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LIDAR Application for Mapping and Robot Navigation on Closed Environment

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Abstract
Mapping and navigation on robots are now widely implemented in areas such as industry, home appliances, military, exploration and automated vehicles. In the environment that are hard to reach by human, mapping and navigation algorithms are absolutely necessary. In order to support the algorithms, Light Detection and Ranging (LIDAR) sensor is needed. In this research, the LIDAR sensor is built, by using one laser sensor which is rotated by a servo motor, the distance between the sensor position and the measured point around it can be calculated. The distance information are converted into Cartesian axes. Using the Cartesian axes, local maps is built and localization of position information can be determined. The result showed that the proposed Sensor worked properly, and the algorithm is able to generate map and position information.

Keywords: *Mapping and Navigation; LIDAR; Localization; Local Map; Global Map*

1. Introduction
Environmental mapping is one of the most important aspects of robotics studies when dealing with localization, positioning, automatic navigation, and also search and rescue [1]. Environmental mapping can be used for narrow caves, low oxygen underground passage ways, unknown environments that humans cannot reach. In addition, the number of manufacturing jobs, mining, and industry that are still manually done by humans are very prone to the occurrence of accidents. Therefore it needs a device that can do map and navigation automatically so that the robot can replace human workers.

In order to create a map of environment requires sensors that have a high level of accuracy and it can reach some point in long distance. LIDAR is one of remote sensing technology that has the potential to help (map, monitor, and estimate spatial element locations) of many fields/applications related to the provision of geospatial databases [2]. Due to data density and high accuracy, LIDAR sensor is very suitable to be implemented in robot mapping and navigation. Many researchers reported has used laser range finders in their system [1], it uses RP Lidar sensor to create the mapping with a mobile robot. Rusdinar used laser range finders in order to fix error poses correction of mobile robot using particle filter [3] and a vision-based indoor localization method for autonomous Vehicles [4]. A. Rubinstein and T. Erez created a robot called LiTank which is a robot used for tunnels mapping using Lidar sensors made by Velodyne [5].

Automatic navigation of the robot is also required in the mapping environment so that the robot can run properly. Data from LIDAR can be mapped and used by robots to determine localization to the environment. Then the mapping data is used by robots for navigation and movement planning. In addition, data from LIDAR is also used to estimate the robot position required during mapping of the surrounding environment. Localization and road planning is fundamental to the problem of robotic navigation. To achieve successful navigation, the robot must be able to localize itself and produce a simultaneous environmental map (SLAM) [6].

The main objective of this research is to create a spinner for LIDAR sensors in order to scan the surrounding environment with a range of 360 degrees using only one sensor only. Then the spinner is tested by making a mapping based on the data obtained. then the results of the two scans are compared so that it can be predicted the position of the robot movement. the last spinner is tested by creating a navigation path on the previously generated map.

Then it is expected that the device can be developed so that it can be used on the robot to do the mapping and navigation. Most of the device for lidar spinner in the market are so expensive that researchers are expected to develop better and cheaper sensor players for research on mapping and navigation of robots.

2. System Design
To be able to do the mapping and navigation in need of several stages of data collection from the sensor, robot position estimation, map creation and navigation. The sensor is rotated 360 degrees using a stepper motor. Arduino retrieves data from LIDAR Lite V3 sensor using PWM communications. The data from the sensor is taken each step of the stepper motor rotation. Data from the sensor is sent by Bluetooth and the data is taken using serial communication by Matlab software. After the data obtained, then Matlab change the data to be processed into a map and navigation. Each movement of the stepper motor is controlled by a command from Matlab which is sent via Bluetooth with serial communication.

Figure 1 shows a flowchart of the mapping and navigation system. The first program run Matlab software connects serial communication with Arduino. Then Matlab gives Arduino command to move the sensor and send data every step. After the data obtained then the data processed by Matlab to make the map of probability. Then Matlab retrieves the data again and stored on different variables. The first data and newly processed data using the scan matching function to obtain a new robot position. Position and orientation data are then used to update the new data to a global map. The data retrieval process and global map updates continue until all environments are mapped. Once map mapped data previously obtained plus limits for robots with inflating map function. After that, a graph of possible paths can be passed using the PRM function. Thereafter searched the shortest path based on the map and the previous PRM.

