Design and Implementation of a Path Finding Robot using Modified Trémaux Algorithm

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Abstract: Using a robot to find a path to achieve a target location in an unknown maze requires a robot that can explore the maze and determine the direction of the intersection in the maze. The robot must map the maze, determine a route and try to reach its destination as fast as possible through the closest path. Trémaux algorithm is one of the maze solver algorithms that is used to explore a maze and its use to find a way out of the maze, meaning that this algorithm is designed for purposes that are on the edge of a maze and not in the middle of a maze. For this reason, Trémaux algorithm was modified by adding the Manhattan Distance algorithm to improve the ability of the robot to find targets in the middle of the maze. Using the Manhattan Distance algorithm made able to make better decisions compare to Trémaux random decision at branch position. The application of a combination of these algorithms enables the ability to search for paths in an unknown maze environment. The success rate to explore, map the maze, and find the shortest path to the destination is dramatically increased using a modified Trémaux algorithm.

1 INTRODUCTION

The development of an autonomous mobile robot that can find itself and reach its destination without being controlled has been growing rapidly. The ability of a mobile robot to move automatically from a place to a destination without the assistance of an operator is an important part of the capability of a mobile robot which is continuously being developed. This is an application that is often used in the gaming industry. Its use in warehouse, search and rescue applications, its development in the era of automatic vehicles, is one of the developing researches. Various researches, methods, and algorithms have been developed to support autonomous mobile robots. These methods and algorithms are unique along with their respective advantages and disadvantages.

Various studies on the development of maze pathfinding have been carried out, Flood Fill Algorithm (Chu et al., 2019; Jabbar, 2016; S. Tjiharjadi & Setiawan, 2016), Fisher-Yates Shuffle algorithm (Hoetama et al., 2019), A-Star (Downey & Charles, 2015; Kumar & Kaur, 2019; S. Tjiharjadi et al., 2017; Zikky, 2016), Pledge Algorithms (S. Tjiharjadi, 2019), Modified A-Star (Kang et al., 2018), Hybrid approach (Ansari et al., 2015), Artificial Bee (Faridi et al., 2018), Dijkstra algorithm (Reddy, 2013), and also Trémaux (Yew et al., 2011).

In this paper, it is reported that research using the Trémaux algorithm is applied to a mobile robot that has a job to find the route from the start position to the target position automatically, it finds a path in an unknown maze. For this need, the algorithm is modified so that it can reach the target in the middle of the maze. This research focuses on implementing a small mobile robot designed to solve a maze using the Trémaux algorithm.

Robot maze problems are based on decision-making algorithms that are a very important field of robotics. The mobile robot has the task of finding the way to resolve a maze in the least amount of time and using the shortest way (Elshamarka & Bakar Sayuti Saman, 2012). It needs to navigate from a maze corner to the center as quickly as possible (Semuil Tjiharjadi, 2020).

The robot knows where the starting point is and where the target is, but it needs to look for all the information on the obstacles to reach the target. The maze is made up of 25 square cells, each of which is

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approximately 18 cm x 18 cm in size. The cells are set up to form a labyrinth of 5 rows x 5 columns. A cell at its angles is a starting location and the target location is in the middle of the maze. Only one cell is open to get past. Requirements for maze walls and support platforms are given in the IEEE standard.

2 METHODS (AND MATERIALS)

The Trémaux algorithm, created by Charles Pierre Trémaux, is a method invented to find a way out of a maze. The way it works is to draw a line on the floor to mark a path, being able to find an existing exit. Only the path found by this algorithm is not necessarily the closest route.

2.1 Trémaux Algorithm

Trémaux algorithm works according to the following rules:

1. Every time the robot passes through the path, the robot marks the path that is being traversed, so that it is visible from both ends of the fork.
2. Check each lane when entering the lane, do not enter the road that has been marked twice.
3. The robot can choose which path at a random fork that does not have a mark.
4. When the Robot hits a dead end, it will turn back through the road and re-mark the road so that the road has two signs which means it doesn't need to be crossed again.
5. The robot will always choose the path that has the least marks.

There are three types of paths to the Trémaux algorithm in total:

- Unmarked, which means the section has not been explored,
- Marked once, which indicates that the line has been crossed once,
- Marked twice, the robot has passed and is forced to return because there is no way.

This algorithm is effective in finding a way out of the maze, but it has several problems, such as difficulty in drawing a line to mark a path in real life, and then the path found to exit is not necessarily the closest path.

