

Object Distance Detection System with Ultrasonic Sensor on Mobile Robot

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Abstract

Indonesia is home to 76 active volcanoes, one of them being Mount Tangkuban Parahu. To ensure that a robot that can move around to collect data does not get stopped in its tracks, HC-SR04 ultrasonic sensors are used to detect obstacles within 100 cm. The sensors were first characterized by measuring distances between 10 and 100 cm with an increment of 10 cm. They were then tested in a laboratory environment with differing conditions. Finally, they were tested on Mount Tangkuban Parahu. Characterization shows that, within 100 cm, one of the two sensors had good linearity, while the other showed larger error values. This difference in performance carried onto the laboratory scale test and the field test.

Keywords: mobile robot, object distance, tangkuban parahu, ultrasonic sensor, volcanic eruption

INTRODUCTION

Indonesia resides within the ring of fire. Owing to the fact, there are 147 volcanoes within Indonesia, 76 of them active. Between 1900 and 2016, volcanic eruptions caused the second highest amount of deaths after earthquakes [1]. In 2023, 23 people lost their lives to volcanic eruptions, while 12 others were injured and 6,355 lost their homes [2].

Mount Tangkuban Parahu is an active volcano located in West Bandung Regency. Its last large eruption occurred in the 18th century, and has since shown weak activity. Its eruption can still cause damage, particularly because of the poisonous gases it produces such as carbon monoxide, carbon dioxide, and sulfur dioxide [1].

In order to minimize the damage done by eruptions, a device to detect eruptions in advance could be utilized. MONICA is a system designed to monitor volcanic activities. It consists of a fixed-mode and a mobile-mode. The fixed-mode is the default mode of operation, and is able to monitor parameters such as seismicity, dome growth, gas emission, spreading cloud and eruption ash, surface temperature, and pyroclastic zone. Should the sensors fail, the mobile-mode activates as an emergency measure [3]. The mobile-mode utilizes MERLIN, which is a mobile

robot designed for outdoor use. It is equipped with sensors to maneuver itself and can navigate around obstacles [4].

PRAWIRA is a mobile robot specifically made for monitoring the area around a volcano. Its large wheels and symmetrical shape allows maneuverability even when flipped. It is equipped with a SO₂ and CO₂ sensor, a temperature sensor, and a vibration sensor to monitor the surrounding area. It is also equipped with ultrasonic sensors to detect obstacles in its path. A PID controller is used to control its motors and adjust its speed [5].

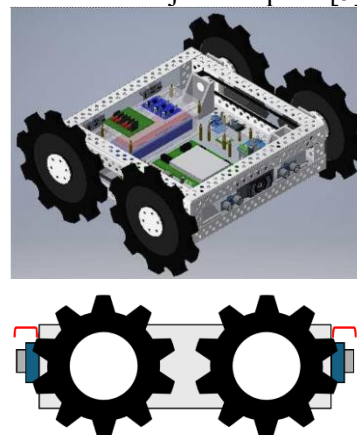


Figure 1. PRAWIRA mobile robot [5] (top), and the ultrasonic sensor placement on PRAWIRA, marked in red (bottom).

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A way for mobile robots to detect obstacles is necessary, which can be done using methods such as object detection or using ultrasonic sensors. Object detection with machine learning can be used to detect obstacles and determine a traversable path [6].

This research tests the performance of the ultrasonic sensors as obstacle detectors for mobile robots. The sensor is characterized in a controlled setting using a ruler. Data is then taken with a variety of ground conditions.

This research improves the previous research done by Maria Evita about Design of Object Detection System for Tangkuban Parahu Volcano Monitoring Application. In the previous research, the system was able to detect the object type without measuring the distance [13]. This research is focused on improving the system's object distance detection by using ultrasonic sensor HC-SR04.

METHOD

HC-SR04 ultrasonic sensor operates with a transmitter-receiver system for ultrasound waves [7]. The concept is similar to echolocation like how bats used to detect a distance, this sensor detects distance by transmitting ultrasound waves with the transmitter and the echo will be received by the receiver. The sensor operates around 40kHz frequency and 3.3 ~ 5 V DC voltage. The effective range for this sensor to detect distance is around 2 cm ~ 400 cm with 15° of effective angle [8].

