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Hostage Liberation Operations Using Wheeled Robots Based on LIDAR (Light Detection and Ranging) Sensors

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ABSTRACT

Hostage release operations require a high level of precision, alertness, and skill, which are carried out manually by soldiers of the Indonesian National Army. This medium presents a significant risk to soldiers. This research aims to improve the effectiveness of hostage release operations by integrating wheeled robot technology based on Light Detection and Ranging (LIDAR) sensors. The research method used is experiment-based in developing and testing a prototype of a mobile robot equipped with LIDAR technology and a web camera capable of mapping the location of hostages in three dimensions. The research showed that this robot has high accuracy, reaching 97.87%, and can create three-dimensional route maps and display real-time video on a computer. The use of this technology has the potential to reduce risks to soldiers and improve the accuracy of mapping hostage locations, which can ultimately improve the safety and effectiveness of hostage release operations in the context of special operations tasks by soldiers of the Army.

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1. INTRODUCTION

Hostage release operations are a critical task carried out by military special units, such as the Special Forces Command within the Army [1, 2]. This task covers various aspects, from outdoor operations to closed indoor situations. The key to success in carrying out hostage release operations is skill, accuracy, and efficiency in executing the task [1]. In several previous studies, it has been found that hostage release operations often involve high risks [3, 4], And increased effectiveness in running it is very desirable. Moreover, in such operations, punctuality and minimal personnel risk are paramount [1]. Although there have been several studies addressing various aspects of hostage release operations [5], there are still gaps that need to be addressed. Some previous studies may not have provided fully adequate solutions to address the challenges in hostage release operations, especially in the context of technological equipment that can help improve the effectiveness of these operations. In this context, research focuses on using LIDAR sensor-based wheeled robot technology in hostage release operations. Researchers identified that the use of this technology has not yet been fully explored in the context of the Indonesian Armed Forces, and its potential to improve the effectiveness of hostage release operations is still an area open to further research. In the researchers' view, using wheeled robots based on LIDAR sensors could address several key challenges in hostage release operations, such as navigation in difficult environments and real-time data collection.

However, this research aims to fill the knowledge gap by designing, developing, and evaluating a LIDAR sensor-based wheeled robot system [6, 7] which can increase the effectiveness of hostage release operations. With this approach, researchers hope to significantly contribute to solving this important problem and make it safer, more efficient, and more effective in the context of the Indonesian Armed Forces, possibly having broader implications in similar operation scenarios. Related research has been conducted by the researcher [8] regarding using lidar sensors and PID methods in legged robot navigation systems. The results showed that using PID control in legged robot navigation systems can improve the stability of robot movement. The use of lidar sensors also helps in avoiding collisions with walls. One of the areas for improvement in this journal is the limited ability to simulate experiments using Matlab. In addition, research conducted by the researcher [9] discussed the implementation of a location mapping system using LiDAR sensors on AUMR (Automatic UVC Mobile Robot) robots to assist in the process of disinfection and sterilization of isolation rooms for COVID-19 patients. The research results are that the location mapping system using the LiDAR sensor on AUMR has good accuracy. The test results showed that the average error in map formation using LiDAR sensors was 2.19%, and the robot localization test had an average error of no more than 2.15%.

The shortcomings of this study are that there needs to be a discussion of the factors that can affect the accuracy of mapping and localization of robots using LiDAR sensors. In addition, related research conducted by the researcher [10] discusses using Autonomous Surface Vehicle (ASV) as an environmental monitoring tool using waypoint navigation methods. The advantage of this study is the use of waypoint navigation methods that allow ASVs to conduct environmental monitoring automatically. **However**, the drawback is that this study only focused on ASV applications as environmental monitoring tools and did not discuss other applications of waypoint navigation methods. In addition, the researcher conducted related research [11] Regarding the design of an automatic mobile robot that can move to the desired set point or position using omni wheels attached to the robot's frame. The advantage of this robot is its ability to move in any direction without taking much time, thus allowing the robot to maneuver quickly. However, the journal does not explicitly mention the shortcomings of the designed robots. In addition, research [12] discusses the performance analysis of two SLAM algorithms, namely Gmapping and Hector Mapping, for mobile robot navigation. The advantages of the study presented experimental results using RViz widget visualization and Rviz measurement tools. However, the journal does not provide information about the experimental environment used, such as the size of the room and the type of obstacles that exist. The researcher also conducted related research [6], which discusses using Robot Operating System (ROS) software for simulation and its applicability in real-world scenarios. The study aims to provide a reference for future research in developing wheeled robots for logistics distribution. The advantages of this research are that it discusses relevant and important topics in robot development, namely the localization and design of wheeled robots. The lack of this research means that more detailed information about the design and development of wheeled robots used in the study is needed.

