Autonomous Robot Navigation in Unknown Maze Environment

by

Nur Aqilah binti Mustafa

Dissertation submitted in partial fulfillment of
the requirements for the
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UniversitiTeknologi PETRONAS
Bandar Seri Iskandar,
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr. Jafreezal bin Jaafar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NUR AQILAH BINTI MUSTAFA

Abstract

An autonomous robot navigation that is able to navigate itself in unknown maze environment. The objective of this project is to design and develop an autonomous robot navigation using a selected algorithm which is pledge algorithm by using the concept of obstacle avoidance besides studying its accuracy to solve the given environment. The result of the chosen algorithm then is compared to Wall Following algorithm, a typical algorithm used to solve obstacle avoidance maze. This project covers artificial intelligence field of study and it is designed to solve the issue of robot limitation in feeling its surrounding and to make any decision by its own. Thus, by using evolutionary prototyping, the author coded the chosen algorithm and tested on the robot to see how it is going to react in the given environment especially when the walls are disconnected. At the end of the report, the author concluded the project and recommends some improvement or expansion that can be done in the future.

Acknowledgements

First and foremost, the author would like to thank Allah the Almighty for His bless and pleasure so that the author can finish the project within the time frame with the given strength and health.

A big thanks to the author's parents and family for all the support and courage materially and spiritually, that contribute a lot along the way of doing this project. All the given motivation and prayers are the main drive force for the author to always keep on moving.

Not to be forgotten, a special appreciation to the author's supervisor, Dr. Jafreezal Jaafar for all the guidance and advices to the author throughout the whole stages of the project. His undoubted dedication and sacrifices have become the author's inspiration especially during her hard times.

A big gratitude goes to the author's Embedded System lecturer, Dr. Low Yan Jung and the author's friend from Electrical and Engineering department, Mr. Hazwan Syahmi Waginoh for their advices and ideas especially in the hardware part. Special thanks also goes to Petrobots UTP club for their help and support to the author along the way of finishing the project.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Exploration, also known as geographic expedition [1] is the act of exploring, penetrating, or ranging over for purposes of discovery, especially of geographical discovery [2]. Land exploration, sea exploration and space exploration have been very familiar to human being nowadays. New places are identified and civilized, natural resources are detected and exploited, and more and more information about the outer space world is gathered as the result of exploration.

Human explorers have begun land exploration since thousands of years ago as they have been fascinated by the land beyond what they know [3].However, sending human to explore a new 'untouched' terrain like dense forest is not necessarily a good option. They might be exposed to unforeseen dangerous and risks such as wild animals attack, insufficient food supply, unknown infection, physical damage or even lost in the deep jungle. Thus, sending robot instead of human to do exploration can be a better alternative since they are more durable and resilient. Robot will not have problem neither on food supply nor infection and they can withstand in a long duration mission.

Nevertheless, for a robot to discover a new place, it has to be intelligent enough to react with the environment that it never been before. How it is going to navigate itself? What if it meets obstacle along the way of its navigation? Which way it is going to choose? Obstacle can be defined as something immaterial that stands in the way and must be circumvented or surmounted [4]. Consequently, robot needs to be equipped with sensor for it to detect any input from the surroundings. A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument [5]. Plus, how the robot makes any decision will be based on the algorithm chosen. An algorithm is any set of detailed instructions which results in a predictable end-state from a known beginning [6]. Therefore, combination of sensor as the detector and algorithm as the decision making's rule will help a robot to think like a human and respond to the surrounding accordingly.

Though, what is the best algorithm to be applied for a robot to avoid any obstructions? Which algorithm will result to the fastest and the smartest solution? Is the physical demography factors affect the algorithm chosen? How the chosen algorithms have an effect on the robot's way of thinking? All of the questions arose will be the basis of the author's work of research. Comparison on a few algorithms will be done to find the best algorithm to be applied on the robot. The findings will be a beneficial reference for a new era of robotic exploration and will assist others to understand the art of autonomous robot navigation in unknown environment.

1.2 Problem Statement

1.2.1 Problem Identification

Sending a robot instead of human to do exploration will benefits people a lot especially in the area that is not accessible by human due to safety and cost factor. However, robot naturally does not have capability to feel its surrounding and to make any decision by its own specifically when having obstacle in front of it. Thus, a right sensor should be used and plug in to the robot so that it can be eyes and ears for the robot. For the robot to think diligently and react accordingly to what it feels in a very efficient way, the best algorithm needs to be applied so that robot can compete human in the ability to reason and solve whatever problems may arise.

1.2.2 Significant of the Project

Autonomous robot navigation in exploration brings a lot of positive impacts to human being. More information about the place can be gathered without putting human on risk and even saving more money. Besides, research on the best algorithm for a robot to navigate itself when facing obstacles can be a real representation on how the robot will react in the actual unknown environment. The result will help on determining the most applicable algorithm depending on the variation of variables and factors.

1.2.3 Proposed Solution

A few algorithms will be studied to know how they affect robot's way of thinking. Then, the best algorithm will be chosen and translated into programming language. The coded programming will be tested into the robot to see how it solves a given maze by avoiding obstacles concept.

1.3 Objective

a) To investigate the use of chosen algorithm, pledge algorithm for robot navigation and obstacle avoidance in unknown maze environment
b) To design and develop autonomous robot navigation using pledge algorithm for obstacle avoidance
c) To test and evaluate the accuracy of pledge algorithm in autonomous robot navigation

1.4 Scope of Study

The focus of this project is to study and choose the best algorithm to be implemented on the autonomous robot navigation in obstacle avoidance focusing in disjoint wall maze. Thus, artificial intelligence knowledge will be the main scope of study. Artificial intelligence is the branch of computer science concerned with making computers behave like humans [7]. In this project, the robot will be programmed based on the algorithm chosen to think and make its own decision on solving any problem arises.

1.5 Related Research Question

a) How pledge algorithm can be used in autonomous robot navigation on unknown maze environment
b) What are the advantages of pledge algorithm over other algorithms?

1.6 Relevancy of the Project

This project covers study of algorithm and choosing the best one to solve autonomous robot navigation in obstacles avoidance. This project will prove whether the chosen algorithm is able to solve unknown maze environment by avoiding obstacles. Granting robot responsibility to explore new places and letting them react and think like human being will surely open more good opportunity in exploration history.

1.7 Feasibility of the Project within the Scope and Time Frame

The narrow scope of the project makes it feasible to be achieved in the given time frame. A simple analysis will be done on maximum three algorithms to see how they affect the robot's decision in navigating in unknown maze environment by avoiding obstacles. The best algorithm will be tested on the robot to see the accuracy and the efficiency of the robot.

1.8 Conclusion

In conclusion, this project is designed to investigate the best algorithm to be implemented into autonomous robot navigation in exploring unknown maze environment. A simple wall maze will be designed and algorithms will be tested on the robot to see how it thinks and react whenever it confronts any physical obstacles. The author hopes this project can contribute to the advancement of a new era of exploration. Robot will be fully utilized to discover new untouched places without putting aside the benefit of the exploration to the human being.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition and Types of Algorithm

An algorithm is a specific set of instructions for carrying out a procedure or solving a problem, usually with the requirement that the procedure terminate at some point[8]. Specific algorithms sometimes also go by the name method, procedure, or technique. The word "algorithm" is a distortion of al-Khwarizmi, a Persian mathematician who wrote an influential treatise about algebraic methods. The process of applying an algorithm to an input to obtain an output is called a computation.

There are a few types of algorithms available. All these algorithms represent many ways of attacking a problem. Algorithm type can be considered includes simple recursive algorithm, backtracking algorithm, divide and conquer algorithm, dynamic programming algorithm, greedy algorithm, branch and band algorithm, brute force algorithm and randomized algorithm[9]. They can be further defined as per below:

- **Dynamic Programming Algorithms:** This class remembers older results and attempts to use this to speed the process of finding new results.
- **Greedy Algorithms:** Greedy algorithms attempt not only to find a solution, but to find the ideal solution to any given problem.
- **Brute Force Algorithms:** The brute force approach starts at some random point and iterates through every possibility until it finds the solution.
- **Randomized Algorithms:** This class includes any algorithm that uses a random number at any point during its process.
- **Branch and Bound Algorithms:** Branch and bound algorithms form a tree of subproblems to the primary problem, following each branch until it is either solved or lumped in with another branch.
- **Simple Recursive Algorithms:** This type goes for a direct solution immediately, then backtracks to find a simpler solution.
- **Backtracking Algorithms:** Backtracking algorithms test for a solution; if a solution is found the algorithm has solved, if not it recurs once and tests again, continuing until a solution is found[6].
- **Divide and Conquer Algorithms:** A divide and conquer algorithm is similar to a branch and bound algorithm, except it uses the backtracking method of recurring while dividing a problem into subproblems.