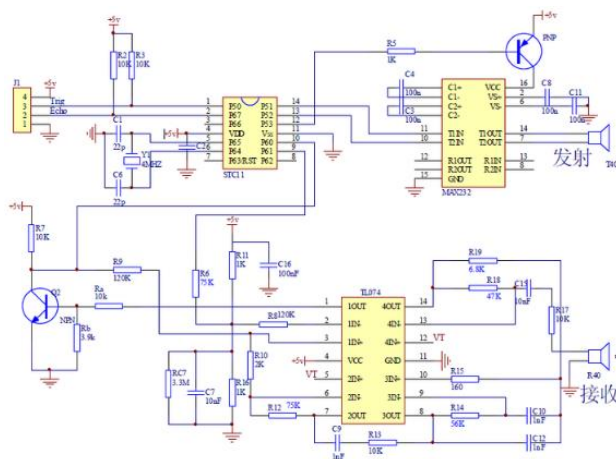


Figure 2. HC-SR04 circuit diagram [9].

In object distance detection system, the ultrasonic sensor serves as the primary and most essential component. In this experiment, the mobile robot is prototyped by a toy truck moved manually by a person. The movement velocity is assumed constant so that we could get the mean velocity. We use two ultrasonic sensors attached at the front of the mobile

robot, in the same position at a height of 10 cm from the ground as shown in Figure 3.



Figure 3. The toy truck as the mobile robot prototype with two ultrasonic sensors.

The received measurements are sent via MQTT, a messaging protocol consisting of publisher clients, a broker, and subscriber clients. Messages consist of payload data, a Quality of Service, Properties, and a Topic Name [10]. The measurements are then sent to Grafana, an open source software that can visualize data, amongst other things, via Node-Red, a flow-based development tool [11][12].

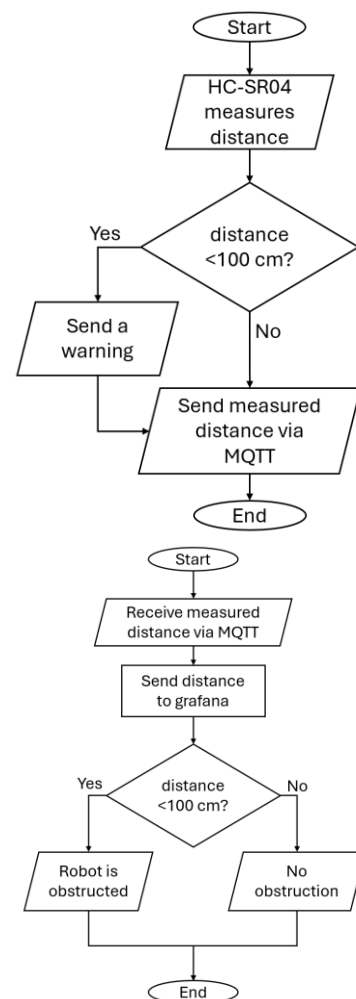


Figure 4. Program (up) and Node-Red (bottom) flowchart.

The experimental methods are divided into 3 segments. The first segment is the characterization method by using the sensor to measure distance within 10 - 100 cm with 10 cm increase of every measurement with one minute time interval of data recording in order to determine the sensor linearity characteristic and effective range by comparing the sensor measured distance with a calibrated distance measurement, which in this case is the measuring tape. The characterization was done because sensors will detect objects within the effective range of 100 cm in front so that the robot will not collide with the objects in range. This process is illustrated in Figure 5.



Figure 5. Sensor characterization.

Second, the sensors were tested on laboratory scale with 5 kinds of test field. The test fields are ramp or inclined field, road with rocks, wet dirt road, grassy path, and rough surface as shown in Figure 6. Every test field has the same distance of 500 cm on a straight path with various travel times depending on the difficulty of the robot to move on every test field.



Figure 6. The test fields used for sensor testing on a laboratory

scale: a) Ramp or inclined field, b) Road with rocks, c) Wet dirt road, d) Grassy path, e) Rough surface.

Third, the sensors were tested in the field on a stratovolcanic mountain located in Jl. Raya Subang, Desa Cicadas, Kec. Sagalaherang, Kabupaten Subang, Jawa Barat, called Gunung Tangkuban Parahu. In equivalence of the previous segment test fields, the test fields on the stratovolcanic mountain chosen were rocky inclined surface descending, rocky inclined surface climbing, straight surface, rocky straight surface, and sandy road as shown in Figure 7. Every test field has the same description of distance and assumption like in the previous segment. The test on stratovolcano was held three times in three different times, which are the morning, noon, and dusk time.