This research highlights its differences from previous research by focusing on the robot's real-time ability to monitor indoor conditions and create accurate location mapping. The aim is to reduce the risks faced by personnel in prisoner release operations. By utilizing LIDAR technology, **this research aims** to present an innovative solution that enables surveillance and mapping without direct personnel involvement, hoping to increase the effectiveness of captive release operations and minimize the risk of personnel losses. **This research contributes** to the development of science by combining LIDAR technology for security. Thus, this research not only provides practical solutions for critical operational situations but also enhances our theoretical understanding of the application and optimization of this technology in a security context. Overall, this research can become a basis for further development in advanced technology integration to increase the success of prisoner release operations and personnel safety. Based on the problems described, the research's writing structure is as follows: the second subsection discusses the research methods used. The third subsection discusses the design results, test results, and discussion. The last subsection discusses conclusions and suggestions for further research from the research that has been done.

2. RESEARCH METHOD

The stages in this research are conducting problem analysis, data collection and literature study, system design, system design implementation, and system testing [13]. This research method includes literature studies for understanding the research context, design and development of wheeled robots with LIDAR sensors, data collection from various sources, robot trials and evaluations, analysis of the resulting data, and conclusions and recommendations. In addition, various methods such as computer vision, mapping, robotic control algorithms, and hostage release will be used. The required data includes the LIDAR sensor, environmental, and robot movement data. This research uses special wheeled robots with appropriate hardware and software. Testing involves functional testing, navigation, and hostage release operations, including field trials where possible. With this approach, this research aims to improve the effectiveness of hostage release operations with robotic technology based on LIDAR sensors. The stages of research can be shown in Figure 1.

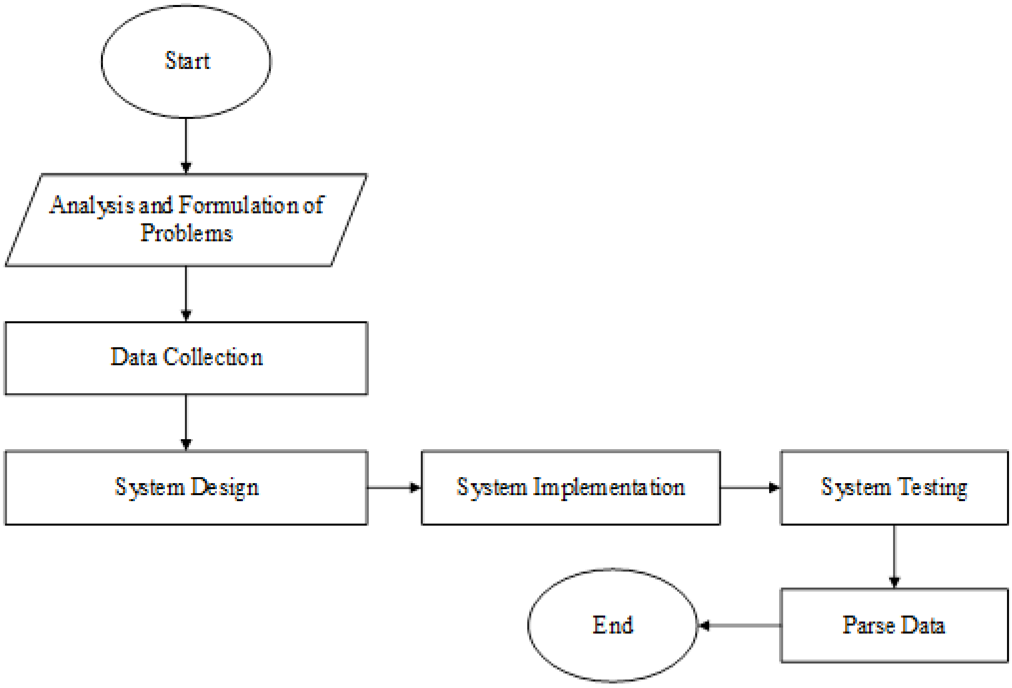

Figure 1. Stages of research

2.1. Overall Circuit System Design

A block diagram is a system diagram in which the main parts or functions represented by the blocks are connected by lines, showing the relationships of the blocks [14]. Block diagrams are widely used in engineering in hardware design, electronic design, software design, and process flow diagrams [15]. The functions of the components in the circuit system can be described, among others. First, Sensor Light Detection and Ranging (LIDAR) [16] is an input device to detect the distance between the robot and its objects or obstacles. Secondly, the Raspberry Pi 4, as a data processing center, receives distance information from the LIDAR sensor and sends it to the RViz application. Third, the RViz application is a monitoring interface that displays visual representations of the surrounding environment in three dimensions [9]. The Overall Circuit System Design Block Diagram is shown in Figure 2.

