wjert, 2025, Vol. 11 Issue 2, 13-25.

Case Study

ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org

SJIF Impact Factor: 7.029

INTELLIGENT MAZE-SOLVING ROBOT EQUIPPED WITH ADVANCED OBSTACLE DETECTION TECHNOLOGY

Rahmot Ullah[*1], Kazi Wohiduzzaman[2], Md. Mahbub Anam Riyad[3], Md. Sazzadul Islam Sakib[4] and Suhel Ahmed[5]

[1,2,3,4]Metropolitan University.

[5]Gloucestershire University.

Article Received on 17/12/2024 **Article Revised on 06/01/2025** **Article Accepted on 26/01/2025**

***Corresponding Author**

Rahmot Ullah

Metropolitan University.

ABSTRACT

Autonomous navigation is an important feature that allows a mobile robot to independently move from a point to another without an intervention from a human operator. Line Maze Solving Robot is a modified line follower robot used to find the shortest path in a maze. This paper presents the design and implementation of a Line Maze Solving Robot, an autonomous mobile robot capable of navigating through a maze to find the shortest path without human intervention. The robot utilizes a novel Short Path Finder algorithm, which operates in three distinct modes: search mode, short path mode, and path mode. To enhance performance, an improved PID-based motor speed controller is incorporated to regulate the robot's speed and ensure accurate line-following behavior. Key components include infrared (IR) sensors for line detection, a microcontroller for data processing, a motor driver for controlling the DC motors, and an ultrasonic sensor for obstacle detection. Experimental results demonstrate the robot's ability to efficiently navigate from the starting point to the finish line while avoiding obstacles, effectively identifying and following the shortest route in the maze.

INTRODUCTION

A maze is a network of paths, typically from an entrance to exit. The concept of Maze is approximately thousand years old[1] which was invented in Egypt. From then, many mathematicians made various algorithms to solve the maze. Modern robotics technologies are focused on developing self-navigating autonomous robots to automate our day-to-day processes. This means that most of the research focuses on improving sensors and algorithms to build flexible and accurate robots. The maze solving robots also known as micro-mouse are designed to find a path without any assistance or help[2] As a type of autonomous robot, it has to decode the path on its own to solve the maze successfully. So, its logic is quite different from the line following the robot which follows a predetermined route.

These types of autonomous mobile robots can be used in a wide variety of applications such as material handling, warehousing management, pipe inspection and bomb disposal. Nowadays, maze solving problems is an important field of robotics. It is based on one of the most important areas of robotics, which is "Decision Making Algorithm". Because, this robot will be placed in an unknown place, and it requires a good decision-making capability. There are many types of mazes solving robots using various types of algorithms. In this project, the system design of the Maze solving robot consists of an IR sensor and then sensors will detect the line. To solve the maze, this robot will apply line following algorithms such as the left- or right-hand rule. We are using the left hand rule for this project so the robot will follow the rules for finding the shortest path.

Background Study

The micro mouse first needs to explore the maze to locate the shortest path from the start point to end point of the maze. After the robot is finished mapping a maze, it can travel from start point to end point as quickly as it can. In early robotics, line following was a way of allowing one to move autonomously. In the 1960s, one of the biggest exploration projects of all time was in full swing: the space race. Most robots that were built for moon landing were remote-controlled. The first line following robots is the Stanford Cart. The Stanford cart started life as a remote-controlled mobile robot. A four wheeled card, its chassis consisted of a rectangular box fitted with cameras and on-board TV system. Researchers at the university worked on the cart from 1960 to 1980; for a period in 1970 they outfitted the cart with line sensors to test autonomous navigation algorithms.

Later, the cart would be turned into a fully autonomous vehicle; for a time, it was at the cutting edge of vision-controlled robots. The team famously let the robot roam the campus unaccompanied and created a sign that read "CAUTION ROBOT VAHICLE" to hang on it when it was out and about. This sign caused the lead researcher a lot of headaches, as they had to get it remade after it was repeatedly stolen. In the middle of the 20th century, Maze solving problems became an important field of robotics.[3] In the year of 1972, editors of IEEE Spectrum magazine came up with the concept of micro-mouse which is a small microprocessor-controlled vehicle with self-intelligence and capability to navigate a critical maze.[4,5] Then in May 1977, the fast US Micro mouse contest, called “Amazing micro mouse Maze Contest” was announced by IEEE Spectrum. Late 1970s the designs of the maze solving robot’s designs were used to have huge physical shapes that contain many block logic gates. Figure 2.1 shows the example of early maze solving robots (micro mouse). Due to technological development the physical size of the robot becomes smaller and the features of the robot become modern.