Figure 7. The test fields on the stratovolcanic mountain: a) Rocky inclined surface descending, b) Rocky inclined surface climbing, c) Straight surface, d) Rocky straight surface, e) Sandy road.

RESULTS AND DISCUSSION

Figure 8 shows curves of the linear regression model and the sensor's residual plot from the characterization process.

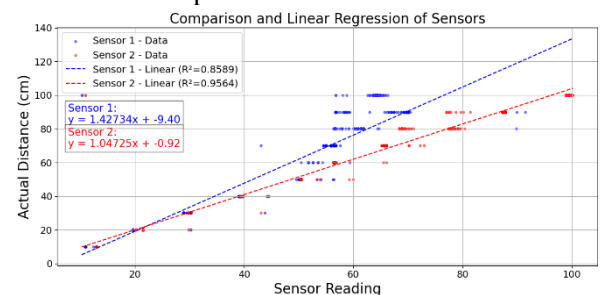




Figure 8. Comparison of two sensors results of characterization process (up) linear regression, (bottom) absolute error plot.

Figure 8 shows that there are different capabilities of the sensors to detect and measure distance from an object within 100 cm range. Sensor 1 detects objects in a bit unusual behavior with linearity of R^2 in 0.8589 with residual shown in around 50 - 70 of sensor reading. The absolute error plot interprets that sensor 1 has a lot of absolute error compared to sensor 2. The plot concludes that sensor 1 has a significant error measurement to detect objects within an effective range under 100 cm.

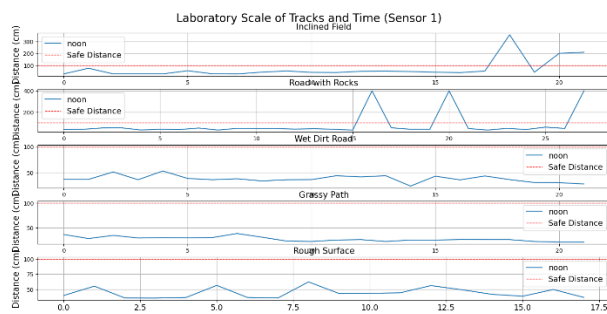


Figure 9. Comparison of two sensors results in laboratory scale on 5 different fields (Sensor 1).

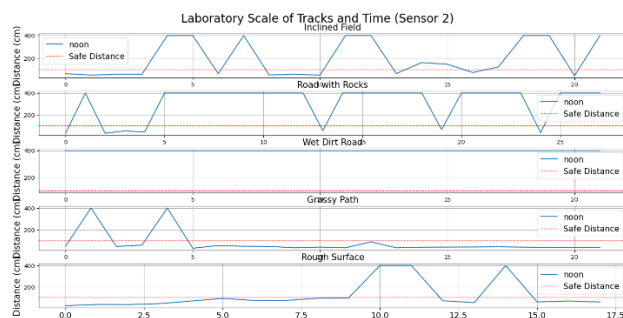


Figure 10. Comparison of two sensors results in laboratory scale on 5 different fields (Sensor 2).

Table 1. Average velocity of laboratory scale tests

Number	Terrain	Time (s)	Average Velocity (m/s)
1	Inclined	21.82	0.229
2	Rocky	27.39	0.183

3	Wet dirt	21.68	0.231
4	Grass	21.19	0.236
5	Hard floor	17.78	0.281

Figure 9 & 10 shows the results for both sensors in laboratory scale test fields. The results show that the left sensor (sensor 1) is mostly unable to detect distances above the effective range of 100 cm. This can be seen from the blue lines rarely reaching a peak of 400 cm, which indicates a lack of obstacles as it's the maximum detection range of the sensor [8]. The relation from Figure 7 & 8 which states that sensor 1 is not really effective on higher distance is further proven by Figure 9 & 10.

The results on Figure 9 & 10 shows that sensors will most likely detect objects on fields with a lot of obstacles such as grassy path, road with rocks, or inclined field. Since sensor 1 does not detect effectively in higher distances, the sensor tends to detect everything lower than 100 cm. However, sensor 2 shows it effectively detects higher distances so that the sensor is effective on detecting objects blocking the robot better than sensor 1.