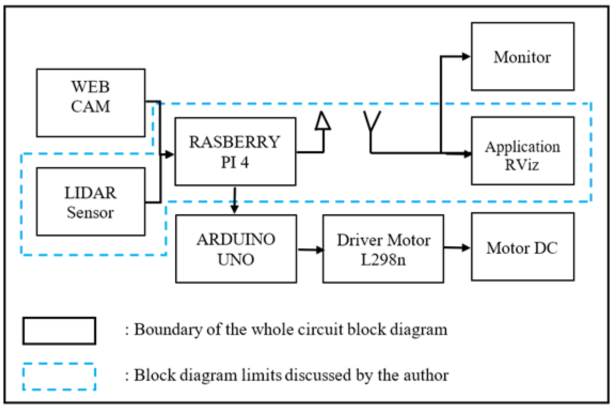

Figure 2. Overall Circuit System Design Block Diagram

The working system of the diagram block in Figure 2 can be described as follows: First, the LIDAR sensor detects the distance between the robot and surrounding obstructions, and the results of this detection are sent to the Raspberry Pi 4 for further processing. Second, the Raspberry Pi 4 receives input data from the LIDAR sensor and processes it into more detailed distance data. This processed distance data is sent wirelessly through the router to the laptop. Third, after the laptop receives the processed distance data, the RViz application converts the data into a three-dimensional map image that appears on the laptop monitor screen, allowing the robot to monitor and navigate the surrounding environment. The success rate of Wheeled Robot Design employing LIDAR Sensor can be quantified by applying Equations (1) and (2).

$$\bar{X} = \frac{X_1 + X_2 + X_3 \ldots X_n}{n} \tag{1}$$

$\bar{X}$ is Area average rating, $X_1, X_2, X_3, \ldots, Xn$ is data value ke $1, 2, 3 \ldots,$ and n is Amount of data. $\bar{X}$ is the Average of actual area values and $\bar{X}$I is Average LIDAR Sensor reading area value.

$$Error = \frac{\bar{x} - xi}{\bar{x}} \times 100\% \tag{2}$$

2.2. Design of the Raspberry Pi 4 range

In this study, the authors chose Raspberry Pi 4 as the main processor to process distance data and transmit it wirelessly to the RVIZ application to create three-dimensional sketch maps. The Raspberry Pi 4 is equipped with Wi-Fi, which allows wirelessly transmitting distance data to the receiving system. In this configuration, the Raspberry Pi 4 only uses a USB port to connect with a LIDAR sensor, while a micro-USB port is used to connect it to a power bank with a capacity of 10000 mAh. The shape of the Raspberry PI 4 series will be shown in Figure 3.

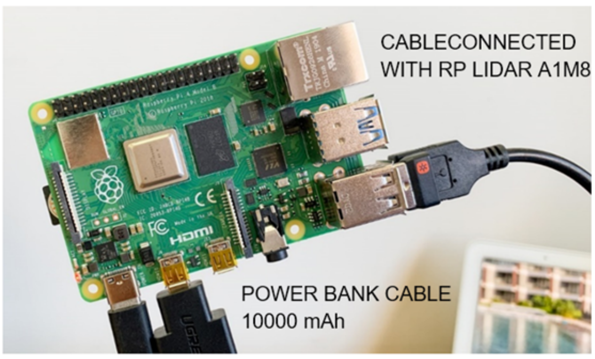

Figure 3. Raspberry PI 4 Series

2.3. LIDAR Sensor Family Design

A LIDAR sensor with the type of RP LIDAR A1M8 is used to detect the distance of objects around the robot. This sensor connects to the Raspberry Pi 4 using a microB USB cable and connects to one of the ports on the device. The LIDAR sensor circuit is shown in Figure 4.

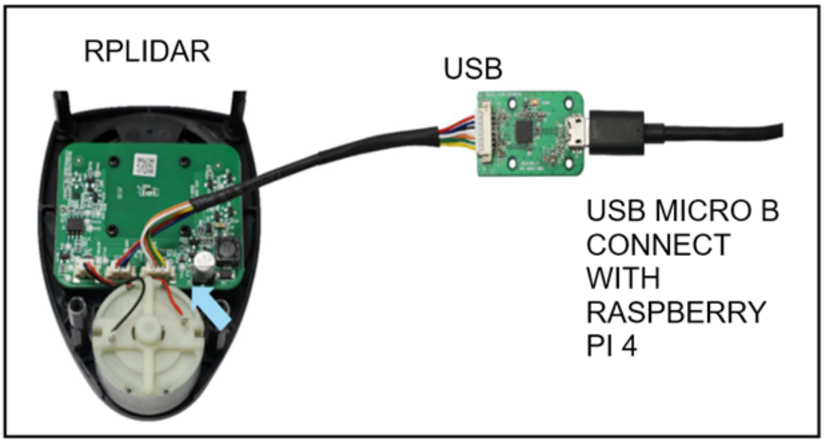

Figure 4. LIDAR Sensor Network

2.4. Wireless Circuit Design

Wireless is a wireless network formed without cables to transmit data. This research used a Linksys EA2750 N600 Dual-Band Smart Wi-Fi Router type router to create this network. This network transfers data directly between the Rasberry Pi 4 and the laptop when processing data generated by LIDAR sensors. The preparation of this network is necessary to assess whether the wireless connection can function properly. The design of the wireless network will be shown in Figure 5.

Figure 5. Wireless Network Network Network Design

2.5. RVIZ Application Suite Design

RVIZ is an open-source-based framework that contains tools and libraries useful in developing programs or applications for robot systems [1, 17, 12]. This application must be installed on the Linux operating system to be used. The following is the display of the main page of RVIZ specifically for mapping or mapping, which will be shown in Figure 6.