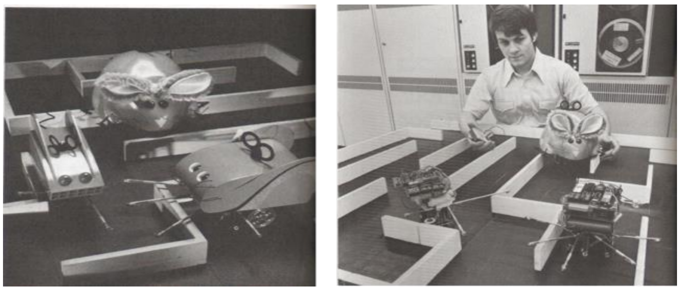

Figure 1: Old Generation micro mouse robots.

In the year 1999, Michael Gims, Sonja Lenz and Dirk Becker from University of East London developed a micro mouse. They used a non-graph theory algorithm, Wall Following Algorithm. But their robot did not move intelligently on the map and it could not solve the maze with a loop.

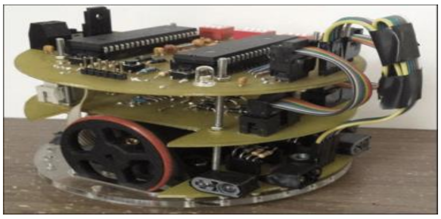

Figure 2: Micro mouse University of East London.

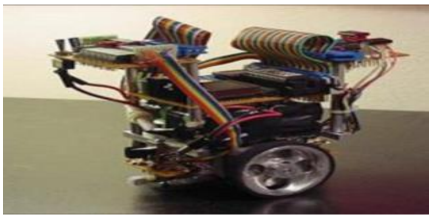

Figure 3: Micro mouse by Chang Yuen Chung.

Chang Yuen Chung, a student of Universiti Teknologi Malaysia (UTM) designed a micromouse using Flood Fill Algorithm. His robot was designed in three layers so that the robot looks more compact and smaller in size. But it was very hard to troubleshoot if there was a circuit fault. Flood Fill Algorithm is one of the graph theory mazes solving algorithms. In paper[6], Chang Yuen Chung claimed that this Flood Fill Algorithm is able to find the shortest path but more memory is required for execution.

Most commercial autonomous robots use range sensors to detect obstacles. The use of radar, infrared (IR) sensor and ultrasonic sensor for developing an obstacle detection system had started as early as the 1980's. Although, after testing these technologies it was concluded that the radar technology was the most suitable for use as the other two technology options were prone to environmental constraints such as rain, ice, snow, dust and dirt. The radar approach was also a very cost-effective technology both for the present and the future.

In 1999, sonar was used for vehicle localization and navigation respectively. I. Ulrich and J. Borenstein developed an algorithm for obstacle detection and avoidance using a sonar ring placed around the robot. Unfortunately, the major drawback of sonar is that a single sensor is inadequate to acquire enough information about the environment around an autonomous vehicle. Oftentimes several rings of sonar sensors are connected together for optimum performance as presented in 1991. This is usually cumbersome and expensive for implementation. However, despite the aforementioned limitations, sonar is still a good safety net for obstacle detection. Also, the use of vision and laser scanners for unmanned ground vehicles to avoid obstacles was presented in 2006. Support Vehicle machine (SVM) has been proposed by C. Qingyang and S. Zhenping for creating a local path for an unmanned ground vehicle. Also, the development of an unmanned ground vehicle system for remote- controlled surveillance has been presented by P. Fofilos and K. I. Xanthopoulos. A reliability and failure test in unmanned ground vehicles was carried out in 2009. A study on the use of industrial robots in various industries in America has been conducted in 2012 and 2014. Finally, the use of ultrasonic sensors for an obstacle avoidance robot vehicle to create a clear path for locomotion has been presented in 2016.