To improve the Trémaux algorithm, researchers added the Manhattan distance algorithm when path selection was made. So that the selected path at the branch is no longer chosen randomly, but is selected based on the calculation of the Manhattan distance. In simple terms, Manhattan Distance calculates the distance by simplifying the distance between two points as the sum of the absolute values of the two coordinate distances (Shen et al., 2021).

$$d1(p,q) = \sum_{i-1}^{n} |pi - qi| \tag{1}$$

The use of the Manhattan distance helps the Robot determine which branch to take, although it does not mean that the branch is the closest path to the target, at least it helps as a reference in choosing a path.

2.2 Robot Design

The robot in this study was designed to use a miniQ 2WD robot frame. The robot chassis is 122mm in diameter, using a pair of wheels driven by a pair of Direct Current (DC) motors as the main drive.

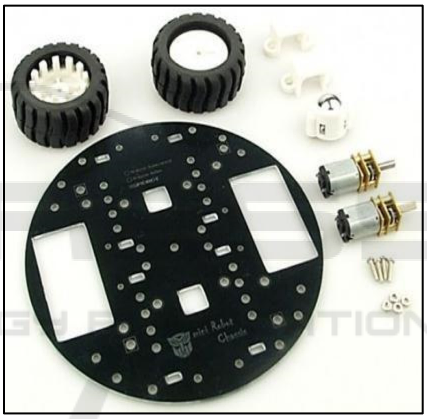


Figure 1: Robot chassis.

This robot can count the number of wheel rotations because it is equipped with several rotary encoders that are mounted on a DC motor.

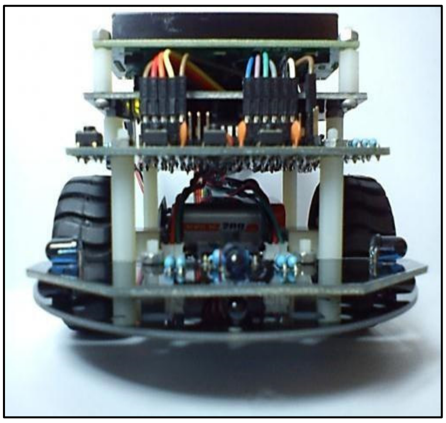


Figure 2: Robot design.

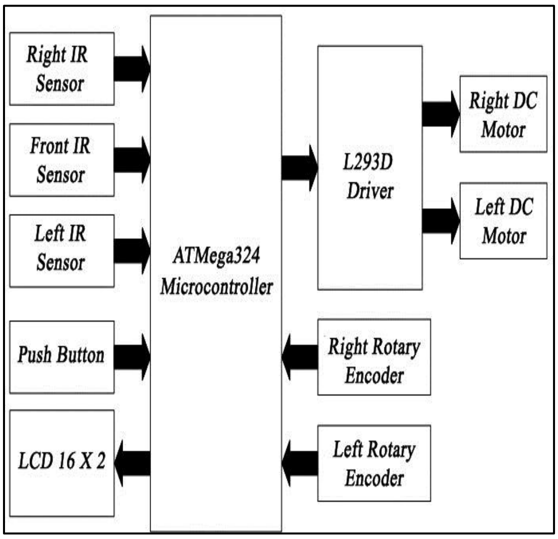


Figure 3: Robot system block diagram.

This robot can control the speed of movement and is equipped with 3 infrared sensors to detect the position of the front, right, and left of the labyrinth wall. By using the AT Mega 324 microcontroller as a control center to respond to input signals, it can run the actuator based on the algorithm that has been programmed. The flowchart of the main program is shown in Figure 6.

2.3 Maze Layout

For testing purposes, a maze was designed that has a cell size of 5 × 5 with a side length of 1.32 m2. Each cell can be placed in a barrier that serves as a wall that the robot needs to detect in its quest to find a path to the target (Figure 4).

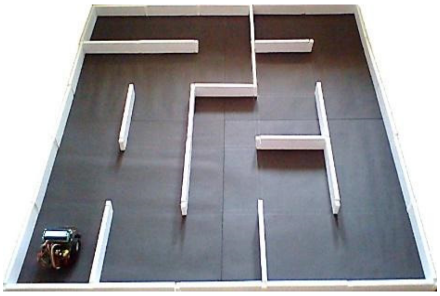
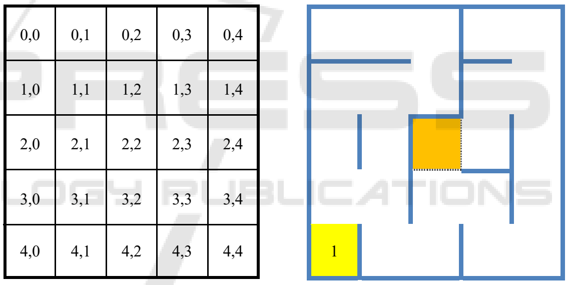


Figure 4: Maze arena.