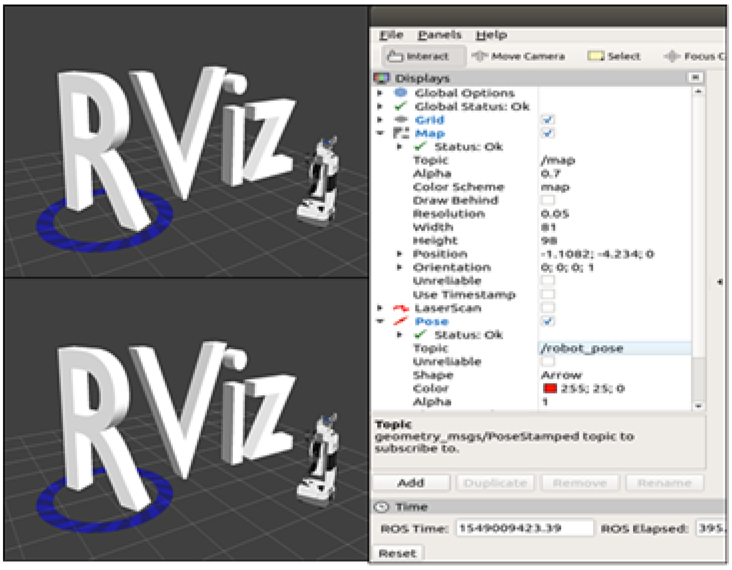

Figure 6. RVIZ Application Suite Design

2.6. Overall Range Design

The whole circuit consists of three main components: the sensor circuit, the controller circuit, and the output circuit. The LIDAR sensor acts as an input component to detect the distance to obstacles the robot may encounter. Raspberry Pi 4 acts as a data processing device to analyze the results of distance detection received from the sensor. The results of distance data processed by the Raspberry Pi 4 will be sent wirelessly to the laptop device through the router network. A micro-B USB cable connects the sensor to the Raspberry Pi 4, while a type C cable connects the power source to the Raspberry Pi 4. The Overall Circuit Design is shown in Figure 7.

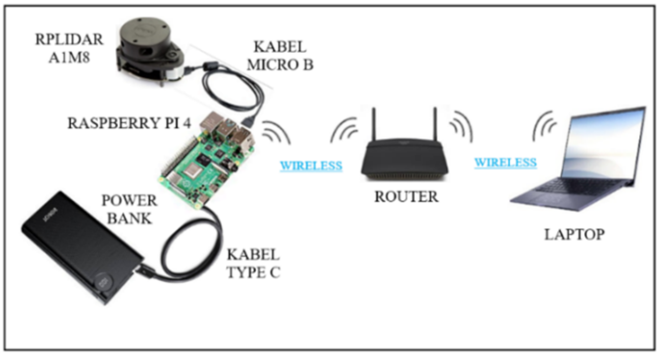

Figure 7. Overall Range DesignOverall Range Design

2.7. System Design

The overall picture of a robot system is a visual representation of the entire robot when viewed from a specific angle. It aims to make it easier to understand the robot's dimensions from different perspectives and help to imagine its shape better. Robot System Design is shown in Figures 8, 9, 10 and 11.

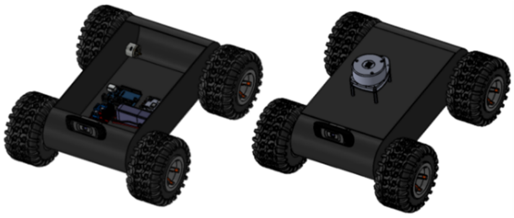

Figure 8. Robot System Design Looks overall

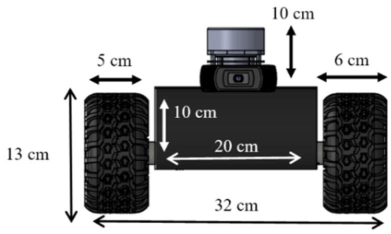

Figure 9. Front View Robot System Design

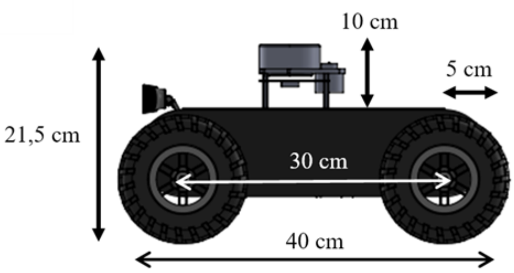

Figure 10. Robot System Design Side View

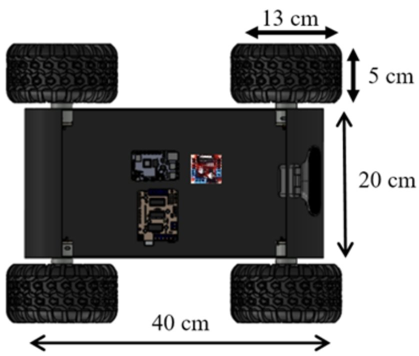

Figure 11. Top View Robot System Design

2.8. Software Design

Software design consists of several stages, namely the design of the sender flowchart software and the receiver flowchart.