2.2 Algorithm for Robot Navigation in Unknown Maze Environment

2.2.1 Random Mouse Algorithm

It is the simplest algorithm and does not require extra memory to implement. The robot will simply proceed in a straight line until it reached an obstacle, which it will make a random decision about the next direction to follow[10]. This algorithm simulate how a human randomly roaming a maze without memorizing where he has been. It is the most inefficient maze solving method and the slowest solution ever as it is not guaranteed to terminate or solve a maze. The pseudo code of this algorithm is per below:

```
Do
{
        If (topLeftSensor && topRightSensor != 1)
                Move forward;
        Else
                 randomly choose any direction
}
While ( All sensors != 1 )
```

2.2.2 Wall Following Algorithm

Wall Following Algorithm is a simple and the best-known rule for transverse maze, is also known as left-hand rule or right-hand rule. In this algorithm, a robot will follow either the left or right wall as a guide around the maze. If it encounters an opening in any of the walls picked up by its sensors, it will stop and take a turn in that direction and then move forward sensing the walls again and keeping the wall as a guide. The pseudo code for right-hand wall following algorithm as per below:

```
Upon arriving in a cell
{
        If there is an opening to the right
                Rotate right

        Else if there is an opening ahead
                Do nothing

        Else if there is an opening to the left
                Rotate left

        Else
                Turn around
}
End If
        Move forward one cell
```

However, this algorithm only best works if the maze is simply connected, that is, all the walls are connected together or to the maze's outer boundary. Then by keeping one hand in contact with one wall, the robot is guaranteed not to get lost and will reach a different exit if there is one; otherwise it will return to the entrance. Else, if the maze is not simply connected which for example the start and endpoints are in the center of the structure or the pathways cross over and under each other, this method will not guaranteed to help the goal to be reached[10].

2.2.3 Pledge Algorithm

Pledge algorithm is quite similar to Wall Following algorithm, and it includes wall following as part of its solution. It is able to jump between islands that wall following cannot do. Besides, it is a non-heuristic procedure for a point automaton to escape an unknown maze. It requires an arbitrarily fixed reference direction to go toward for example north direction, not any position or distance information. Using this reference direction, the robot measures its angle of turn while following a wall in the maze. When an obstacle is made, one hand is kept along the obstacle while the angles turned are counted. When the robot is facing the reference direction again, and the angular sum of turns made is 0, it will leaves the obstacle and continues moving towards the reference direction[10].

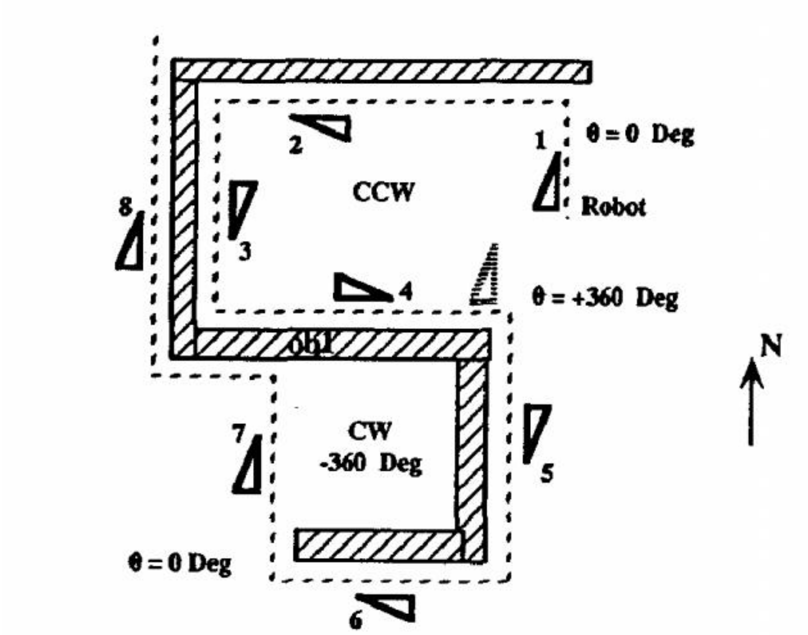


Figure 2.1: The measurement of the angle of turn in the pledge algorithm

The measurement of the angle of turn is explained through the example in Figure 2.1. At location 1, the robot is moving along a straight line towards the north. Here, let the cumulative angle of turn *0,* measured with respect to a north-south line, be zero. At location 4, the robot has completed a rotation in the counter-clockwise direction and *B* is now +360 deg. At location 7, after a clockwise rotation the angle *B* becomes zero again[10][11]. The pseudo code of this algorithm as per below:

```
Initialize a counter C to zero.
Do
{
    If(topLeftSensor&& topRightSensor !=1)
        Move Forward;
    If(obstacle is detected)
        {
            wallFollowing Algorithm;
            Increment counter C by +1 whenever the robot has made +360 degree angle of turn
            (i.e. counter clockwise rotation), and -1 if the angle of turn is -360 degree
            If(topLeftSensor&& topRightSensor !=1 && Counter==0)
                Leave the wall
            }
}
```

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The author has done some research on the best algorithm to be applied in this autonomous robot navigation in unknown maze environment project and she find out that there are a lot of considerations have to be taken in choosing the most suitable and appropriate algorithm. Besides, there are uncertainties on how the algorithm will affect the robot's way of thinking especially when it comes to the stage of coding the chosen algorithm. Thus, the author has chosen Evolutionary Prototyping as the software lifecycle model to run this project.

Evolutionary Prototyping is a lifecycle model in which a system is developed in increment so it can be readily be modified in response to feedback or result collected. This project basically will involve a lot of testing and simulating activities, where the aim is to ensure that the code tallies with the specified algorithm chosen. Thus, by choosing this methodology, the author able to implement any result collected from every testing with the code changes without disturbing any other activities planned in the methodology.

3.2 Project Activities

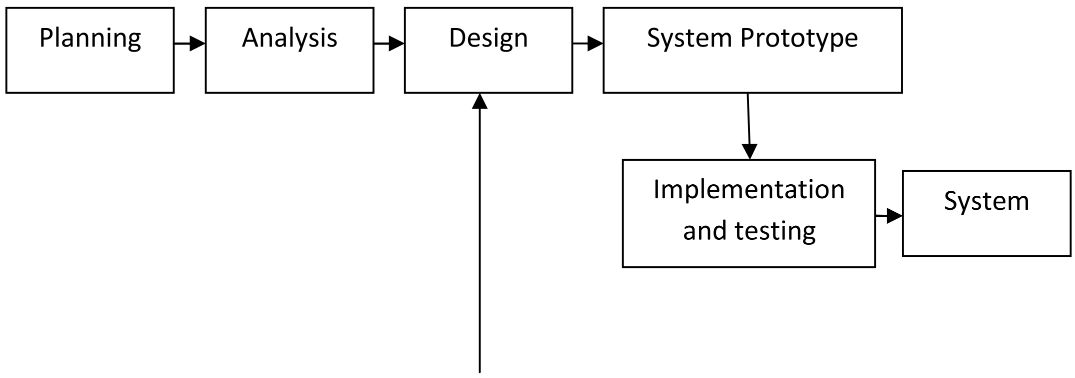


Figure 3.1: Phases in project planning

3.2.1 Planning

Planning is the phase where the author makes initial identification on what is the real problem regarding autonomous robot navigation in unknown maze environment and in what aspect the project should cover to solve the issue. After identifying the purpose and the objective of the project, the methodology is chosen to plan how the project will be run and what are the main activities involves, as well as the time line for every activities so that this project will always be on track. The software and hardware involves are also defined in this stage to make sure the project is really feasible and realistic.

3.2.2 Analysis

In the analysis phase, the background of the study is thoroughly identified, and study on the available algorithm is also conducted. The limitations of the algorithms as well as the how it is going to affect decision making made by the robot later on is analysed. Based on the analysis result, the best algorithm is chosen to be implemented in design phase.

3.2.3 Design

Test case which defined how the simulation will be done to test the success rate of the robot solving maze and also the design of the algorithm is being conducted in this phase. Data collected from analysis phase before will be taken into account to make sure the project run in the desired manner. Designation phase will produce system prototype which defined how the simulation of the autonomous robot navigation will be done.

3.2.4 Implementation and Testing

In this phase, the selected algorithm will be coded into programming language and will be run into the robot to test how it reacts in the system prototype. If the result does not meet the expectation, the author can always come back to the design phase to verify any fault made earlier. This situation will loop until the targeted result has been achieved.