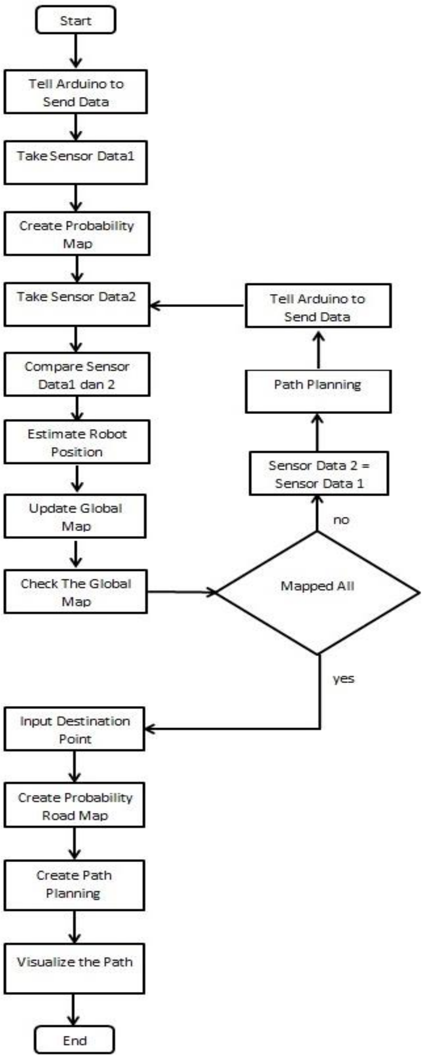

Fig. 1.Flowchart of System

2.1 Occupancy Grid

The Occupancy Grid reflects the multidimensional map of its environment (usually 2D or 3D) into the cell, where each cell stores its probabilistic state value [7]. Environmental information can be drawn from distance sensor data, camera and bump sensors commonly used to determine obstacles in the robot environment. There are 2 representations of the Occupancy Grid map of Binary Occupancy Grid and Probability Occupancy Grid.

The Binary Occupancy Grid uses the True value to represent the occupied workspace (obstacle) and the False value to represent the free workspace. This box shows where the obstacles are and whether the robot can move through that space. While Probability Occupancy Grid uses probability values to create more detailed map representations. This representation is the preferred method for using the Residential Grid. This grid is usually referred to simply as a dwelling. Each cell in the Residential Grid has a value that represents the probability of the cell's occupancy. A value close to 1 represents a high certainty that the cell contains obstacles. A value close to 0 represents the certainty that the cell is not occupied and barrier-free [8].

2.2 Probability Road Map

Probability Road Map (PRM) is a network graph of paths that may be present in a map determined by a free and unimpeded space [9]. Basically, the way PRM works is to take a random sample from the map, each sample is checked whether it is in an empty room or barrier-free. Then made local planning then each plan is connected to each other based on the nearest.

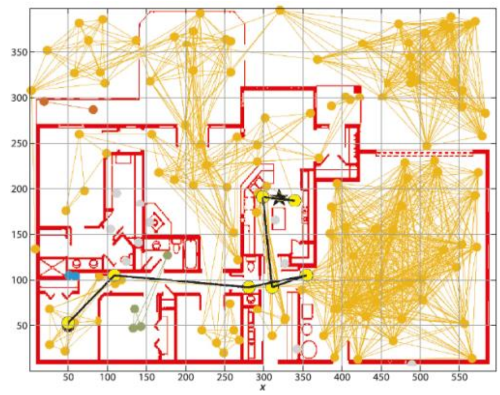

Fig. 2. PRM and minimum robot path planning [10]

There are two stages to PRM. First is the construction stage of making a road map approaching the robot movement that can be done on the environment. Initially a random configuration is created and then connected to some of its neighbors, usually the closest one is less than the specified distance. Second is the query stage of the initial position configuration and the end position is connected with the graph according to the Dijkstra Algorithm to determine the shortest path.

2.3 System Design

Figure 3 shows the connection between the components that exist in the system. First, the sensor data is taken by the Arduino through the slip ring so that the sensor can rotate 360 degrees continuously. Arduino controls the motion of a stepper motor using a motor driver. Data from sensors is sent via Bluetooth communication to PC. Then the PC with Matlab software processes the data to become a map.