The use of the Trémaux algorithm, which requires marking line by line, is difficult in actual conditions. Therefore, tagging is done by mapping using a two-dimensional memory array with a size of 5x5. For this purpose, two 5x5 memory arrays are designed, the first array is used to store information on each cell wall of the maze, while the second array stores the tagging in each cell. The position of the robot expressed in coordinates (row, column) is used to calculate the Manhattan distance from the target destination.

3 RESULTS AND DISCUSSION

The real robot was tested on an arena maze (no software simulation) with a layout as shown in Figure 6. The robot started walking and marked the path by updating the information on the cells in the memory array. The robot started moving from the initial cell (row 4, column 0) to the target cell (row 2, column 2) and then returned to the starting cell. The robot's initial orientation was facing North.



0,0	0,1	0,2	0,3	0,4
1,0	1,1	1,2	1,3	1,4
2,0	2,1	2,2	2,3	2,4
3,0	3,1	3,2	3,3	3,4
4,0	4,1	4,2	4,3	4,4

Figure 5: Coordinate Cell and Maze Arena Layout.

The following was one of the experiments carried out by the robot from the starting point to the target point, using the Trémaux algorithm and the Manhattan distance. The robot position was marked as Yellow and the destination was marked as Orange. Figure 6 shows the Labyrinth coordinates and a schematic of the Robot's starting position (4,0). Whenever the robot moves to a new cell, it would update the value cell in the robot's memory. Cell value = 1 means that the robot had only visited once.