3.3 Gantt Chart

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic	x	x												
Preliminary Research Work		x	x	x	x									
Submission of Extended Proposal Defence					x									
Proposal Defence						x								
Project Work							x	x	x	x	x			

Continues														
Submission of Interim Draft Report											x			
Submission of Interim Report												x	x	

Table 3.1 Timeline for FYP I

Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Work Continues	x	x	x	x	x	x	x							
Submission of Progress Report							x							
Project Work Continues								x	x	x	x			
Pre-EDX										x				
Submission of Draft Report										x	x			
Submission of Dissertation (softbound)											x			
Oral Presentation												x	x	
Submission of Technical Report														x

Submission of Project Dissertation (hardbound)														x

Table 3.2 Timeline for FYP II

3.4 Tools

3.3.1 Hardware

- Laptop or desktop that support USB technology
- 4 or more AAA batteries
- AVR ISP programmer with 6 pin connector
- Pololu 3pi robot
- Sharp GP2D120XJ00F Analog Distance Sensor
- white card board
- ¾" black tape
- pencil and other drawing tools

3.3.2 Software

-WinAVR : a free open suite of development tools for the AVR family of microcontroller, including the GNU GCC compiler for C and C++

-AVR Studio: Atmel free development environment(IDE) that natively works with WnAVR's free GCC or C++ compiler. Include AVR ISP software to let upload programs to 3pi

CHAPTER 4
RESULT AND DISCUSSIONS

4.1 Findings

Based on a few researches and studies on almost similar project before, the author found out a few important components that should be given high attention to ensure the successful of the project. The components are:

4.1.1 Maze

The wall maze was constructed to test the 3pi robot ability to detect the wall as the obstacles meanwhile black line are added to the maze to enable the robot to follow wall following algorithm by using Integrated QTR-RC Reflectance Sensors available on the robot due to limited number of distance sensor. The disjoint maze was purposely design to see the robot ability and behavior while facing it. The example of the wall maze is per below:

Figure 4.1: Example of wall maze with disjoint wall

4.1.2 Robot

Since this project combine both pledge algorithm and wall following algorithm by the means of line following, the robot need to meet both requirement which is able to detect obstacles and line at the same time. Thus, 3pi Pololu designed by Pololu Robotics and Electronics are chosen to complete the project based on the specification and the ability of robot that was purposely constructed to solve both line following and maze solving competition. However, since distance sensor which responsible to detect obstacle is not mounted naturally to the 3pi robot, the author need to setup the sensor according to the analog input ports available on the robot so that it can function wells. Subsections in this part will describe more on the specification of 3pi and how the analog distance sensor is added.

4.1.2.1 3pi Pololu Specification

The Pololu 3pi robot is a small, high-performance, autonomous robot designed to excel in line-following and line-mazesolving competitions. Powered by four AAA batteries and a unique power system that runs the motors at a regulated 9.25 V, 3pi is capable of speeds up to 100 cm/second while making precise turns and spins that don’t vary with the battery voltage. This results in highly consistent and repeatable performance of well-tuned code even as the batteries run low. The robot comes fully assembled with two micro metal gear motors, five reflectance sensors, an 8×2 character LCD, a buzzer, three user pushbuttons, and more, all connected to a user-programmable AVR microcontroller. The 3pi measures approximately 3.7 inches (9.5 cm) in diameter and weighs 2.9 oz (83 g) without batteries.

The 3pi is based on an Atmel ATmega168 or ATmega328 microcontroller, henceforth referred to as the "ATmegaxx8", running at 20 MHz. ATmega168-based 3pi robots feature 16 KB of flash program memory and 1 KB RAM, and 512 bytes of persistent EEPROM memory; ATmega328-based 3pi robots feature 32 KB of flash program memory, 2 KB RAM, and 1 KB of persistent EEPROM memory[12]. Below are the top and bottom view of Pololu 3pi robot:

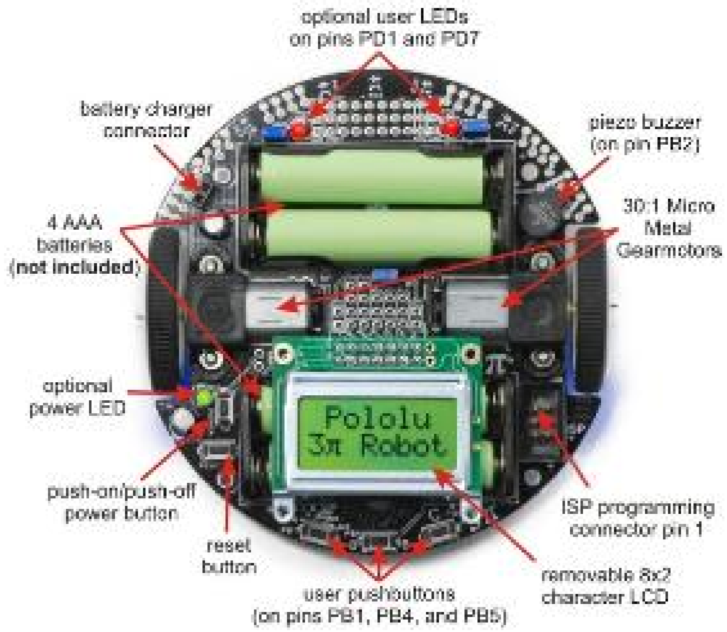


Figure 4.2: General features of Pololu 3pi Robot, front view

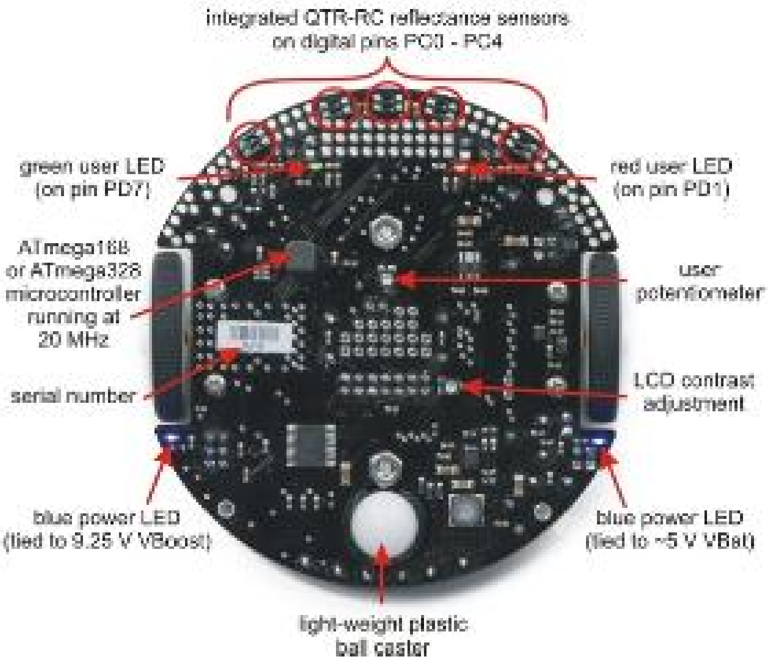


Figure 4.3: General features of Pololu 3pi Robot, bottom view

4.1.2.2 Adding Analog Distance Sensor

In order to enable the 3pi robot to avoid the obstacles, it has to be equipped with distance sensor. Based on the criteria and ability of the sensor, Sharp GP2D120XJ00F Analog Distance Sensor from Pololu has been chosen to suit the project requirement to detect very close objects. The feature summaries of the sensor are per below:

i. Operating voltage: 4.5V to 5.5V
ii. Average current consumption: 33mA (typical)
iii. Distance measuring range: 4cm to 30cm
iv. Output type: analog voltage
v. Output voltage differential over distance range: 2.3V (typical)
vi. Response time: 38+/-10ms
vii. Package size: 29.5x13.0x13.5mm (1.16x0.5x0.53”)
viii. Weight: 3.5g (0.12oz)

Figure 4.4: Analog Distance Sensor

Port ADC7 at the 3pi circuit board has been recognized as the best analog input port for the distance sensor based on the 3pi simplified schematic diagram below:

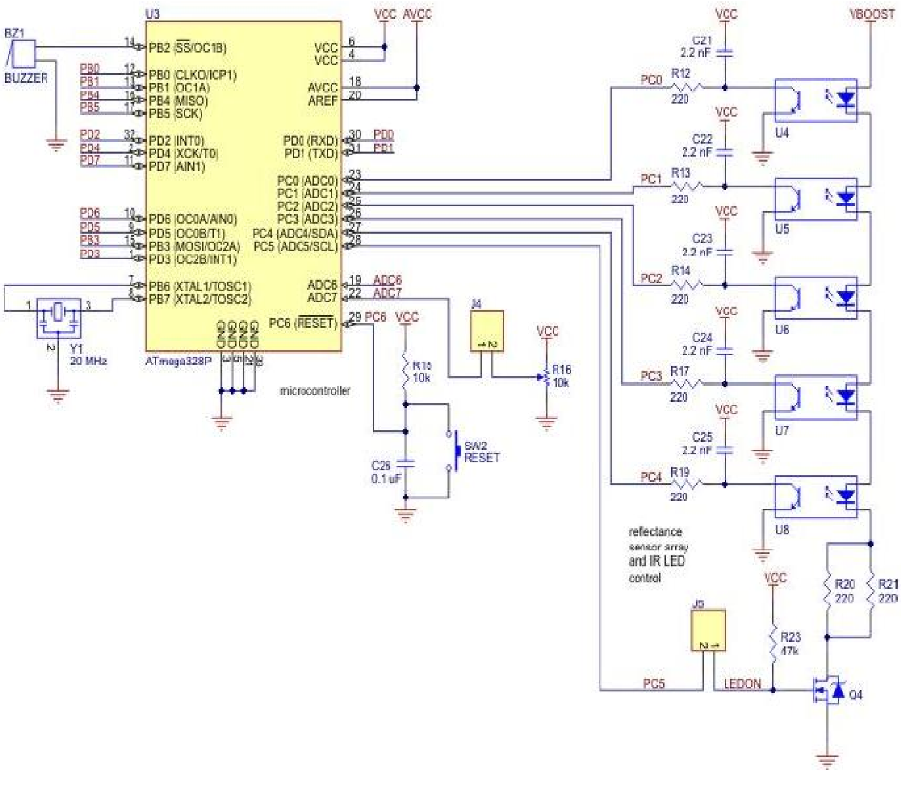


Figure 4.5: 3pi Simplified Schematic Diagram

To complete the connection of the distance sensor, the power and the ground port are connected to the battery charger connector available on the robot. Figure 4.6 shows 3pi Pololu with distance sensor.