1. Shipper Flowchart Software Design
The shipper system flowchart works in several stages, including the LIDAR sensor, and the Raspberry Pi 4 gets power from a 5 V DC battery voltage source provided by a 100,000 mAh power bank. Furthermore, a LIDAR sensor is used to detect the distance of obstacles around the robot and transmit this data as input to the Raspberry Pi 4. If distance data is not detected, the LIDAR sensor will remain in standby mode and continuously monitor the distance. Once distance data is available, the Raspberry Pi 4 will process it into data ready to be transmitted via wireless connection to the receiving system. If the data-sending process fails, the Raspberry Pi 4 will try to continue resending data until it succeeds. After the data is successfully submitted, the data transmission process is complete, and the receiving system will process the data. The Sender System Flowchart is shown in Figure 12.

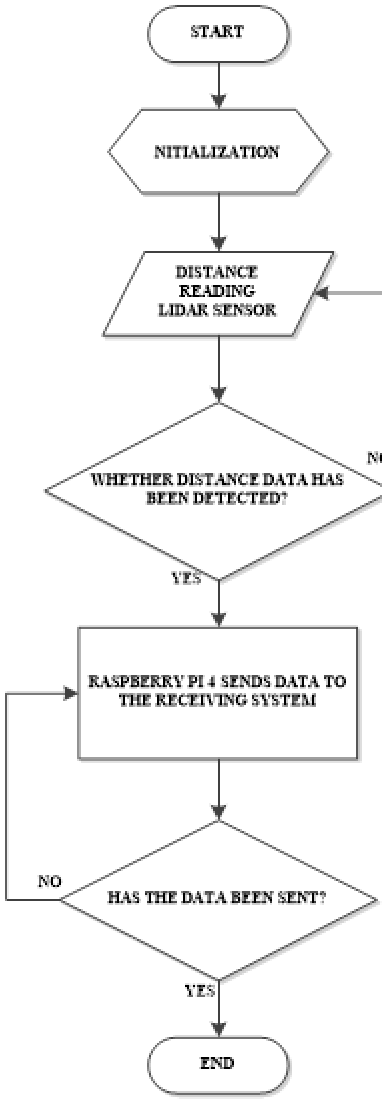

Figure 12. Shipper System Flowchart

2. Receiver Flowchart Software Design
In the design of the receiver flowchart software, there are several stages in operation, including the open-source application

RVIZ in the Linux OS checking whether distance data is received from the Raspberry PI 4. Otherwise, RVIZ remains active and constantly monitors data that may be sent by the Raspberry PI 4. After RVIZ receives the distance data, the data is processed into a 3D room map design display. If the mapping is incomplete, RVIZ will continue trying to map the 2D map according to the existing distance data. If the mapping has been completed, the distance data reception process has succeeded, and a 3D map will be displayed. The Shipper System Flowchart is shown in Figure 13.

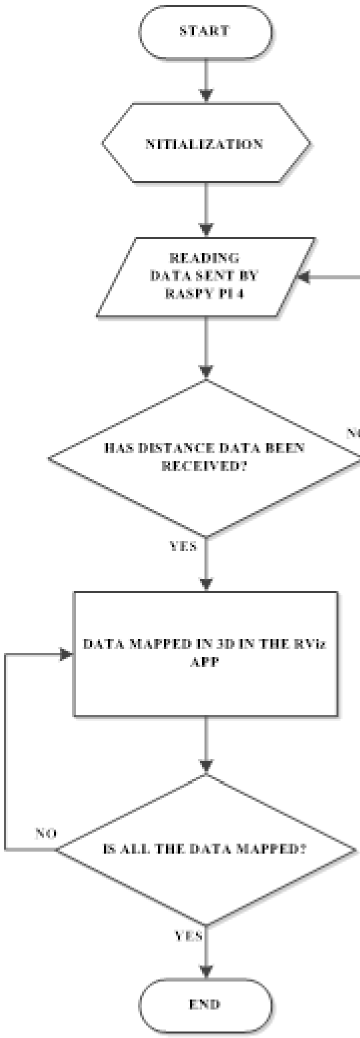

Figure 13. Shipper System Flowchart

3. RESULT AND ANALYSIS

The findings of this research are that using wheeled robots based on LIDAR sensors can significantly increase the effectiveness of hostage release operations. **This finding is supported** by the results of previous research [6, 7, 9], which shows the success of implementing a location mapping system using a LIDAR sensor on an AUMR (Automatic UVC Mobile Robot) robot in assisting the disinfection and sterilization process of isolation rooms for COVID-19 patients. In line with previous research, our results confirm that the accuracy of research success percentages is a critical aspect of primary concern during experiments and measurements. To provide further justification, our results and analysis need to be enriched with an explanation of the implications of our findings and a direct comparison with the results of previous related studies. The practical implications of this research involve the development of more efficient and accurate hostage-release technologies. By comparing our results with previous research, it can be seen that using wheeled robots with LIDAR sensors provides clear advantages in increasing efficiency in hostage release situations. In addition, this comparison also highlights the advantages and disadvantages of each approach, enriching the understanding of the applications of these technologies in various contexts. Thus, this research contributes to the academic literature through its experimental findings and provides valuable insights for developing practical applications in hostage release situations and the potential use of similar robots in other scenarios.