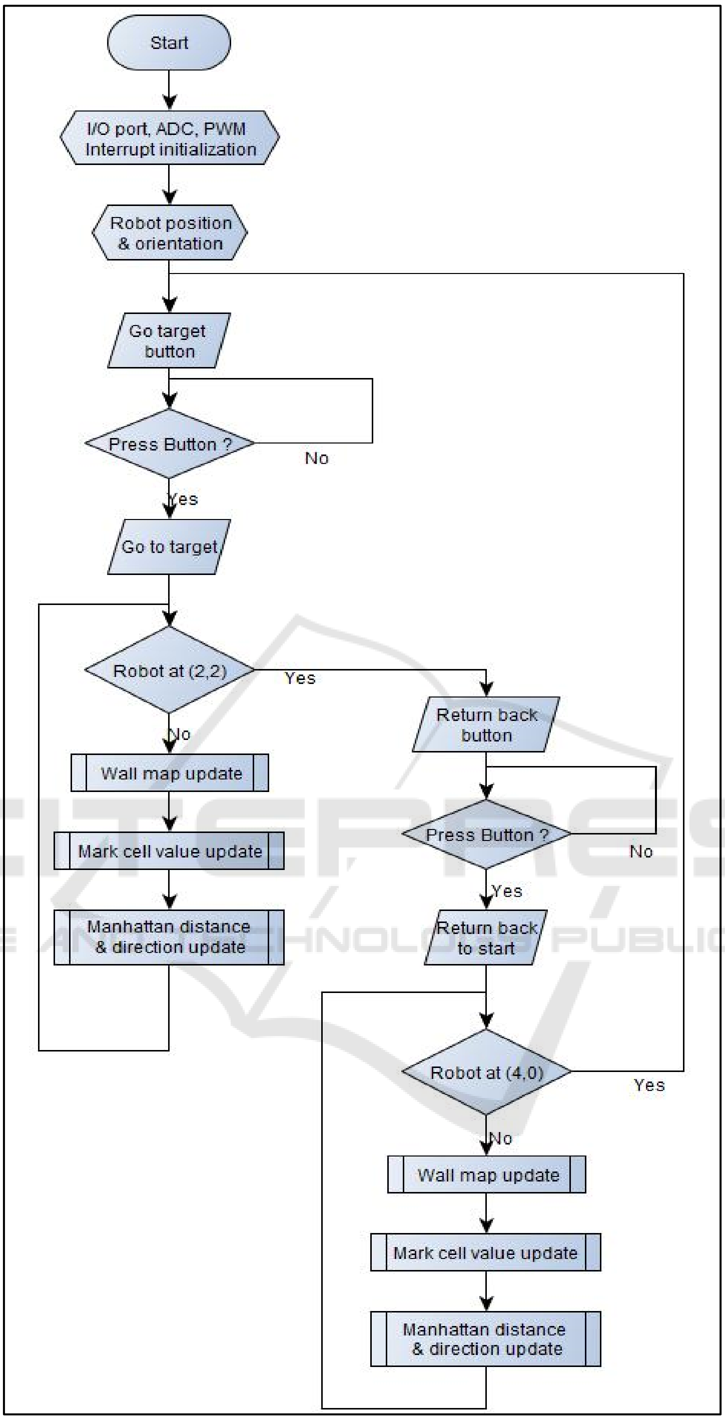


Figure 6: Flowchart of the main program.

When the robot arrives at an intersection, the robot will compare the Trémaux cell value which marks whether the route has been taken or not. The main option is to choose a road that has never been traveled (smaller Trémaux cell value), then if both cell update values are the same, the smallest Manhattan distance value will be selected from the available options. Manhattan distance is the distance from a position to a destination as a straight line.

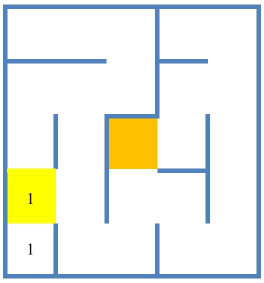


Figure 7: The Robot had only 1 choice and moved to (3,0) and updated Trémaux cell value.

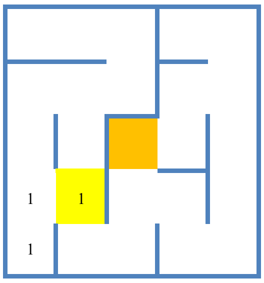


Figure 8: The Robot moved to (3,1) because the Manhattan distance value of (3,1) was smaller than (2,0). Both have the same Trémaux cell value.

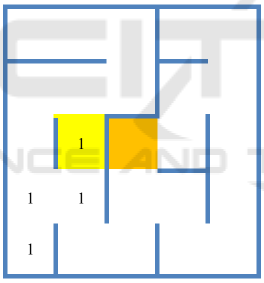


Figure 9: The Robot moved to (2,1) because the Manhattan distance value of (2,1) was smaller than (4,1). Both have the same Trémaux cell value.

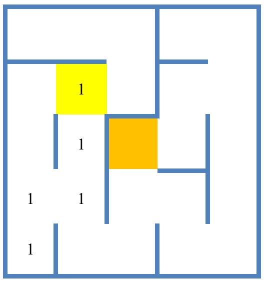


Figure 10: The Robot had only 1 choice and moved to (1,1) and updated Trémaux cell value.

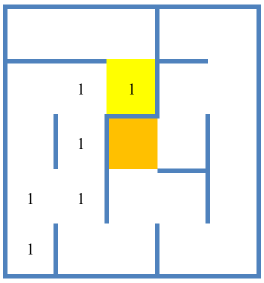


Figure 11: The Robot moved to (1,2) because the Manhattan distance value of (1,2) was smaller than (1,0).

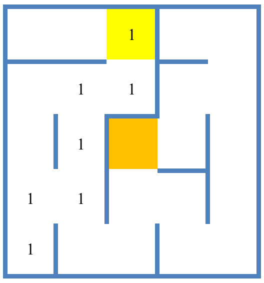


Figure 12: The Robot had only 1 choice and moved to (0,2).

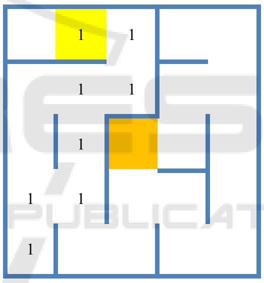


Figure 13: The Robot had only 1 choice and moved to (0,1).

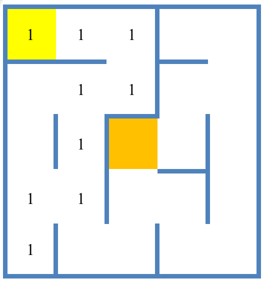


Figure 14: The Robot had only 1 choice and moved to (0,0).

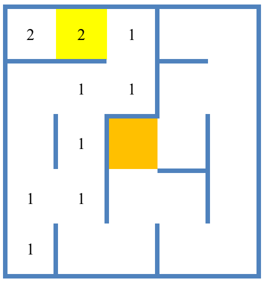


Figure 15: The Robot found a dead end and returned to the previous path and marked it with the value Trémaux +1 = 2. This means that it had been visited twice.