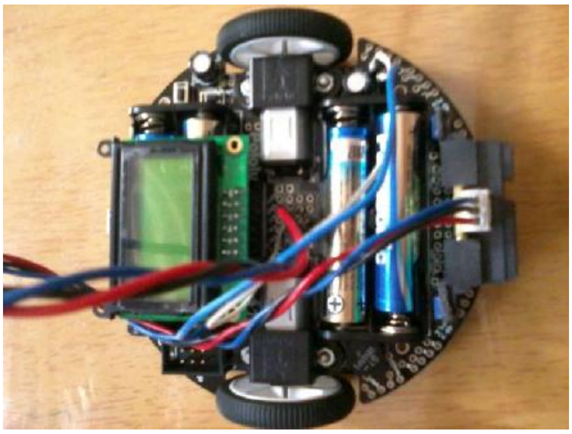


Figure 4.6: 3pi Pololu with distance Sensor

4.1.3 The Algorithm

Since the maze is a disjoint maze, two algorithms will be applied and hybrid to help the robot in making the best decision which are wall following algorithm and pledge algorithm. Both algorithms will be applied by using line following method instead of using the original wall following method, which distance sensor is used to always detecting and keep the wall in a predefined distance. The two algorithms will be compared and analysed to measure which algorithm apply best on a disjoint maze. As the wall following algorithm can be divided into two types, right wall following and left wall following algorithm, the right wall following is chosen randomly to be combined with pledge algorithm. The concept of pledge algorithm is as per below diagram:

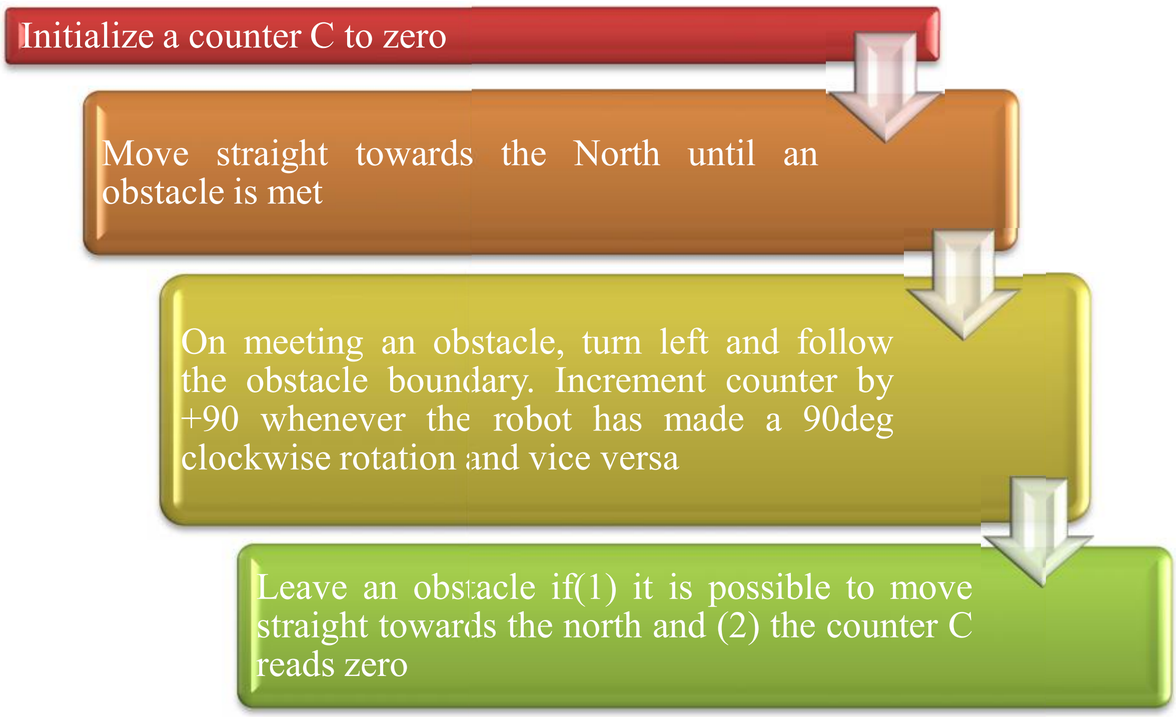


Figure 4.7: Pledge algorithm concept

4.2 Data Gathering/ Data Analysis

4.2.1 Wall Maze with Black Line

The author has decided to use combination of wall maze and line maze to achieve the project objective which is to test robot ability to avoid distance and follow the wall by detecting line maze at the same time. Wall maze is a maze that consisted of a few walls connected together to build a route that can be passed through by the robot. Meanwhile, in this project, black line are stretched at the wall maze only at the direction other than the ‘preferred’ direction to replace robot capability to follow the wall by using distance sensor with only detecting the line maze through reflectance sensor. The maze is purposely designed to have disjoint wall and “G-shaped” area to compare how both wall following algorithm and pledge algorithm has an impact on the robot’s ways of thinking.

Building Wall Maze with Black Line

1. Sketch the wall maze on a piece of paper to help in planning to build the real wall maze. The precise dimensions are included in the sketching.
2. Draft the wall maze on a card board by following the predefined specifications in the sketching.
3. Cut another card board into pieces of 5cm height and a length according to the draft to be the wall of the maze.
4. Place and paste the pieces wall on the card board according to the draft.
5. At the direction other than the initial direction where the robot will begin navigating, stretch the electrical tape inside the path constructed.

4.2.2 Pledge Algorithm and Wall Following Algorithm

Based on study done by the author, pledge algorithm is one of the best algorithms for wall maze. It includes wall following algorithm in the solution, but is able to solve limitation of wall following algorithm in term of disconnected maze. In this project, the author used line following means to do wall following algorithm due to limited number of distance sensor. Below is the pledge algorithm and wall following algorithm in pseudo code and flowchart:

Pledge algorithm in pseudo code:

1. Initialize a counter C into zero
2. If counter C is zero
   2.1 Move straight forward to the north
   2.2 If front wall is sensored
      2.2.1 Turn left
      2.2.2 Decrease the counter C to -90 (as counter clockwise rotation)
      2.2.3 Check If the counter C is 0
         2.2.3.1 If right wall is sensored