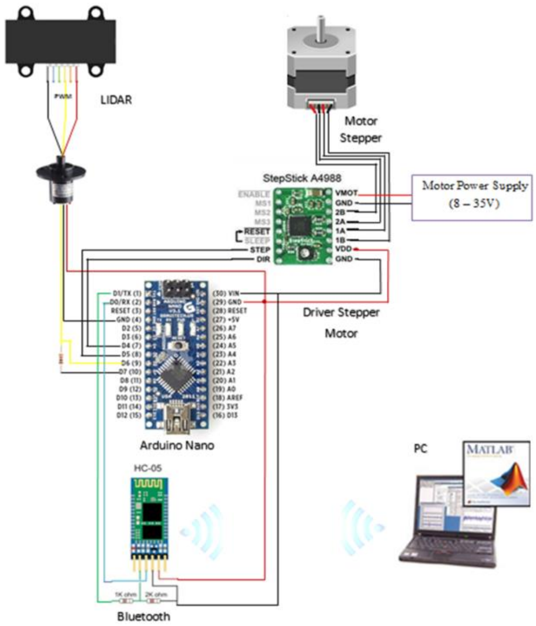

Fig. 3. Connection of Hardware Component

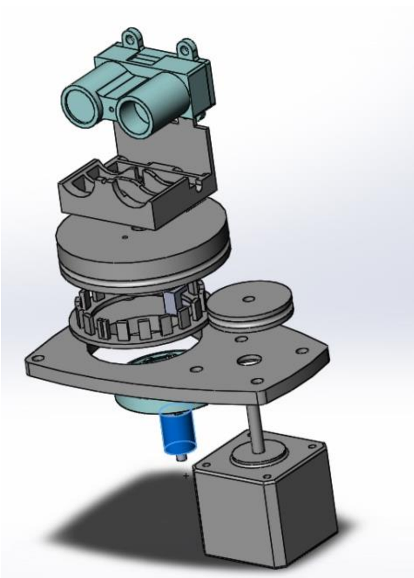

Fig. 4. Design of Hardware

In the design of the lidar spinner, there are several important parts as in Figure 4 which will affect the quality of this Project. First are a Stepper dish and a LIDAR disk connected by a rubber belt. The comparison between the disks is 1: 2 so with the stepper motor resolution of only 200 step can be increased to 400 step so that the mapping can be better again later. Second is the slip ring is a component that connects the 360 degrees lidar sensor with Arduino Uno. This component is very important because this component makes the sensor connector cable is not twisted when rotated. The third is the encoder is a tool to measure angle orientation on the sensor and can be used for feedback motor speed control stepper.

2.4 LIDAR-Lite V3 and Data Collection

LIDAR-Lite V3 is a low-cost laser rangefinder sensor developed from Garmin. this sensor has a great range and good accuracy. this sensor measures the distance by calculating the time difference between sending a laser beam with its reception after it is reflected an object.

There are two basic configurations for this device, I2C and PWM. in this project used PWM configuration to take distance data from the sensor. For the angle, data retrieval is taken based on the calculation of each step of the driving stepper motor. LIDAR-Lite V3 sensor mounted on the sensor spinner connected with stepper motor using a belt. the design of the sensor spinner is made on solidwork software which is then printed using plastic material. Figure 4 shows the LIDAR mounted on the printed spinner and a motor stepper.

Fig. 5. Printed LIDAR and Spinner

Data from lidar sensor is taken by Arduino and then it be sent to PC via Bluetooth communication. The distance and angle data are then converted into cartesian form as follows :

i. convert degree to rad

$$\theta_{rad} = \theta_{deg} \times \frac{\pi}{180} \quad (1)$$

Where θ_{rad} denotes angle in radian and θ_{deg} is angle in degree.

ii. convert polar to cartesian

$$x = rho \times \sin(\theta_{rad}) \quad (2)$$

$$y = rho \times \cos(\theta_{rad}) \quad (3)$$

Where x is position in x-axis and y position is y-axis.

Map and navigation are made in Matlab software that has loaded robotics system toolbox used in this research.