3.1. Rasberry PI 4 Test Results

This test aims to evaluate the results and performance quality of the Raspberry Pi 4 so that it can function optimally. The test procedure was carried out by testing the USB port of the Raspberry Pi 4. Port test results show that when the Raspberry Pi 4 is not connected to any device, it does not detect any connection. However, when a LIDAR sensor is intentionally connected to the Raspberry Pi 4 port and tested using certain coding, the Raspberry Pi successfully detects the presence of the port used. These results show that the USB port of the Raspberry Pi 4 is working properly and can work effectively. Raspberry PI 4 test results are shown in Figures 14 and 15.

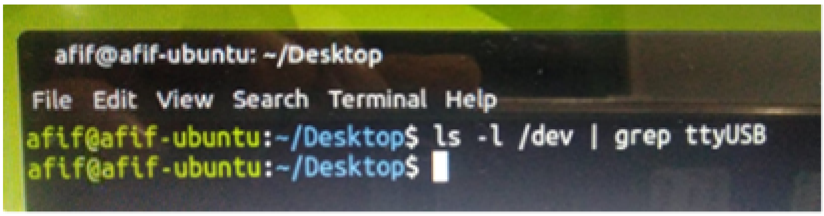

Figure 14. Raspberry Pi 4 Port Without Port test results

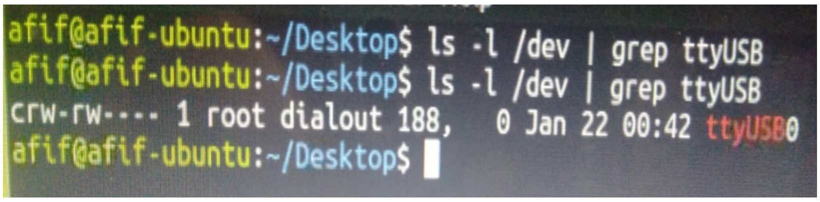

Figure 15. Raspberry Pi 4 Port Test Result With Port

3.2. LIDAR Sensor Test Results

This test aims to evaluate the results and quality of the LIDAR sensor to verify whether the sensor is still functioning optimally. Tests were conducted utilizing ROS and RViz packages to visualize scan data from the RPLidar A1M8 sensor. In a series of tests of 20 experiments in the same room, the study was conducted by comparing the measured distance with the actual distance in the field in each experiment. Measurements were taken at 0^o, 90^o, 180^o and 270^o angles from the LIDAR sensor. From the test results, it was found that the average percentage of error for each angle was (0.82) percent, (0.26) percent, (0.26) percent, and (0.49) percent so that the average total error percentage was 0.46%. LIDAR Sensor Test Results are shown in Table 1.

Table 1. LIDAR Sensor Test Results

Number	Real distance (m) At an angle				Distance on LIDAR (m) At an angle				Submit an error (%) At an angle			
	0^o	900^o	1800^o	2700^o	0^o	900^o	1800^o	2700^o	0^o	900^o	1800^o	2700^o
1	2	6.5	7.1	3.6	2.02	6.52	7.12	3.62	1.0	0.3	0.3	0.6
2	2	6.5	7.1	3.6	2.02	651	7.11	3.61	1.0	0.2	0.1	0.3
3	2	6.5	7.1	3.6	2.02	6.52	7.12	3.62	1.0	0.3	0.3	0.6
4	2	6.5	7.1	3.6	2.01	6.51	7.12	3.62	0.5	0.2	0.3	0.6
5	2	6.5	7.1	3.6	2.02	6.52	7.11	3.61	1.0	0.3	0.1	0.3
6	2	6.5	7.1	3.6	2.01	6.52	7.12	3.62	0.5	0.3	0.3	0.6
7	2	6.5	7.1	3.6	2.01	6.52	7.11	3.61	0.5	0.3	0.1	0.3
8	2	6.5	7.1	3.6	2.01	6.51	7.12	3.62	0.5	0.2	0.3	0.6
9	2	6.5	7.1	3.6	2.02	6.52	7.12	3.62	1.0	0.3	0.3	0.6
10	2	6.5	7.1	3.6	2.02	6.51	7.12	3.61	1.0	0.2	0.3	0.3
11	2	6.5	7.1	3.6	2.02	6.51	7.12	3.62	1.0	0.2	0.3	0.6
12	2	6.5	7.1	3.6	2.01	6.52	7.12	3.62	0.5	0.3	0.3	0.6
13	2	6.5	7.1	3.6	2.01	6.52	7.12	3.61	0.5	0.3	0.3	0.3
14	2	6.5	7.1	3.6	2.02	6.51	7.12	3.62	1.0	0.2	0.3	0.6
15	2	6.5	7.1	3.6	2.02	6.52	7.12	3.61	1.0	0.3	0.3	0.3
16	2	6.5	7.1	3.6	2.02	6.52	7.11	3.62	1.0	0.3	0.1	0.6
17	2	6.5	7.1	3.6	2.02	6.52	7.12	3.62	1.0	0.3	0.3	0.6
18	2	6.5	7.1	3.6	2.02	6.51	7.12	3.61	1.0	0.2	0.3	0.3
19	2	6.5	7.1	3.6	2.02	6.52	7.12	3.62	1.0	0.3	0.3	0.6
20	2	6.5	7.1	3.6	2.01	6.52	7.12	3.62	0.5	0.3	0.3	0.6
Average error percentage per corner									0.82	0.26	0.26	0.49
Average total error percentage									0,46			