Structure modelling and design

The project begins with the generation of ideas for the design and construction of the Maze Solving Robot and Obstacle Detector. Power supply of the system is directly connected with the two buck modules which steps down the supply voltage. One of the modules steps down the voltage to 9V which goes to the motor driver as input and another one steps down the voltage to 5V which goes to the Arduino nano, IR sensor array, ultrasonic sensor and push button circuit as input. Arduino Nano receives the sensor's reading and pushbutton as an input. After that, it will process the data and control the motor driver pins according to the input data.

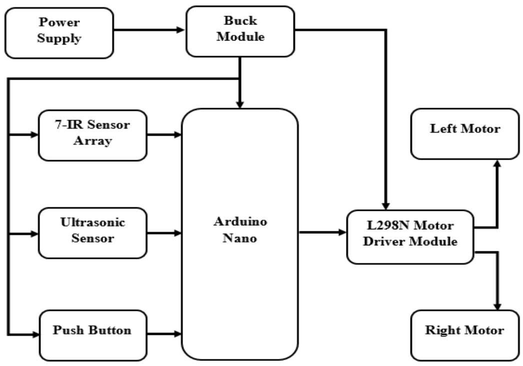

Figure 4: Block Diagram of Maze Solving Robot with Obstacle Detection.

Figure 5 shows the circuit diagram of "Maze Solving Robot with Obstacle Detector". This project consists of several hardware components shown through a block diagram. At first, a DC power source is used as a power supply consisting of 3 pieces of Li-ion cells in series. Arduino Nano is used as the main brain and controller of this project. An IR sensor array is used for tracking the path, and an ultrasonic sensor is used for detecting an object in front of the robot. A pushbutton is used for turning the robot on and off, and a buck module is used to reduce the supply voltage according to the need.

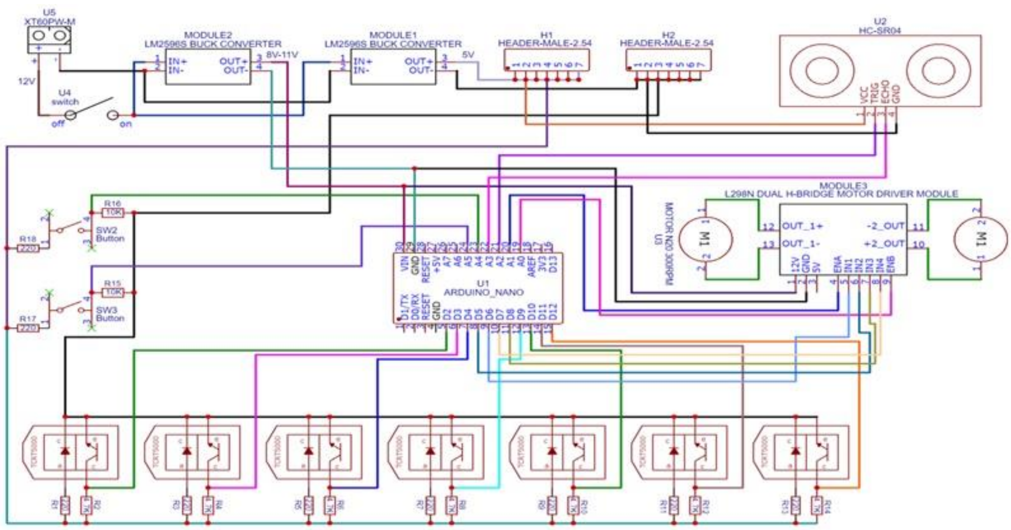

Figure 5: Circuit Diagram of Maze Solving Robot with Obstacle Detector Power Supply Unit.

Figure 6 shows the input section of our project which contains the XT60 male connector which helps us to connect the supply battery, XT60 is connected to two buck modules input by a switch which help us to break the supply of the system. The outputs of the buck module are connected to Arduino nano, IR sensor array, ultrasonic sensor, pushbutton circuit and motor driver module.