Table 1 lists the amount of time and the average velocity of the toy truck during the test. The test was done by dragging the toy truck along for 5 meters. The average velocity is obtained by dividing the distance travelled, which is 5 meters, by the time listed on the table.

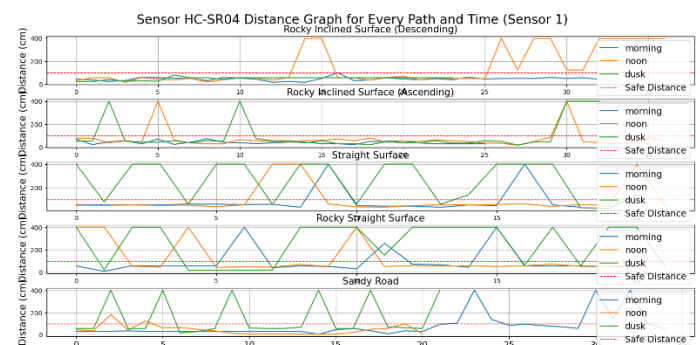


Figure 11. Comparison of two sensors results in the stratovolcano Tangkuban Parahu (Sensor 1).

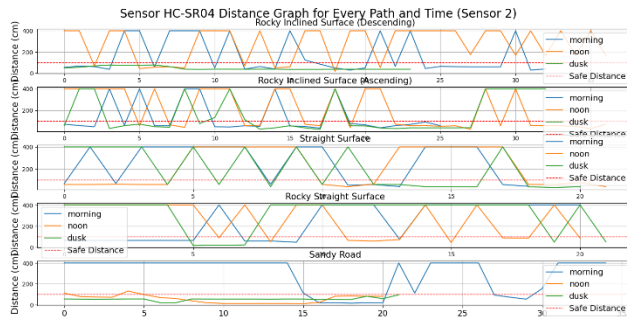


Figure 12. Comparison of two sensors results in the stratovolcano Tangkuban Parahu (Sensor 2).

Table 2. Average velocity of morning time on test fields

Number	Terrain	Time (s)	Average Velocity (m/s)
1	Rocky, downhill	32.39	0.154
2	Rocky, uphill	25.72	0.194
3	Flat ground	18.61	0.269
4	Flat ground, reverse	22.12	0.226
5	Flat rocky ground	19.8	0.253
6	Flat rocky ground, reverse	19.55	0.256
7	Flat sandy ground	34.43	0.145
8	Flat sandy ground, reverse	17.87	0.280

Table 3. Average velocity of noon time on test fields

Number	Terrain	Time (s)	Average Velocity (m/s)
1	Rocky, downhill	36.1	0.139
2	Rocky, uphill	36.82	0.136
3	Flat ground	20.96	0.239

4	Flat ground, reverse	15.97	0.313
5	Flat rocky ground	19.77	0.253
6	Flat rocky ground, reverse	23.43	0.213
7	Flat sandy ground	19.98	0.250
8	Flat sandy ground, reverse	19.13	0.261

Table 4. Average velocity of dusk time on test fields

Number	Terrain	Time (s)	Average Velocity (m/s)
1	Rocky, downhill	23.58	0.212
2	Rocky, uphill	32.39	0.154
3	Flat ground	20.89	0.239
4	Flat ground, reverse	20.86	0.240
5	Flat rocky ground	21.6	0.231
6	Flat rocky ground, reverse	23.34	0.214
7	Flat sandy ground	21.78	0.230
8	Flat sandy ground, reverse	25.58	0.195

Figure 11 & 12 shows the results for both sensors in the stratovolcano Tangkuban Parahu. The data recording process was held within the forest region of Tangkuban Parahu Mountain. The test fields are mostly rocks, sand fields, and trees. The results show

that both sensors detect a lot of obstacles on the fields. The results show that sensors will detect objects with an effective range lower than 100 cm on fields with a lot of obstacles, such as rocky surfaces or inclined surfaces. There are a lot of trees and other obstacles on the mountain therefore sensors will most likely detect more objects within 100 cm range. Sensor 2 more consistently detects a distance of 400 cm as the maximum distance detection for HC-SR04 sensor [8], where the blue line stays above the red dotted line, while sensor 1 tend to return a reading of under 100 cm causing a false positive detection of obstacles.