3. Testing and Analysis

The first test is the sensor measurement test of the straight line. This test aims to determine the distance reading by the LIDAR sensor compared to the actual distance from some specified distance. This test is done by placing the sensor at a distance adjusted to the measurement from the barrier to the sensor surface. The barrier is a white concrete wall. The retrieval of data from the Lite V3 LIDAR sensor uses the reading of the PWM value by the Arduino controller. Data is taken in 30 samples for each distance. The sensor readout data is processed by the PLX-DAQ add-on to be stored in Microsoft Excel software and created graphics. The distance is taken every 1 second.

Table 1. Distance Measurement Results By LIDAR Sensor

Actual distance measure-ment (cm)	Average 30 Times Distance Measure-ment By Sensor (cm)	*Error Average Distance Measurement By Sensor* (%)	Standard Deviation of Distance Measure-ment by Sensor (cm)
15	16	0.0667	1.05
16	16.73	0.0458	1.53
17	17.13	0.0078	1.59
18	18.30	0,0167	1.95
19	19.50	0.0263	1.69
20	20.50	0.0250	1.94
30	33.27	0.1089	3.18
75	74.93	0.0009	1.57
90	90.87	0.0096	1.38
100	103.80	0.0380	2.11
150	155.17	0.0345	2.12
300	308.17	0.0272	3.51
600	603.37	0.0056	3.77
1200	1218.77	0.0156	10.11
2000	2008.87	0.0044	9.62

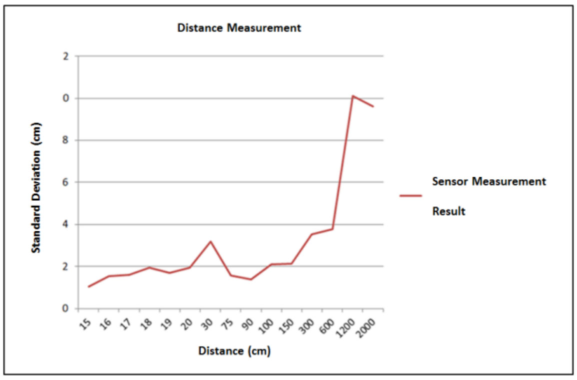

Fig. 6. Graph of Standard Deviation of Distance Measurement by Sensor

Based on table 1 if the distance measurement by LIDAR sensor is done 30 times then taken the average value it will get the measurement value with error less than 0.109% from the actual distance. Based on the graph of Fig. 6 . it is found that the measurement at the smaller distance of the measurement result is better shown with the decreasing standard deviation value. In this test is limited to the measurement of only up to 20 meters because when measured more than 20 meters, the distance data is not error obtained continuously. It can be concluded that the good measurement distance limit for mapping is less than 20 meters and the minimum measurement limit can be adjusted to the robot dimension.

The second test is distance measurement and visualization at a certain angle. This test aims to determine the results of reading at a certain angle range. The reading results will determine the accuracy of the sensor in the data readings for the mapping. This test is done by placing the sensor in the room with a white styrofoam barrier. Measurements were made at an angle of 0 degrees to 90,882 degrees with an angle difference of 1,782 degrees so that 20 samples of data were made. The actual distance measurements at each angle are measured using a meter gauge. The retrieval of data from the Lite V3 LIDAR sensor uses the reading of the PWM value by the Arduino controller. The sensor readout data is processed by the PLX-DAQ add-on for storage in Microsoft Excel software. The distance is taken every 1 second.

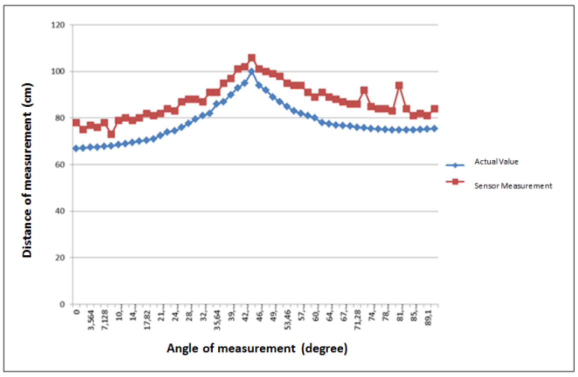

Fig. 7. Graph of sensor and distance measurement results

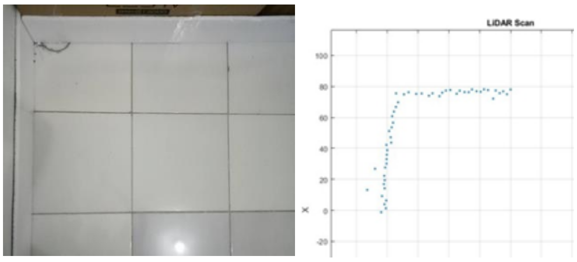

Fig. 8. Measurement Room and Ploting Result

Based on Figure 7 test results can be seen that the results of LIDAR sensor distance reading at a certain angle close to the actual distance value and based on Figure 8 obtained that the data visualization of the measurement of each angle is close to the form of the test room although there is still Error. Error reading of the distance itself can be overcome by making a map that is divided into boxes with a certain resolution.