2.2.3.1.1 Turn 180deg to the back

2.2.3.1.2 Increase the counter C to +180 (as clockwise rotation)

2.2.3.1.3 Check If the counter C is 0

2.2.3.2 Else

2.2.3.2.1 Move forward

2.2.3.2.2 Check If the counter C is 0

2.2.4 Else

2.2.4.1 Move forward

2.2.4.2 Check If the counter C is 0

2.3 Else

2.3.1 Move forward

2.3.2 Check If the counter C is 0

3. Else

3.1 Move forward according to the line

3.2 If preferred side is open

3.2.1 Turn to the right

3.2.2 Increase the counter C to +90 (as clockwise rotation)

3.2.3 Check If the counter C is 0

3.3 Else

3.3.1 Turn to the left

3.3.2 Decrease the counter C to -90 (as counter clockwise rotation)

3.3.3 Check If the counter C is 0

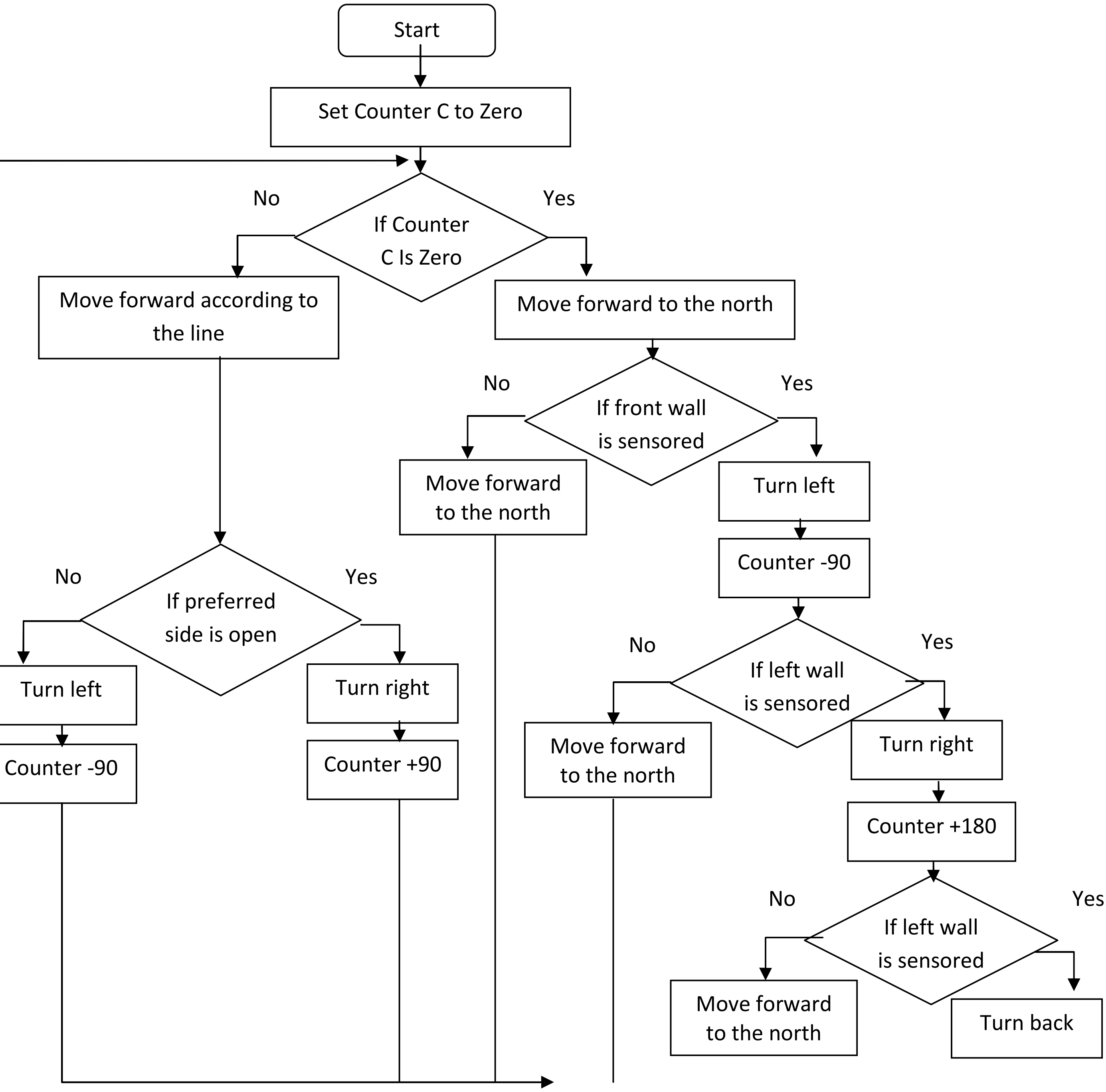
4. If the end point is reached

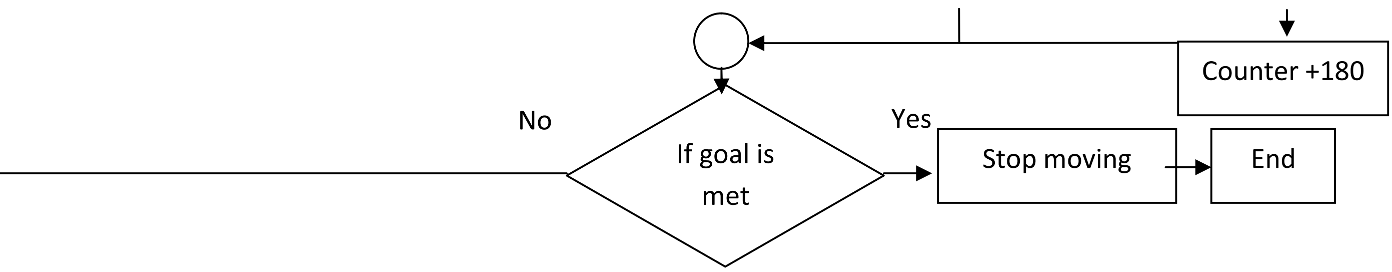
4.1 Stop

Wall Following Algorithm in pseudo code

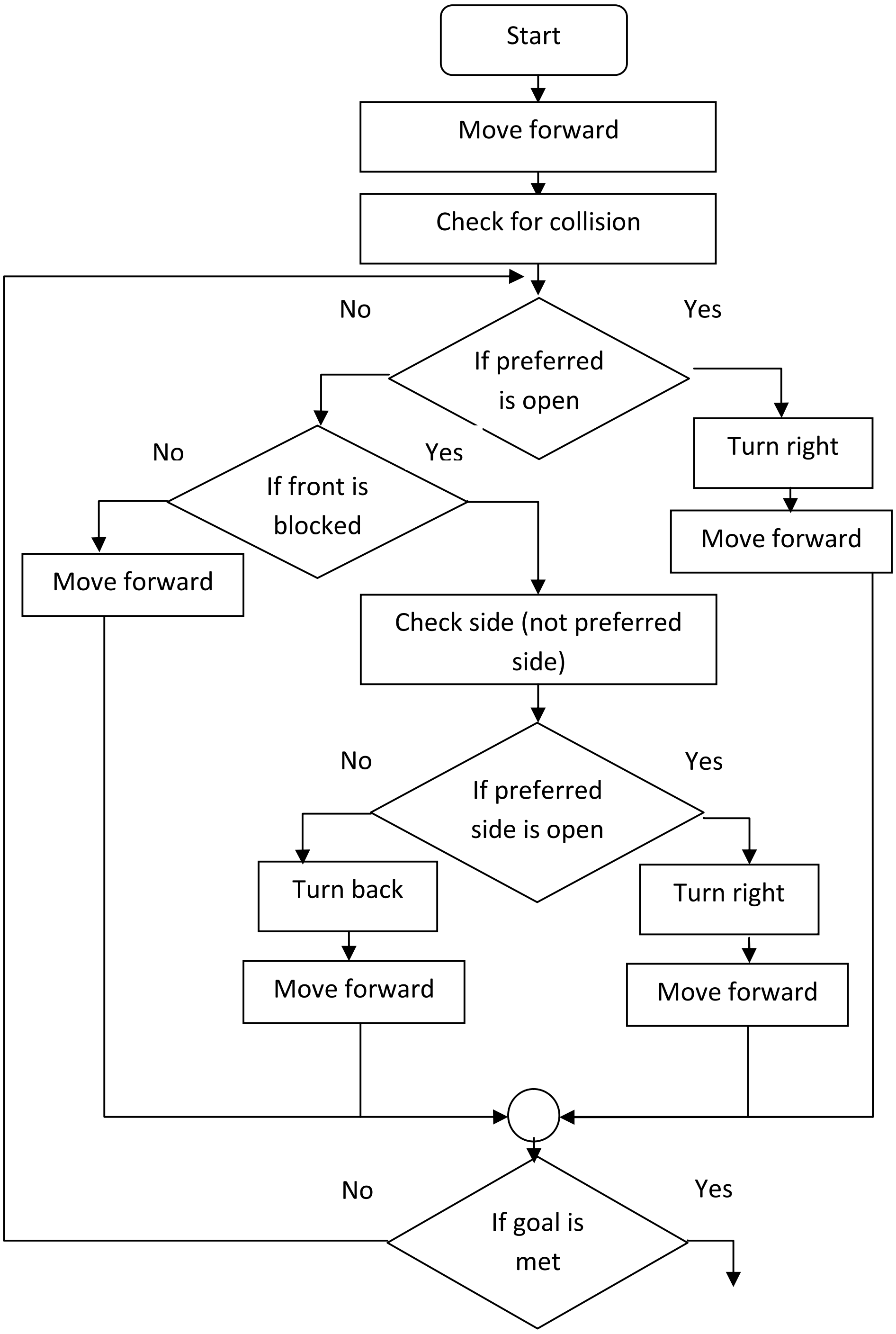
1. Move forward
2. Check for collision on the front and both side of the robot
3. If the preferred side is open(right)
   3.1 Turn right
   3.2 Go to step 1
4. If the front is blocked
   4.1 Check which side is open(left or right)
   4.2 If the preferred side is open
      4.2.1 Turn right
      4.2.2 Go to step 1
   4.3 If the preferred side is block
      4.3.1 Turn left
      4.3.2 Go to step 1
   4.4 If both sides are blocked
      4.4.1 Turn 180 degree
      4.4.2 Go to step 1
5. If the end point is reached
   5.1 Stop