On the rocky inclined surface descending field, the sensor will most likely detect less objects than the rocky inclined surface climbing field. The climbing field detects more objects because when the truck is climbing, sensors are heading towards the inclined surface. Since it's an inclined rocky surface, sensors will most likely detect rocks while climbing the surface. As shown in Figure 11 & 12, rocky inclined surface tends to detect rocks, therefore the sensors will likely detect distance under 100 cm, which is below the red dot line as the safe distance for robot to move. The sensor effective range is 0.3 m ~ 3.0m, and the effective angle of the sensor detecting distance is below 15° [8]. The sensor was used in rocky surfaces with a lot of collision which could cause fluctuations to the sensor positioning in robot prototype. This could be the main reason why the sensor cannot effectively detect distance greater than 100 cm. Even though it's still possible to detect distances up to 400 cm, but the fluctuations caused by robot prototype collisions with rocks and other obstacles can cause the sensors move from ideal position for measuring distances.

Tables 2, 3, and 4 lists the amount of time taken and the average velocity over the test for morning, noon, and dusk respectively. The toy truck is dragged for 5 meters, and in addition to the variation in ground conditions, is also tested while moving forward and moving in reverse. The velocity is calculated from dividing the distance of 5 meters by the time taken.

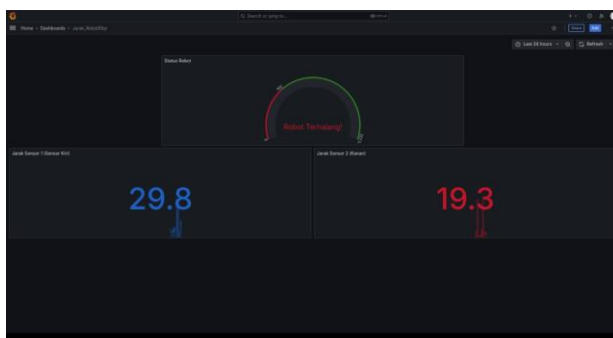


Figure 13. Internet of Things dashboard of sensor system by Grafana.

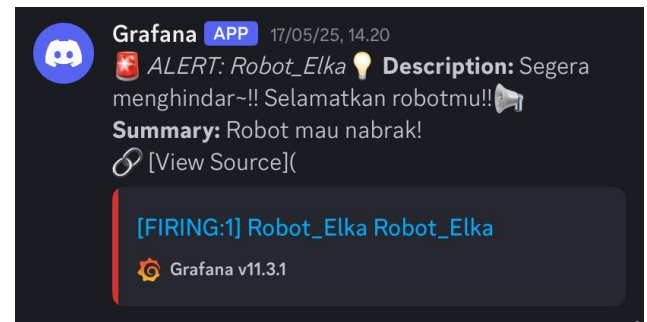


Figure 14. Robot collision alert notification by Grafana on Discord.

Figure 13 shows the IoT dashboard of the sensor system powered by Grafana. The dashboard is published on local network with hotspot Wi-Fi through mobile phone using Mosquitto as open source MQTT broker. The system has included with GSM communication, so that when Wi-Fi is unable to be accessed, GSM can still be used. The GSM use Telkomsel operator which is usable in the data acquisition spot and some other spots in Tangkuban Parahu Mountain. The dashboard panel shows three different information. The top middle panel shows the robot status which will inform the user that the robot is blocked if the sensor system detects objects within 100 cm distance. The middle-left panel shows sensor 1 (left sensor on Figure 3) distance measurement. The middle-right panel shows sensor 2 (right sensor on Figure 3) distance measurement.

Figure 14 shows the alert notification if sensor detects object within 100 cm distance, which will inform the user that the robot is blocked. The alert notification is powered by Grafana and uses Discord as a platform to receive alert messages through webhook.

CONCLUSION

This experiment tested how well ultrasonic sensors would work as obstacle detectors for a mobile robot around Mount Tangkuban Parahu. During characterization for detection within 100 cm, one of the sensors underperformed with an R-square score of 0.8589 while the other had a much better 0.9564. Further projects may reduce the error of the ultrasonic sensors by means such as readjusting the position of the sensor or testing the sensors individually in a more controlled environment. A way to alert the robot's system when an obstacle is detected can also be developed.

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