The third test is distance measurement on certain surface colors. This test aims to determine the effect of distance reading on a particular color. This test is performed by facing the sensor surface on the paper guides with red, green, blue, white and black at a distance of 1 meter. Sampling data is done 20 times. The retrieval of data from the Lite V3 LIDAR sensor uses the reading of the PWM value by the Arduino controller. The sensor readout data is processed by the PLX-DAQ add-on for storage in Microsoft Excel software. The distance is taken every 1 second.

Table 2. Distance Measurement Results By LIDAR Sensor on Certain Color on cm

No.	Distance Measurement on Color				
	Red	Green	Blue	White	Black
1	103	104	104	101	88
2	103	105	106	103	99
3	105	105	105	102	104
4	114	105	105	102	105
5	110	104	103	105	96
6	102	103	105	104	101
7	102	106	104	102	102
8	105	103	103	103	98
9	103	104	107	104	106
10	102	104	106	101	103
11	105	105	107	105	106
12	104	103	101	102	104
13	103	104	103	104	101
14	105	103	105	102	96
15	102	104	104	101	102
16	104	106	103	101	98
17	103	104	103	100	99
18	102	103	103	101	102
19	106	103	102	102	100
20	105	103	102	103	98
Average (cm)	104.4	104.05	104.05	102.4	100.4
Standard Deviation (cm)	2.96	0.99	1.67	1.43	4.22

Based on the test results in Table 2 it is found that each different measurement color has different standard deviation value so it can influence on mapping result. Surface colors with high standard deviation will result in the possibility of large error readings due to the large value distribution as well.

The fourth test is distance measurement on specific surface materials. This test aims to determine the effect of distance reading on certain types of surface materials that are measured. This test is almost the same as the test on a particular color only in this test every material is different in measured by the sensor.

Table 3. Distance Measurement Results By LIDAR Sensor on Certain Material on cm

No.	Distance Measurement on Material				
	Con-create	Plas tic	Wood	Iron	Card-board
1	81	87	84	102	101
2	104	97	102	104	109
3	103	106	101	103	110
4	105	100	103	105	117
5	106	103	102	103	118
6	102	96	104	103	110
7	100	101	101	109	111
8	100	101	103	105	108
9	107	100	102	106	106
10	106	98	104	105	113
11	101	101	103	103	109
12	100	101	104	95	110
13	105	101	99	105	120
14	106	99	101	108	115
15	106	115	100	104	106
16	100	111	101	106	114
17	102	117	103	105	116
18	97	105	102	109	107

19	81	105	101	105	111
20	107	102	100	107	116
Average (cm)	100.71	102.42	101.09	104.6	111.35
Standard Deviation (cm)	7,39	6,62	4,24	2,99	4,75

Based on the standard deviation value in Table 3 it is found that any material that is measured can influence the measurement result. Differences in the results of measurements in environments with significant material variations can affect the shape of the mapping visualization.

The fivth test is visualization test of lidar sensor scan results. This test aims to see the visualization results of LIDAR sensor scans rotated 360 degrees compared with the actual form of test environment. The test is done by rotating the LiDAR sensor as far as 360 degree using stepper motor. The stepper motor spinner has 404 step to rotate 360 degrees. Data collection is done every step. The data is then transmitted through serial communication which then taken data by Matlab software. The scanned data processed by Matlab to be visualized with the X mark is the robot position.