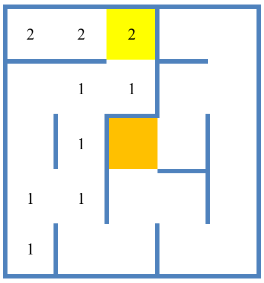


Figure 16: The Robot only had 1 choice and moved to (0,2).

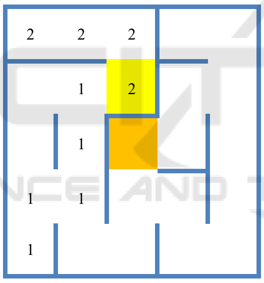


Figure 17: The Robot only had 1 choice and moved to (1,2).

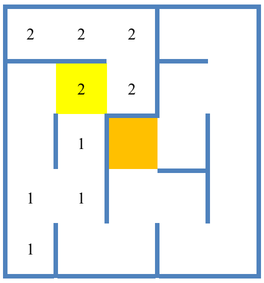


Figure 18: The Robot only had 1 choice and moved to (1,1).

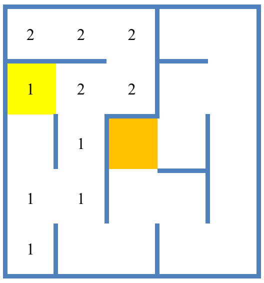


Figure 19: The Robot moved (1,0) that never been visited.

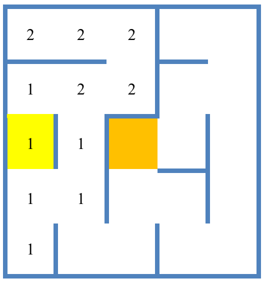


Figure 20: The Robot moved to (2,0).

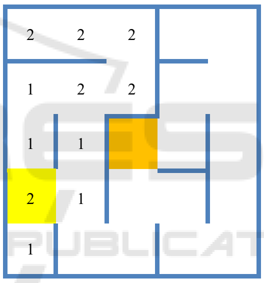


Figure 21: The Robot moved to (3,0) and marked it as 2.

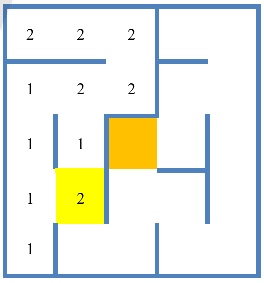


Figure 22: The Robot moved to (3,1) because it had a smaller Manhattan Distance value.

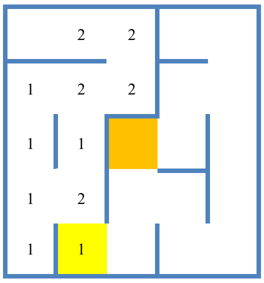


Figure 23: The robot moved to (4,1), it had a smaller Manhattan Distance value.

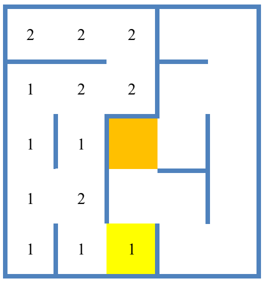


Figure 24: The Robot moved to (4,2) and updated Trémaux value.

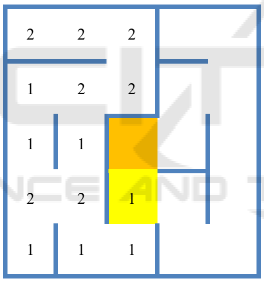


Figure 25: The Robot moved to (3,2) and updated Trémaux value.

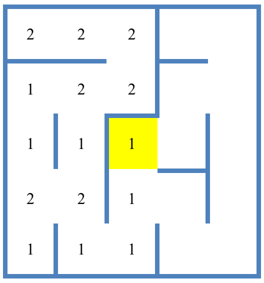


Figure 26: The Robot arrived at its destination (2,2) in 20 steps.

Figure 7 to Figure 26 shows the experiment of the robot's journey using the Trémaux algorithm and Manhattan Distance to reach the target point while updating the Trémaux cell value. Each time the robot is in a new cell, the robot updates the cell value incremented by one. After the robot arrived at the destination, then that point became the starting point, and the starting point turned into the destination point on the robot's return journey.

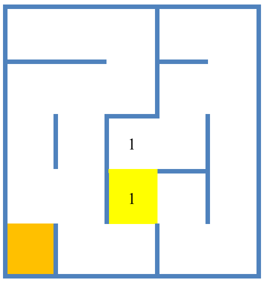


Figure 27: The Robot moved to (3,2) that had a smaller Manhattan distance.