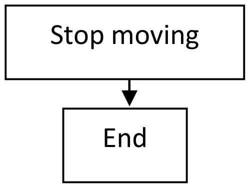
Pledge algorithm's flow chart





Wall following algorithm's flow chart





4.2.3 Probability Sets

There are a few possible situations that will be encountered by the robot while navigating itself within the wall maze. However, it can be divided into two major situations which are:

i. Counter is zero
ii. Counter is not zero

4.2.3.1 Counter is zero

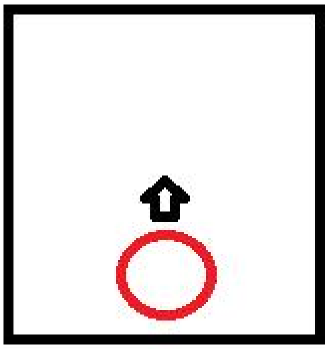
Condition	Description
	**Condition:** Counter is zero **Action:** The current direction is defined as 'favorite' direction and robot will move forward freely until it bounds to any obstacle

Table 4.1: Probability when Counter is zero

4.2.3.2 Counter is not zero

Since line following is just a replacement of wall following in this project, there are only a few probabilities of line following conditions that will be faced by the robot according to the design of the maze. They are:

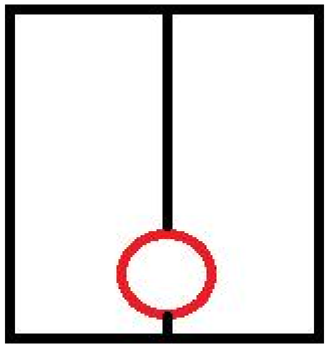
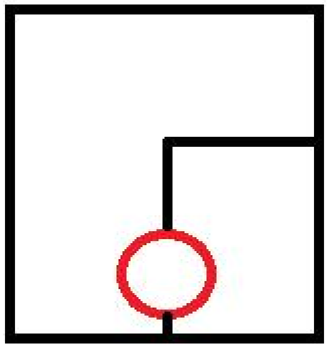
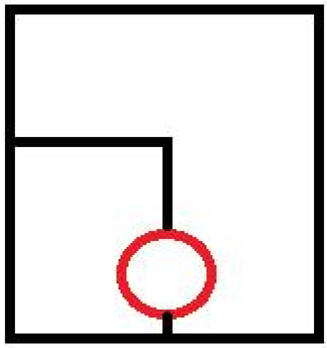
Condition	Description
	**Condition**: Straight line **Action**: The robot will move forward according to the line
	**Condition:** Right turn is open, the front and left side are blocked **Action:** The robot will turn 90 degrees to the right(preferred turning side) and follow along the line
	**Condition:** Left turn is open, the front and right side are blocked **Action:** The robot will turn 90 degrees to the left(opposite preferred turning side) and follow along the line

Table 4.2: Probability when Counter is not zero

4.3 Experimentation/ Modelling

4.3.1 Implementation

The robot is tested to run on the designed maze by using both pledge algorithm and wall following algorithm. The results are compared to analyse which algorithm works well in a disjoint wall maze. Other variables such as surface of the maze and battery power are made constant in both tests to get a valid result.

4.3.2 Result and Discussion

The results for both algorithms are recorded as per below. The path taken by the robot is identified by the red line.

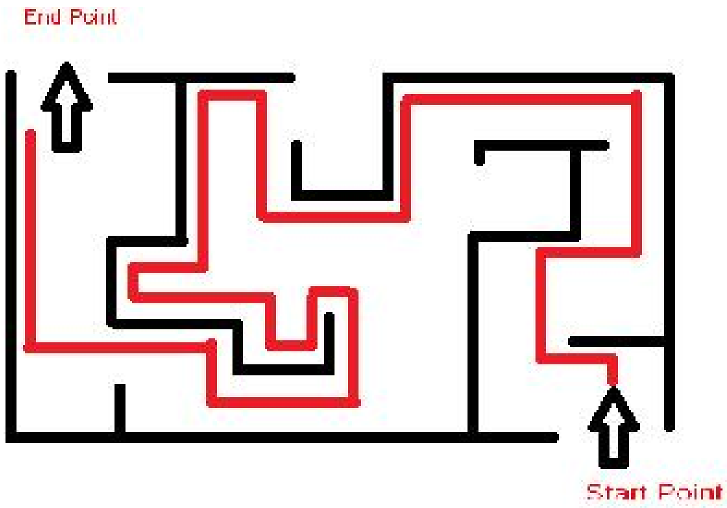


Figure 4.8: Path taken by using pledge algorithm

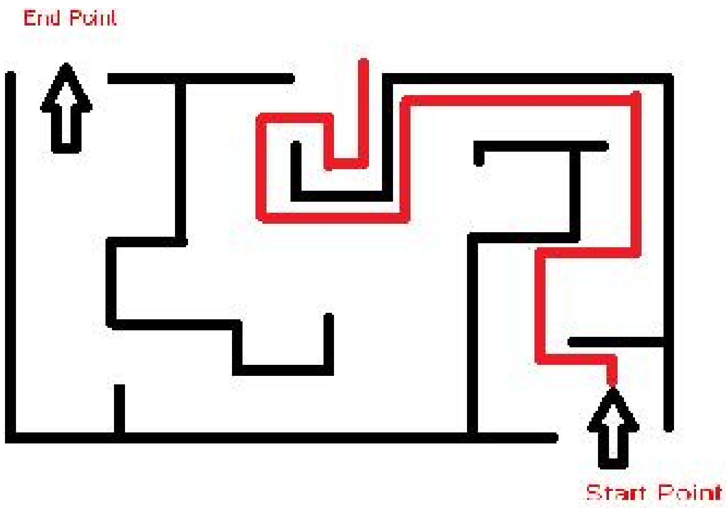


Figure 4.9: Path taken by using wall following algorithm

Based on the result, robot with pledge algorithm is able to finish the maze as compared to robot with wall following algorithm. The main part that differentiates the results is the area where the wall is disconnected. The different path taken by robot at the disjoint maze with both algorithms is described as per below table:

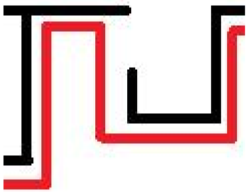
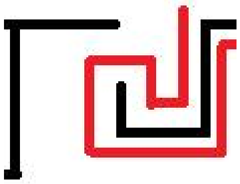
Path Taken	Explanation
 Pledge Algorithm	As robot will move forward freely everytime it faces its “favorite” direction, the robot will not turn right to follow the disjoint maze. Instead, it will move towards the front wall and follow it accordingly.
 Wall Following Algorithm	At the disjoint maze, robot will turn right to follow the wall and finally leave the maze without solving it.

Table 4.3: Effect of algorithms at disjoint maze

CHAPTER 5

Conclusion and Recommendation

5.1 Relevancy to the objectives

In conclusion, pledge algorithm is able to solve wall following algorithm‘s limitation in solving autonomous robot navigation in disjoint wall maze. The ability of pledge algorithm to make a robot not fully depending on the wall to do navigating, making the learning process of the environment become much more practical and easier.

Besides, autonomous robot navigation has a bright future to be discovered as the rule of robot in human life is expanding as technology evolves. A lot of benefits can be gained by exploring this field of study as robot can do things that human cannot or human might be exposed to danger if they are doing it. Besides, artificial intelligence is a scope of knowledge that is very interesting and able to bring a lot of big impact to the society. Thus, this field should be further explored by every potential bright technologist.

5.2 Suggested Future Work for Expansion and Continuation

This project does not cover how the robot should solve the unknown maze in the shortest path and time. Thus, for future expansion, there is a need to solve this issue in order to make sure the exploration made by a robot able to think the shortest way to come to a determine destination on the maze for certain purpose so that the function of robot navigation can be expanded not only in exploring purpose but also other functionality such as putting out a fire.

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[12] Corporation, P. (2001-2011). Pololu 3pi Robot User's Guide. [PDF document] retrieved from http://www.pololu.com/catalog/product/975/resources

Autonomous Robot Navigation

in Unknown Maze Environment

Nur Aqilah Mustafa
Bachelor of Technology(Hons) in Information and Communication Technology
Universiti Teknologi PETRONAS
Tronoh, Perak, Malaysia
yellowqizz@gmail.com

Abstract— **An autonomous robot navigation is a robot that is able to navigate itself in unknown maze environment by implementing Artificial Intelligence(AI). The objective of this project is to design and develop an autonomous robot navigation using a selected algorithm which is pledge algorithm by using the concept of obstacle avoidance besides studying its accuracy to solve the given environment. This paper explains the type of maze built, the robot used and its specifications, the algorithm chosen and how its functions, the probability that the robot will face and its action selections. The paper ends with some conclusion and recommendation for the future.**

I. INTRODUCTION

Exploration, also known as geographic expedition [1] is the act of exploring, penetrating, or ranging over for purposes of discovery, especially of geographical discovery [2]. Human explorers have begun land exploration since thousands of years ago. However, sending human to explore a new 'untouched' terrain is not a good option as they might be exposed to unforeseen dangerous and risks. Thus, sending robot to do exploration can be a better alternative since they are more durable and resilient.

A. Problem Statement

Robot naturally does not have capability to feel its surrounding and to make decision by its own especially when having obstacle in front of it. Right sensor should be plugged in so that it can be eyes and ears for the robot. For the robot to think diligently and react accordingly to what it feels, the best algorithm needs to be applied so that it can compete human in the ability to reason and solve whatever problems may arise.