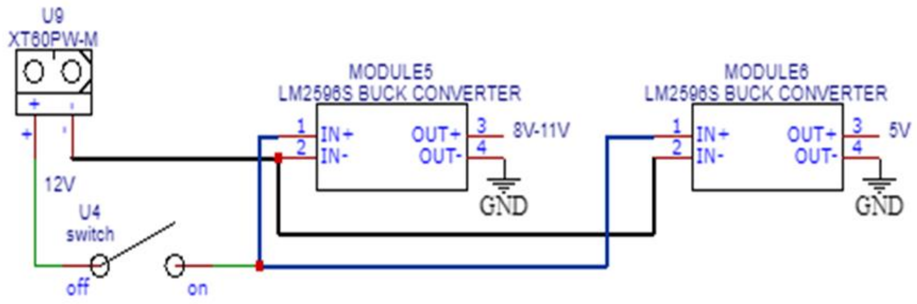

Figure 6: Input Section Schematic.

The Sensors

Figure 7 shows the circuit of the IR sensor array. We used 7 IR sensors for tracking the line. All of the IR sensor LED anode and phototransistor collector is connected to positive terminal of buck module which is stepped down the voltage to 5V by 220ohm and 4.7kohm resistor respectively and all of the IR sensor LED cathode and phototransistor emitter is connected to GND or negative terminal of buck module. The feedback is taken from between the phototransistor and 4.7kohm of all sensors.

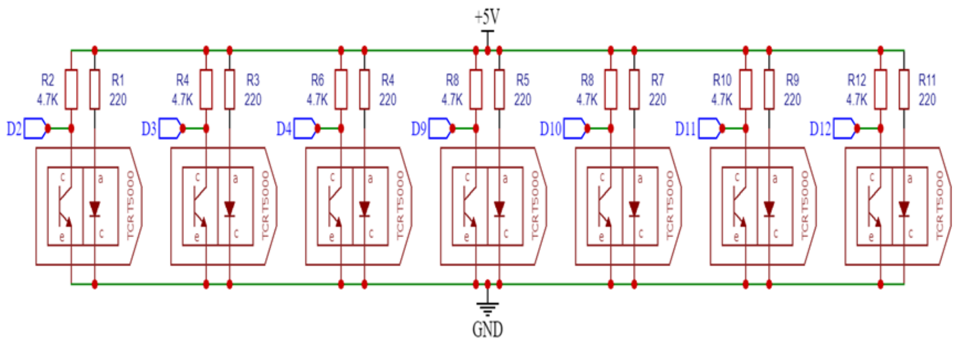

Figure 7: IR (TCRT5000) Sensor Array Schematic.

Figure 8 shows the connection between the ultrasonic sensor and Arduino nano. VCC and GND are connected to the buck module positive and GND respectively. Trigger and Echo pins are connected to A2 and A3 pins of the Arduino Nano

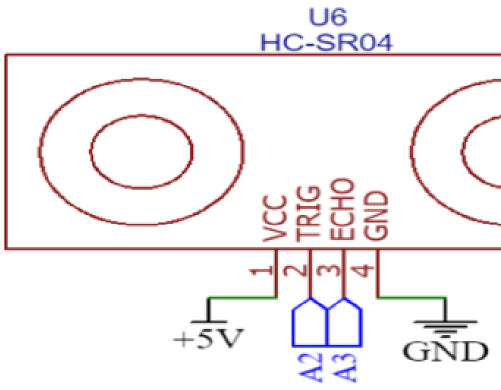

Figure 8: Ultrasonic Sensor Schematic.

Motor Driver Unit

Figure 9 shows the motor driver module schematic. Motor driver module VCC is connected to the buck module positive which has stepped down the voltage to 9V and GND to GND or negative terminal. OUTPUT 1 and OUTPUT 2 are connected to the right motor and OUTPUT 3 and OUTPUT 4 are connected to the left motor. ENA is connected to A1 and ENB is connected to A0. These pins are used to control the speed. Other 4 pins are IN1, IN2, IN3 and IN4 connected to D6, D5, D7 and D8 respectively.