3.3. Wireless Test Results

This test is carried out to assess the results and quality of the wireless network to operate effectively. The method used is connection testing using SSH in the Ubuntu terminal to connect the Raspberry Pi 4 to a laptop. This test aims to verify whether both systems' Robot Operating Systems (ROS) have been successfully connected. The test results show that the network will be well connected if the laptop and Raspberry Pi have the same network. The success of the wireless connection between the laptop and the Raspberry Pi 4 can be confirmed by successfully processing or transmitting data. Wireless test results are shown in Figure 16.

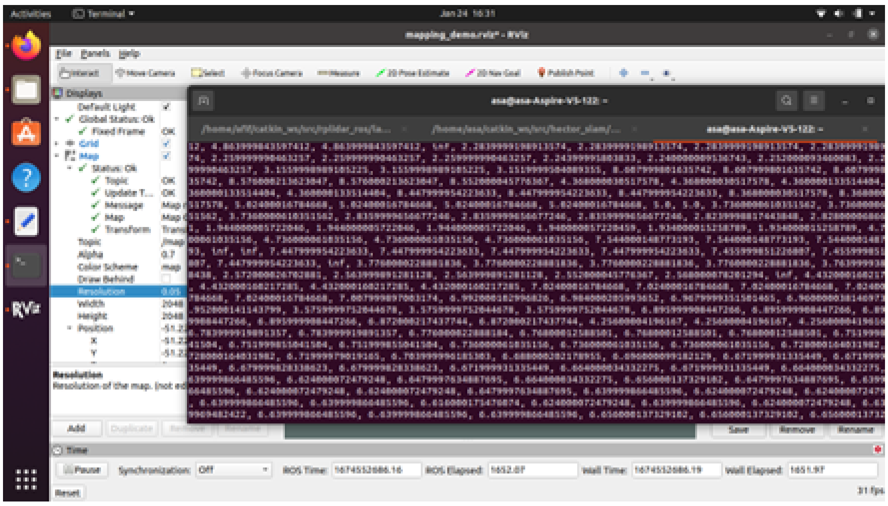

Figure 16. Wireless Test Results

3.4. Rviz Test Results

This test aims to verify a successful connection between the RVIZ application and the system. The test results obtained show that RVIZ can successfully display the main page. Based on the results of these tests, researchers can conclude that RVIZ responds to commands according to the given coding and runs well but is only available for the Linux operating system. RVIZ Test Results are shown in Figure 17.

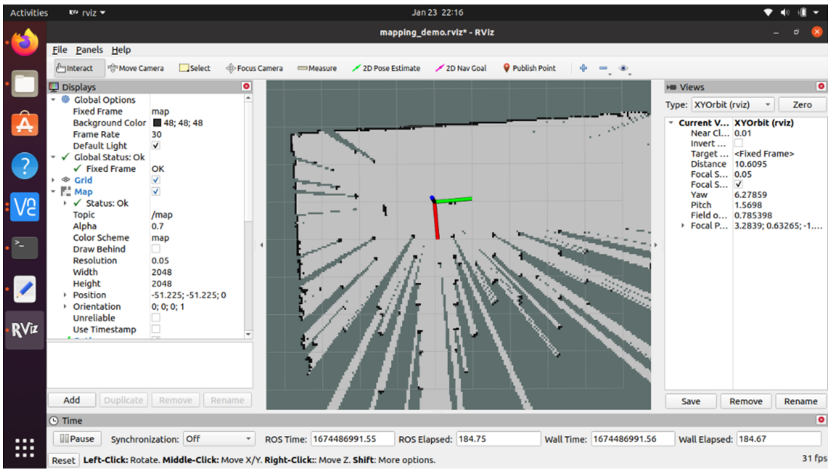

Figure 17. RVIZ Test Results

3.5. Overall circuit test results

The testing of the whole circuit shows that mapping rooms using LIDAR sensors have a high success rate and precision. In this experiment, researchers ran 20 experiments involving comparing the actual area of the measured map with the area of the measured map using Rviz. The comparison of the results of measuring the area of the room is shown in Table 2.