B. Objective

- To investigate the use of chosen algorithm, pledge algorithm for robot navigation and obstacle avoidance in unknown maze environment
- To design and develop autonomous robot navigation using pledge algorithm for obstacle avoidance
- To test and evaluate the accuracy of pledge algorithm in autonomous robot navigation

C. Scope of Study

The focus of this project is to study and choose the best algorithm to be implemented on the autonomous robot navigation in obstacle avoidance focusing in disjoint wall maze. Thus, artificial intelligence knowledge will be the main scope of study. Artificial intelligence is the branch of computer science concerned with making computers behave like humans [3]. In this project, the robot will be programmed based on the algorithm chosen to think and make its own decision on solving any problem arises.

II. Literature Review

A. Definition and Types of Algorithm

Algorithm is a specific set of instructions for carrying out a procedure or solving a problem, usually with the requirement that the procedure terminate at some point[4]. Algorithm type can be considered includes simple recursive algorithm, backtracking algorithm, divide and conquer algorithm, dynamic programming algorithm, greedy algorithm, branch and band algorithm, brute force algorithm and randomized algorithm[5].

B. Algorithm for Robot Navigation in Unknown Maze Environment

a) Random Mouse Algorithm

It is the simplest algorithm and does not require extra memory to implement. The robot will simply proceed in a straight line until it reached an obstacle, which it will make a random decision about the next direction to follow[6].

b) Line Following Algorithm

A simple and the best-known rule for transverse maze, is also known as left-hand rule or right-hand rule. In this algorithm, a robot will follow either the left or right wall as a guide around the maze. If it encounters an opening in any of the walls picked up by its sensors, it will stop and take a turn in that direction and then move forward sensing the walls again and keeping the wall as a guide. However, it only best works if the wall maze is simply connected [6].

c) Pledge Algorithm

Quite similar to Wall Following algorithm, and includes it as part of its solution. It requires an arbitrarily fixed reference direction to go toward for example north direction, not any position or distance information. Using this reference direction, the robot measures its angle of turn while following a wall in the maze. When an obstacle is made, one hand is kept along the obstacle while the angles turned are counted. When the robot is facing the reference direction again, and the angular sum of turns made is 0, it will leaves the obstacle and continues moving towards the reference direction[6].

III. Methodology

Since the maze is a disjoint maze, two algorithms will be applied and hybrid to help the robot in making the best decision which are wall following algorithm and pledge algorithm. Both algorithms will be applied by using line following method instead of using the original wall following method, which distance sensor is used to always detecting and keep the wall in a predefined distance. Then, the two algorithms are studied and analysed to discover which one works better in solving a disconnected wall maze. The flowchart for both algorithms is per below:

A. Flow Chart for Wall Following Algorithm

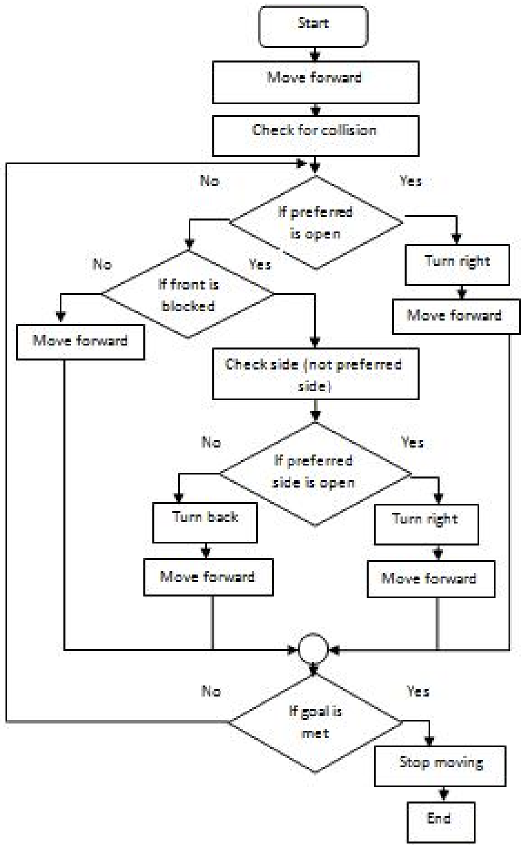


Figure 1: Wall Following in Flow Chart Form

B. *Flow Diagram and Flow Chart for Pledge Algorithm*

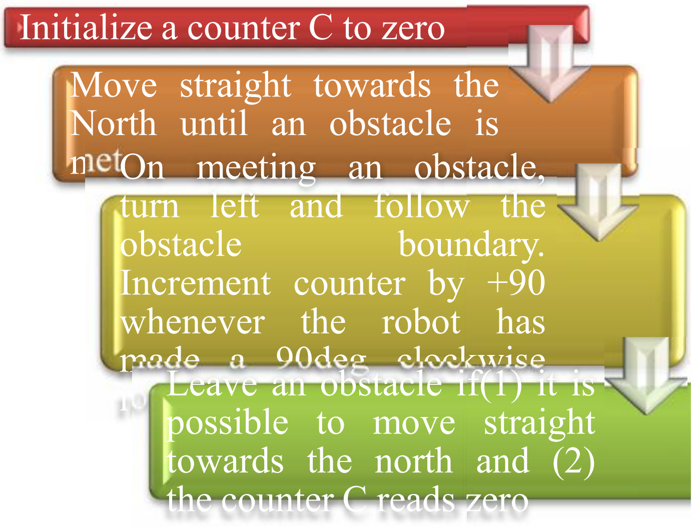


Figure 2: Pledge Algorithm in Flow Diagram

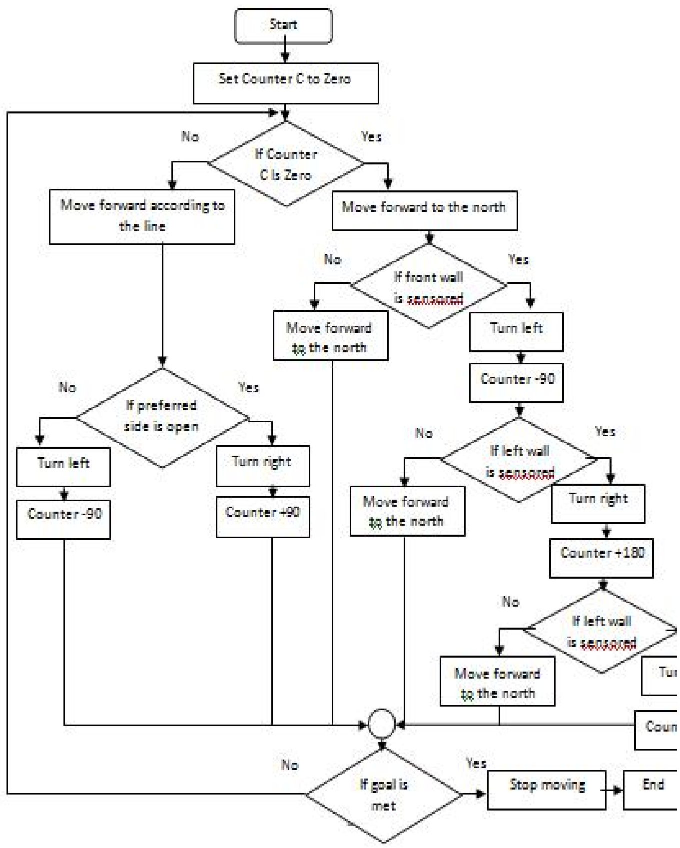


Figure 3: Pledge Algorithm in Flow Chart Form

IV. IMPLEMENTATION

A. *The Robot*

a) *Pololu 3pi*

The Pololu 3pi robot is a small, high-performance, autonomous robot designed to excel in line-following and line-mazesolving competitions. It is powered by four AAA batteries and a unique power system that runs the motors at a regulated 9.25 V.

b) *Important Specifications*

The robot comes fully assembled with two micro metal gear motors, five reflectance sensors, an 8×2 character LCD, a buzzer, three user pushbuttons, and more, all connected to a user-programmable AVR microcontroller. It measures approximately 3.7 inches (9.5 cm) in diameter and weighs 2.9 oz (83 g) without batteries. All the components are connected to a user programmable AVR microcontroller (ATmega328 running at 20 MHz).