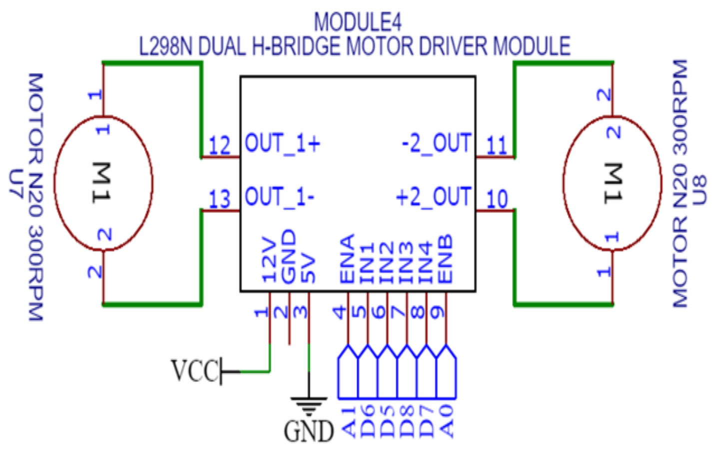

Figure 9: Motor Driver Section.

On-Off Section

Figure 10 shows the pushbutton circuit of our project. Pushbutton circuit is very simple. One pin of the pushbutton connected with positive supply of buck module which stepped down the voltage to 5V by a 220ohm resistor and other pins of the pushbutton connected to ground by 10kohm resistor and the feedback is taken from between 10kohm resistor and push button pin.

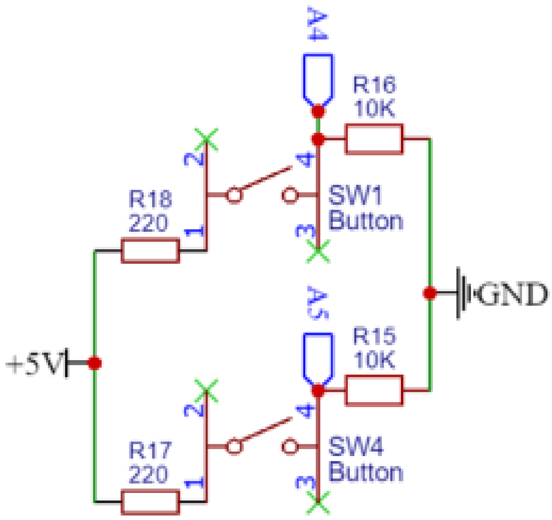

Figure 10: Pushbutton Section Schematic.

Arduino Section

Figure 11 shows the Arduino nano connection with the sensors, pushbuttons and motor driver module. The VIN pin of Arduino nano is connected to the buck module and GND to GND and the rest of the digital and analog I/O pins are connected with sensors and modules.

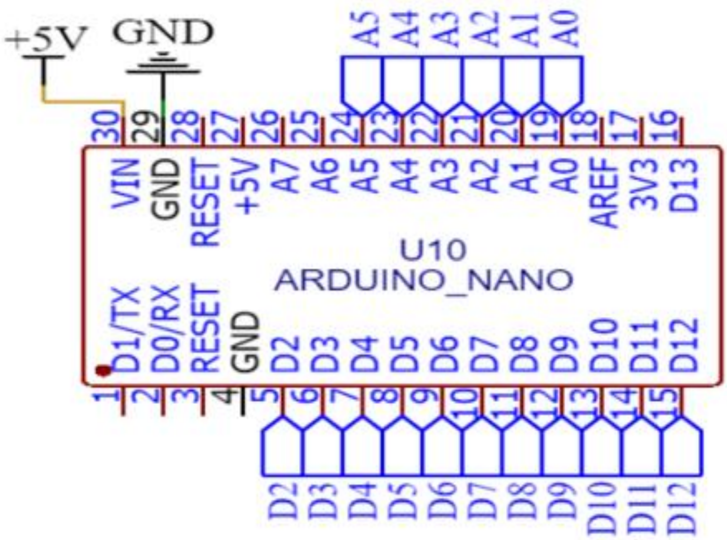

Figure 11: Arduino Section Schematic.

