed Environtment," *e-Proceeding Eng.*, vol. 5, pp. 1–8, 2018.

[16] S. Prayoga, A. Budianto, and A. B. Kusuma Atmaja, "Sistem Pemetaan Ruangan 2D Menggunakan Lidar," *J. Integr.*, vol. 9, no. 1, p. 73, 2017, doi: 10.30871/ji.v9i1.273.

[17] R. Heinzler, P. Schindler, J. Seekircher, W. Ritter, and W. Stork, "Weather Influence and Classification with Automotive Lidar Sensors," in *2019 IEEE Intelligent Vehicles Symposium (IV)*, 2019, pp. 1527–1534, doi: 10.1109/IVS.2019.8814205.

[18] T. Gao *et al.*, "Effects of temperature environment on ranging accuracy of lidar," in *Tenth International Conference on Digital Image Processing (ICDIP 2018)*, 2018, vol. 10806, p. 1080671, doi: 10.1117/12.2503192.