Table 2. Comparison of Room Area Measurement Results

Number	Manual measurement (m^2)			RVIZ Measurement (m^2)			Wide Difference (m^2)	Error (%)
	Length (m)	Width (m)	Area (m^2)	Length (m)	Width (m)	Area (m^2)		
1	10	9	90	10	9.1	91	1	1.1
2	10	9	90	10.2	9.1	92.82	2.82	3.1
3	10	9	90	10	9.2	92	2	2.2
4	10	9	90	10.1	9	90.9	0.9	1
5	10	9	90	10.2	9.1	92.82	2.82	3.1
6	10	9	90	10.1	9	90.9	0.9	1
7	10	9	90	10	9.2	92	2	2.2
8	10	9	90	10.1	9	90.9	0.9	1
9	10	9	90	10.1	9	90.9	0.9	1
10	10	9	90	10	9.1	91	1	1.1
11	10	9	90	10	9.2	92	2	2.2
12	10	9	90	10.1	9.2	92.92	2.92	3.2
13	10	9	90	10.3	9	92.7	2.7	3
14	10	9	90	10.2	9	91.8	1.8	2
15	10	9	90	10.1	9.2	92.92	2.92	3.2
16	10	9	90	10.1	9.3	93.93	3.93	4.3
17	10	9	90	10	9.1	91	1	1.1
18	10	9	90	10	9.2	92	2	2.2
19	10	9	90	10.1	9.2	92.92	2.92	3.2
20	10	9	90	10	9.1	91	1	1.1
Average	10	9	90	10.09	9.12	91.92	1.92	2.13

Based on Table 2, it can be obtained error is (90-91,92)/90 X 100% = 2,13%, and success percentage is 100% - 2,13% = 97,87%. The experimental results showed that the average area difference was about 1.92 square meters, with an average percentage of area error of 2.13% and a success percentage of 97.87%. The results of the Overall Circuit Test are shown in Figure 18.

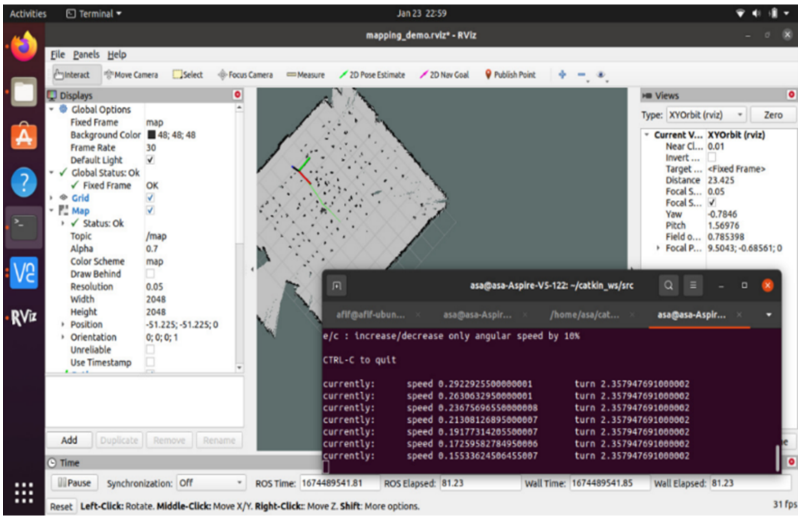

Figure 18. Overall circuit test results

3.6. Wheeled Robot Design Analysis

After testing, it was found that the comparison between manual measurements and measurements using LIDAR sensors showed a difference that did not exceed 0.09 m for length and 0.12 m for room width and did not exceed 1.92 m2 for room area. In addition, test results with 20 attempts showed variations in error percentages, ranging from 0% to 3.2%, with an average error of 2.13%. Indicates that room mapping using LIDAR sensors achieves a 97.87% success rate and precision in real-field situations.

4. CONCLUSION

Based on the design and testing that has been carried out, the wheeled robot was successfully built to increase the effectiveness of Operation Hostage Release. This robot can map locations continuously with an angular radius of 360 degrees using a LIDAR sensor, which has an accuracy and accuracy rate of 97.87%. In addition, to display maps in three-dimensional format, the RVIZ application was chosen because it has a low error rate, only about 2.13%. Although the robot can generate a three-dimensional digital map of a room in real-time, weaknesses still need to be addressed. Robots cannot detect rooms with bumpy terrain, as this can affect the digital maps' quality. Therefore, it is hoped that future researchers will develop alternative methods to overcome this challenge.

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6. DECLARATIONS

AUTHOR CONTIBUTION

All four authors contributed significantly to the conception, design, analysis, and interpretation of the research. author 1 and Author 2 were involved in data collection, while Author 3, Auhtor 4, and Author 5 contributed to the data analysis. All authors participated in drafting and revising the manuscript critically for important intellectual content. Each author has approved the final version of the manuscript and takes responsibility for the accuracy and integrity of the work.

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COMPETING INTEREST
All authors reported this article with no competing financial interests or personal conflicts.

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