Process and Algorithm

The flow chart of the "Maze Solving Robot with Obstacle Detector" is given below-

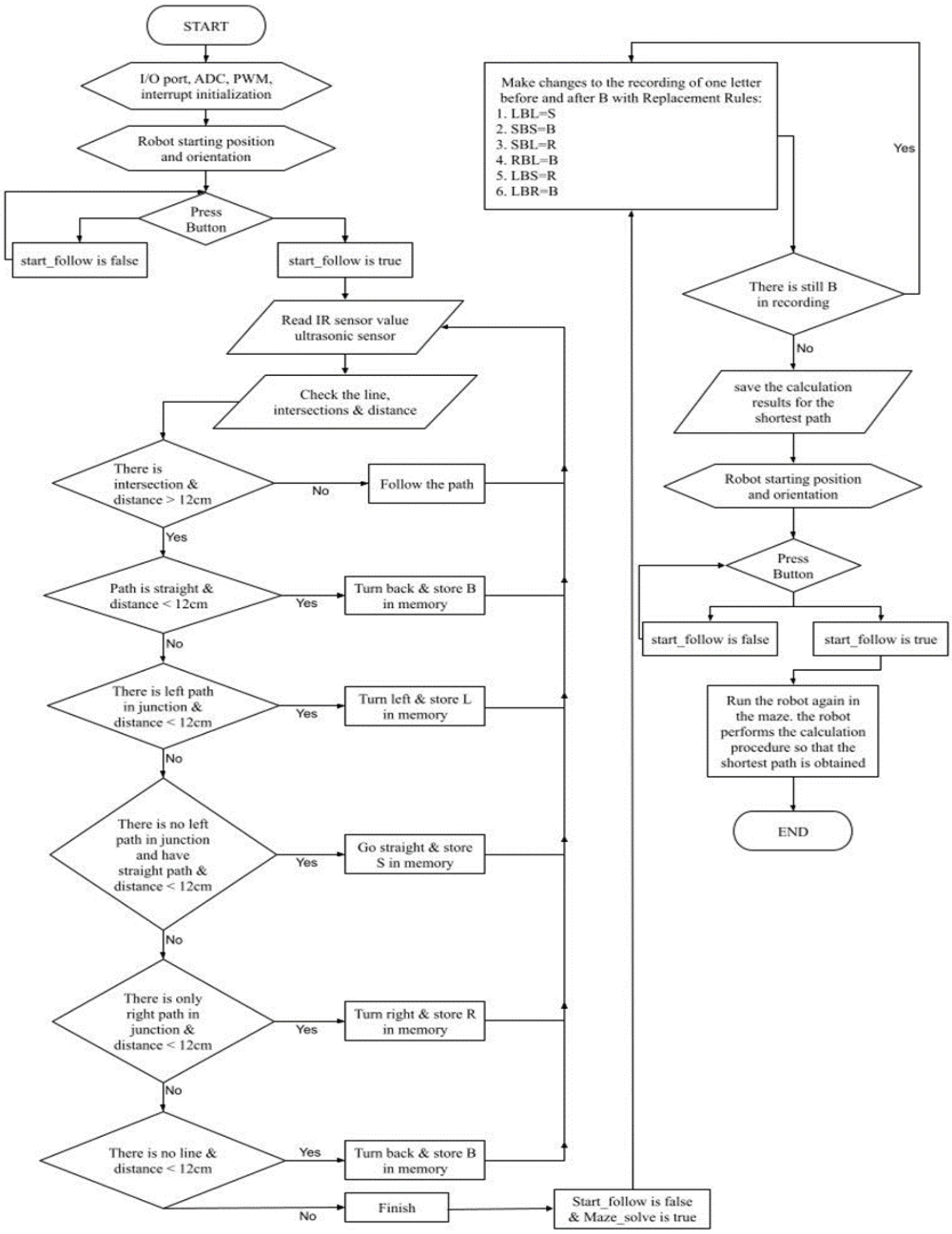

Figure 12: Flowchart of Maze Solving Robot.

In this project, the No-Loop or Short-Loop Maze Algorithm is implemented for solving the maze. In this algorithm, the robot is instructed to follow a preference of directions. Two sets of sequences of preference may be provided: (1) Left-Straight-Right-Back and (2) Right-Straight-Left-Back. For example, directions may be marked as follows: (R) for right, (S) for straight, (L) for left, and (B) for back. Whenever a junction is encountered, a path is always chosen based on the preference sequence. Sequence 1 is implemented in our project. If two paths come out of one junction, one going left and the other right, the left path is first taken by the robot (according to sequence 1) to explore it. The junction and direction are saved in memory. If a dead end is encountered after following the path, a turn back is made, and the previous position is reached. After reaching that position, previously saved values in the data structure are extracted, and the present preferred direction number is added to that value. This new value is then saved again in the same place of the data structure. This procedure is continuously followed until the end-point is found. The robot will then have a record of the number of junctions it came across, along with a corresponding array to record the directions taken. By moving in this way, the robot will eventually reach the end-point, and the recursively updated direction array will generate an error-free simple path from the starting point to the finishing point. An example showing how this works is provided here.