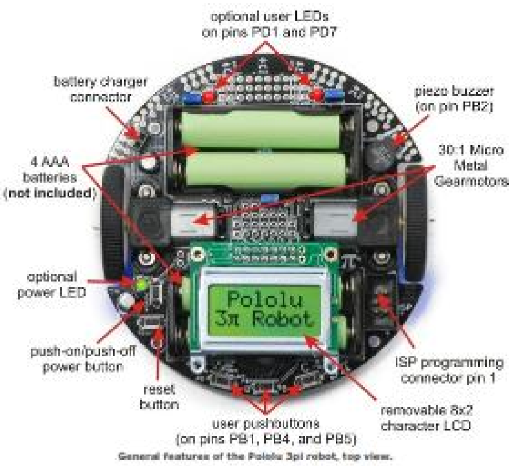


Figure 4: Top View of Pololu 3pi Robot

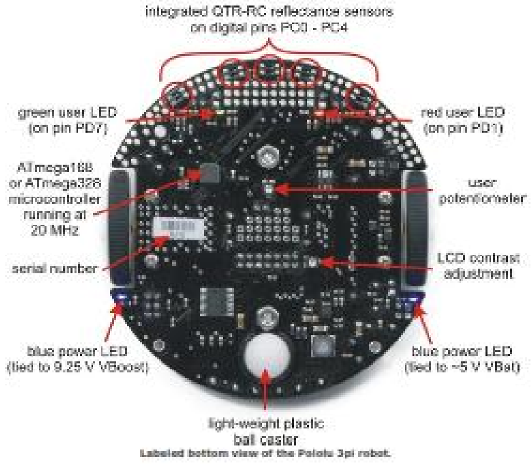


Figure 5: Bottom View of Pololu 3pi Robot

c) Additional Requirements

Since this project combine both pledge algorithm and wall following algorithm by the means of line following, the robot need to meet both requirement which is able to detect obstacles and line at the same time. Since, distance sensor which responsible to detect obstacle is not mounted naturally to the 3pi robot, the author need to setup the sensor according to the analog input ports available on the robot so that it can function wells.

Based on the criteria and ability of the sensor, Sharp GP2D120XJ00F Analog Distance Sensor from Pololu has been chosen to suit the project requirement to detect very close objects. Port ADC7 at the 3pi circuit board has been recognized as the best analog input port for the distance sensor. The feature summaries of the sensor are per below:

i. Operating voltage: 4.5V to 5.5V
ii. Average current consumption: 33mA (typical)
iii. Distance measuring range: 4cm to 30cm
iv. Output type: analog voltage
v. Output voltage differential over distance range: 2.3V (typical)
vi. Response time: 38+/-10ms

d) Hardware Tools

The following tools are required when using 3pi Pololu robot:

- 4 AAA batteries
- AVR ISP Programmer with 6 pin connector (to connect the robot to the computer)
- A desktop or computer laptop

e) Sofware Tools

Below are the software needed to code n uploading the code into Pololu 3pi:

- WinAVR : a free open suite of development tools for the AVR family of microcontroller, including the GNU GCC compiler for C and C++
- AVR Studio: Atmel free development environment(IDE) that natively works with WnAVR's free GCC or C++ compiler. Include AVR ISP software to let upload programs to 3pi

B. The Maze

a) Wall MazeType

The wall maze was constructed to test the 3pi robot ability to detect the wall as the obstacles meanwhile black line are added to the maze to enable the robot to follow wall following algorithm by using Integrated QTR-RC Reflectance Sensors available on the robot due to limited number of distance sensor. The disjoint maze was purposely design to see the robot ability and behavior while facing it. The example of the wall maze is per below:

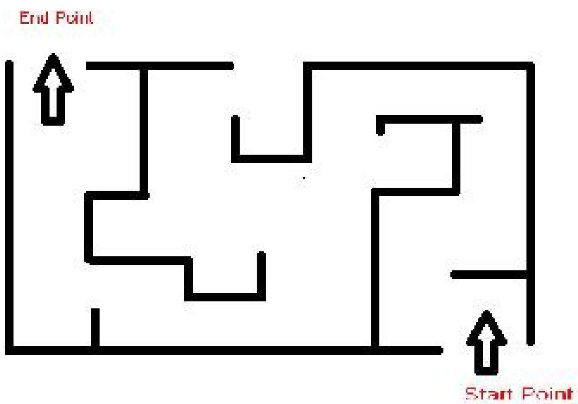


Figure 6: Example of Wall Maze

b) Tools for Wall Maze

- White card board
- ¾ inch (1.8cm) black electrical tape
- Pencil
- Other drawing tools

c) Building the Wall Maze

i. Sketch the wall maze on a piece of paper to help in planning to build the real wall maze. The precise dimensions are included in the sketching.
ii. Draft the wall maze on a card board by following the predefined specifications in the sketching.
iii. Cut another card board into pieces of 5cm height and a length according to the draft to be the wall of the maze.
iv. Place and paste the pieces wall on the card board according to the draft.
v. At the direction other than the initial direction where the robot will begin navigating, stretch the electrical tape inside the path constructed.

C. *Probability Sets and Path Taken*

a) Probability Sets

There are a few possible situations that will be encountered by the robot while navigating itself within the wall maze. However, it can be divided into two major situations which are:

iii. Counter is zero

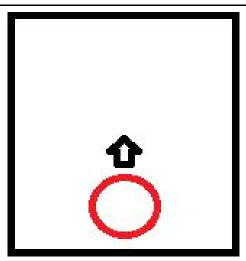
Condition	Description
	**Condition:** Counter is zero **Action:** The current direction is defined as 'favorite' direction and robot will move forward freely until it bounds to any obstacle

Table 1: Probability when Counter is zero

ii. Counter is not zero

Since line following is just a replacement of wall following in this project, there are only a few probabilities of line following conditions that will be faced by the robot according to the design of the maze. They are:

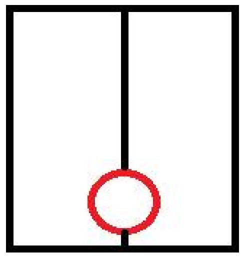
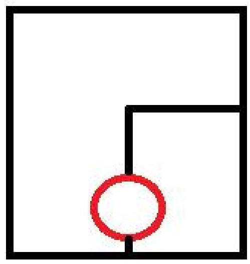
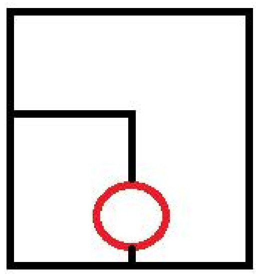
Condition	Description
	**Condition**: Straight line **Action**: The robot will move forward according to the line
	**Condition:** Right turn is open, the front and left side are blocked **Action:** The robot will turn 90 degrees to the right(preferred turning side) and follow along the line
	**Condition:** Left turn is open, the front and right side are blocked **Action:** The robot will turn 90 degrees to the left(opposite preferred turning side) and follow along the line

Table 2: Probability when Counter is not zero

b) Path Taken by Robot

The results for both algorithms are recorded as per below. The path taken by the robot is identified by the red line.

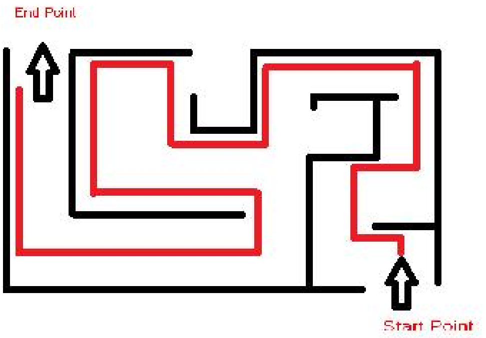


Figure 7: Path Taken by Using Pledge Algorithm

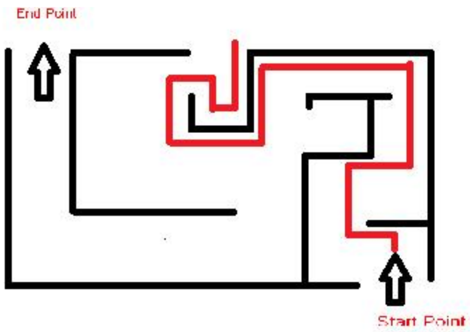


Figure 8: Path Taken by Using Wall Following Algorithm

Based on the result, robot with pledge algorithm is able to finish the maze as compared to robot with wall following algorithm. The main part that differentiates the results is the area where the wall is disconnected. The different path taken by robot at the disjoint maze with both algorithms is described as per below table:

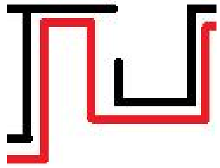
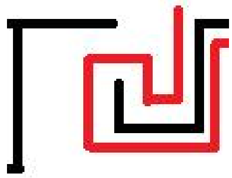
Path Taken	**Explanation**
 Pledge Algorithm	As robot will move forward freely everytime it faces its “favorite” direction, the robot will not turn right to follow the disjoint maze. Instead, it will move towards the front wall and follow it accordingly.
 Wall Following Algorithm	At the disjoint maze, robot will turn right to follow the wall and finally leave the maze without solving it.

Table 3: Effect of algorithms at disjoint maze

V. CONCLUSION

In conclusion, pledge algorithm is able to solve wall following algorithm‘s limitation in solving autonomous robot navigation in disjoint wall maze. The ability of pledge algorithm to make a robot not fully depending on the wall to do navigating, making the learning process of the environment become much more practical and easier.

Besides, autonomous robot navigation has a bright future to be discovered as the rule of robot in human life is expanding as technology evolves. A lot of benefits can be gained by exploring this field of study as robot can do things that human cannot or human might be exposed to danger if they are doing it.

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