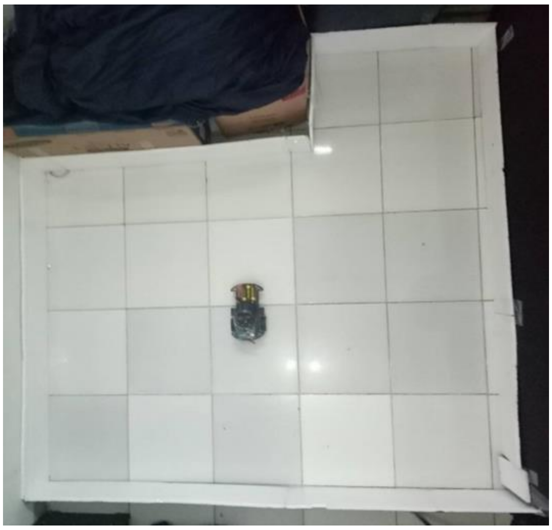

Fig. 9. Test room

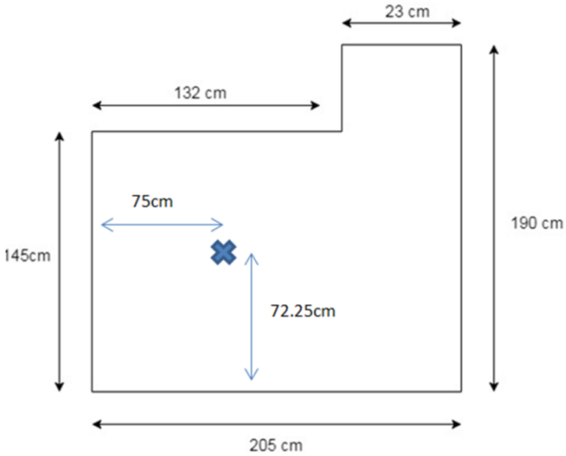

Fig. 10. Test room dimensions

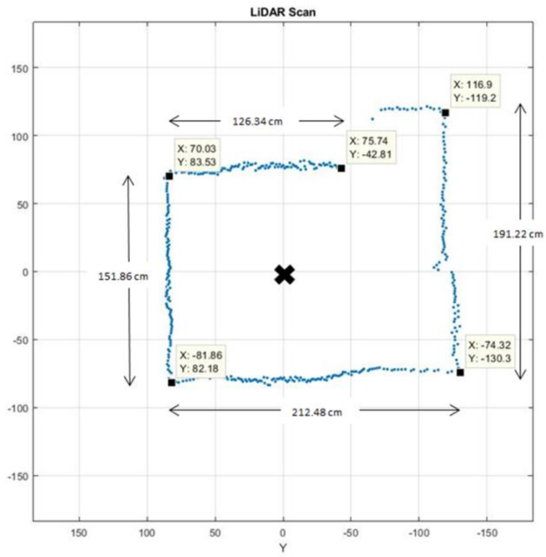

Fig. 11. Sensor Scan Mapping results

Based on the results of the scan data obtained that the form of visualization close to the original form of the room. The form of visualization that is not a straight line is the result of the variation of sensor readout error. The robot is in a position of 0.0 in coordinates. By reducing the X coordinate on the left side the right side length based on the visualization is 191.22 cm or has a error of 0.006% and on the lower side with the reduction of the coordinate value Y is 212.48 cm or has an error of 3.6%. Based on the visualization obtained that dimension closer to the actual dimension.

The last test is mapping navigation test of data from sensor spinner.