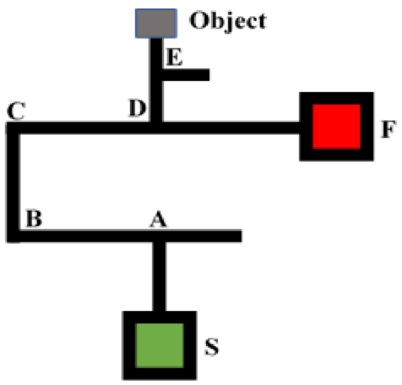

Figure 13: An example of generalized algorithm for 'no-loop' or 'short-loop' maze.

ISSUES AND SOLUTIONS

While working on this project, some issues were faced with the IR sensor array. Unusual values were sometimes given by the IR sensors if their sensing distance was not calibrated. The working distance of the sensors could be calibrated by changing the feedback and LED limiting resistors. A defective wire problem was also encountered, which caused unusual readings from the IR sensor, preventing the robot from tracking the maze.

The speed issue was also faced, which caused unusual movement of the robot and could affect the entire algorithm. To solve this problem, a buck module was used, and the voltage was stepped down. This lower voltage was then used as the input for the motor driver, which helped decrease the speed and made the robot's movement smoother.

RESULTS AND DISCUSSION

Figure 14 shows the Voltage reading graph of all IR sensors. An IR sensor is used to track the maze. The values are measured by using Serial monitor of Arduino IDE and data log is collected by teraterm.

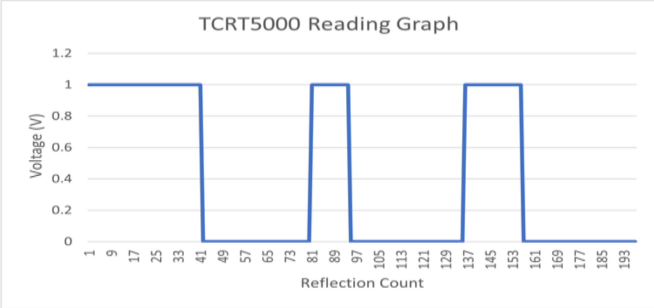

Figure 14: TCRT5000 Reading.

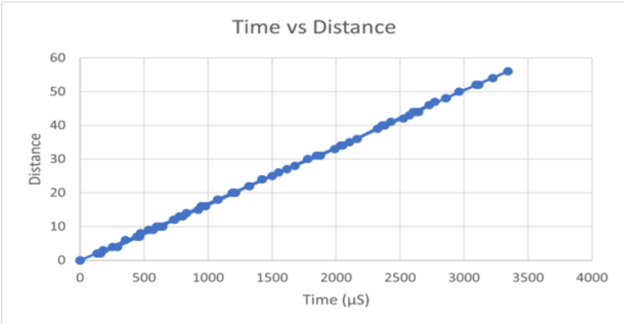

Figure 15: Time vs. Distance Graph of HC-SR04.

Figure 15 shows the Time vs. Distance graph of ultrasonic sensors. Ultrasonic Sensor is used to measure the distance between robot and object. The values are measured by using a monitor of Arduino IDE and data log is collected by teraterm.

The practical implemented image of this project is given below-

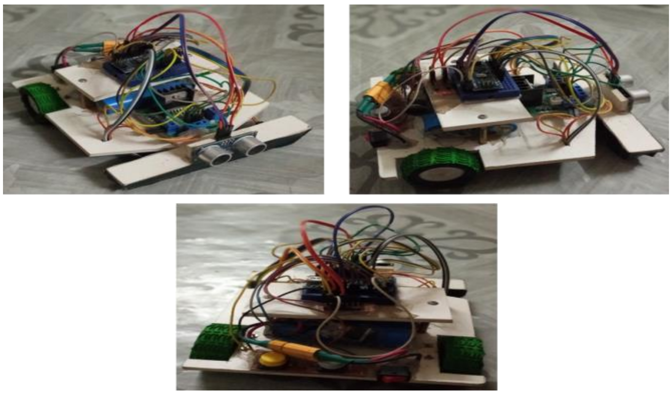

Figure 16: Practical Implementation.

CONCLUSION

As a conclusion, the maze solving algorithm has been successfully implemented in the robot and the objectives of the project have been achieved. The algorithm was the Left hand line following the algorithm. But due to lack of self-intelligence, it failed to solve the closed loop maze. Also the robot struggles to solve the round line, actuate angle which is less than 60 degrees. The robot was trained in a real maze. Several tests have been run to ensure the best performance of the robot.

This project helps us to improve various important information about robotics, knowledge about many decision-making algorithms. It's also helped to learn about many electronics components such as motor drivers, sensors, etc. This gained knowledge will have a significant impact on future work.

REFERENCES

1. W. Matthews, Mazes and labyrinths, 1st ed. New York: Dover Publications, 2013.
2. Comprehensive and Comparative Study of Maze-Solving Techniques by Implementing Graph Theory, Sadik, A.M.J. *International Conference on Artificial Intelligence and Computational Intelligence*, 10.1109/AICI.2010.18, pp.52-56.
3. "Maze Solvers Archives - cyberneticzoo.com", cyberneticzoo.com, 2017. http://cyberneticzoo.com/category/mazesolvers/. [Accessed: 12- Apr2017].
4. "Spectral lines: Announcing the Amazing Micro-Mouse Maze Contest - IEEE Xplore Document", Ieeexplore.ieee.org, 2017. http://ieeexplore.ieee.org/document/6367601/.
5. CHANG, Y. C. 2009. Micromouse Maze Solving Robot. Bachelor of Engineering, Universiti Teknologi Malaysia.
6. Anik Choudhury, Sheikh Tanvir Ahamed and Syed Imam Hasan "Maze solving Algorithm for line following robot and derivation of linear path distance from nonlinear path", *16th International Conference on Computer and Information Technology, Khulna, Bangladesh*, DOI: 10.1109/ICCITechn.2014.6997314.
7. A Chokalingam and N Ramu "DESIGN AND IMPLEMENTATION OF SHORTEST PATH LINE FOLLOWING MAZE SOLVING ROBOT", *International Journal of Creative Research Thoughts (IJCRT)*, 2020; 8.
8. M. Kazimierczuk, Pulse-width modulated DC-DC power converters, 1st ed. Chichester, West Sussex: Wiley, 2016.
9. Mammano Rovert (1999). "Switching Power Supply Topology: Voltage Mode vs. Current Mode" Texas Instruments Incorporated.
10. Tawil, Yahya (19 November 2017). "A Full Review of Easy EDA: A Circuit EDA Online Tool". Atadiat. Archived from the original on 2020-10-21. *Retrieved, January 30, 2020.*

11. Gerard Gibbs, Huamin Jia and Irfan Madani, "Obstacle Detection with Ultrasonic Sensors and Signal Analysis Metrics", International Conference on Air Transport – INAIR 2017, Transportation Research Procedia, 2017; 28: 173-182.
12. Miss Cecilia Jane D'Silva, Miss Delicia Perlin Rebelo, Mr. Linford William Fernandes and Miss Clarissa Joella Costa, "Obstacle Detection using Ultrasonic Sensor", IJIRST – International Journal for Innovative Research in Science & Technology, April-2016; 2(11): ISSN (Online): 2349-6010.
13. Christofer N. Yalung and Cid Mathew S. Adolfo "Analysis of Obstacle Detection Using Ultrasonic Sensor", International Research Journal of Engineering and Technology (IRJET), January-2017; 4(1).
14. Sindhu Naik, Soumya, Srushti G Nayak, Soubhagyalaxmi C Hiremath and Pooja R Ingalahalli "A LITERATURE SURVEY ON MAZE SOLVING AND OBJECT DETECTING ROBOT", International Research Journal of Engineering and Technology (IRJET), March-2021; 8(3).