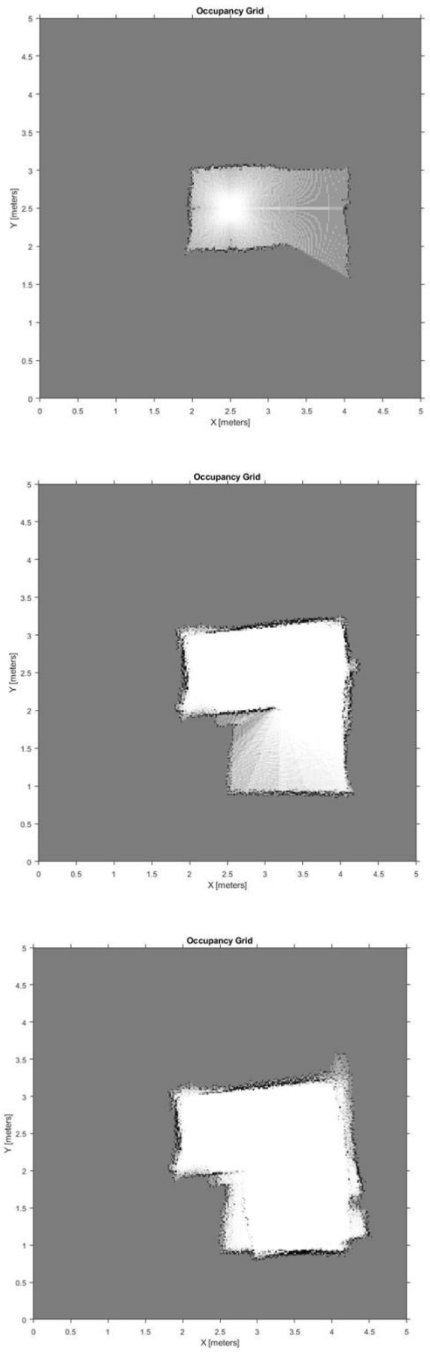

Fig. 12. 1st, 10th and 20th steps of mapping

Based on the visualization of the mapping results on Figure 12 it can be seen that there is an error reading the orientation of the robot causing an error on the visualization of the mapping. Because the position and orientation estimation based on current and previous scan data, the resulting error is getting bigger and cause the mapping result the less good can be seen from the visualization result which is getting away from the actual shape at every step of mapping step.

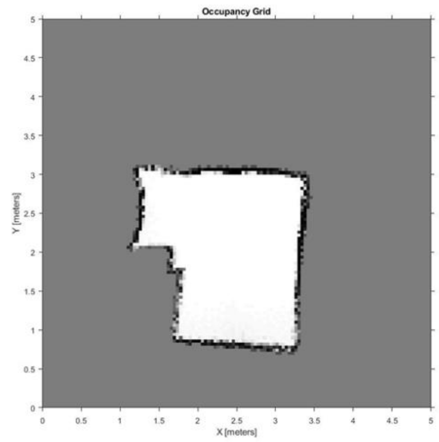

Fig. 13. Test room map

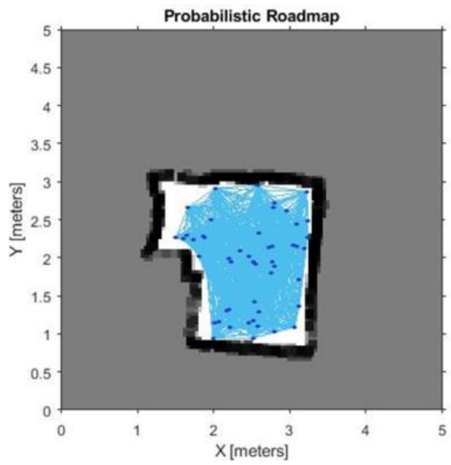

Fig. 14. PRM

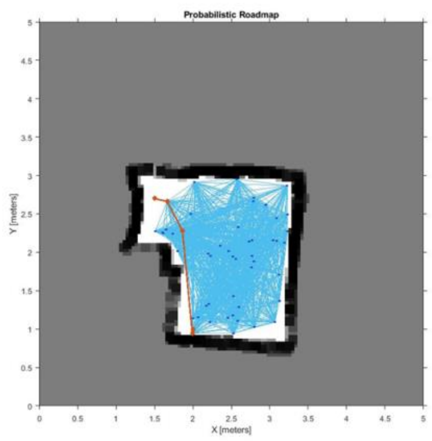

Fig. 15. Path planing

Based on the test results of Figure 13, 14 and 15 obtained that the map can be used as reference navigation robot. Once the path is obtained, the robot can be controlled to follow the path. The determination of the number of nodes in the PRM will be better if more but the calculation time is longer.

4. Conclution

From the results of testing and analysis obtained the conclusion of this Final Project that The LIDAR Lite V3 sensor has a different standard deviation value for each distance read with a range between 1.05 cm to 10.11 cm for measurements less than 20 meters. A good distance for LIDAR Lite V3 sensor to map the environment is less than 20 meters with a standard deviation of 9.62 cm. Color and Material of the measurement medium can affect the reading of distance data by the sensor. Positioning estimates using scan matching resulted in error seen from the visualization results. The resulting error is greater because each stage of the test uses position estimation from the previous stage. Error of position and orientation estimation can cause error on mapping due to insertion of unsuitable scan data.

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