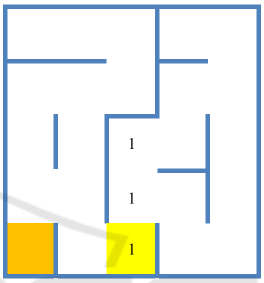


Figure 28: The Robot moved to (4,2) that had a smaller Manhattan distance.

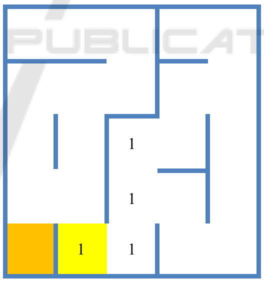


Figure 29: The Robot moved to (4,1) based on Trémaux value.

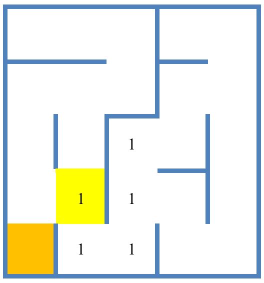


Figure 30: The Robot moved to (3,2) that had a smaller Manhattan distance.

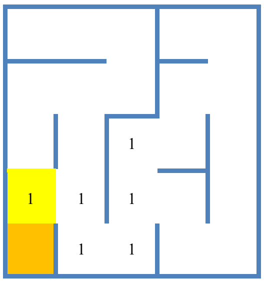


Figure 31: The Robot moved to (3,0) that had a smaller Manhattan distance than (2,1).

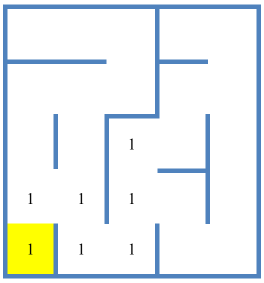


Figure 32: The Robot arrived at its destination in 6 steps.

Figures 27 to 32 show the robot returning to its starting point. The destination point becomes the starting point and the starting point becomes the destination point on the robot's return journey. This layout was also tested using the original Trémaux algorithm without using the Manhattan distance value. This experiment can be seen in table 1.

Table 1: Maze Exploration using only the Trémaux algorithm.

Exp	Status	Routes	Number of steps
1	Run	(4,0) → (3,0) → (2,0) → (1,0) → (1,1) → (1,2) → (0,2) → (0,1) → (0,0) → (0,1) → (0,2) → (1,2) → (1,1) → (2,1) → (3,1) → (4,1) → (4,2) → (3,2) → (2,2)	18
	Return back	(2,2) → (2,3) → (1,3) → (1,4) → (0,4) → (0,3) → (0,4) → (1,4) → (2,4) → (3,4) → (4,4) → (4,3) → (3,3) → (3,2) → (4,2) → (4,1) → (3,1) → (2,1) → (1,1) → (1,0) → (2,0) → (3,0) → (4,0)	18
2	Run	(4,0) → (3,0) → (3,1) → (4,1) → (4,2) → (3,2) → (3,3) → (4,3) → (4,4) → (3,4) → (2,4) → (1,4) → (0,4) → (0,3) → (0,4) → (1,4) → (1,3) → (2,3) → (2,2)	18
	Return back	(2,2) → (2,3) → (1,3) → (1,4) → (0,4) → (0,3) → (0,4) → (1,4) → (2,4) → (3,4) → (4,4) → (4,3) → (3,3) → (3,2) → (4,2) → (4,1) → (3,1) → (2,1) → (1,1) → (1,2) → (0,2) → (0,1) → (0,0) → (0,1) → (0,2) → (1,2) → (1,1) → (1,0) → (2,0) → (3,0) → (4,0)	30
3	Run	(4,0) → (3,0) → (3,1) → (4,1) → (4,2) → (3,2) → (2,2)	6
	Return back	(2,2) → (3,2) → (3,3) → (4,3) → (4,4) → (3,4) → (2,4) → (1,4) → (0,4) → (0,3) → (0,4) → (1,4) → (1,3) → (2,3) → (2,2) → (3,2) → (4,2) → (4,1) → (3,1) → (3,0) → (4,0)	20

Table 1 shows that the use of the Trémaux algorithm in maze exploration did not have the same results, this is because the Trémaux algorithm was developed from the Depth First Search algorithm. Because it is more towards trial error, the Trémaux algorithm will find a destination but not the shortest path.

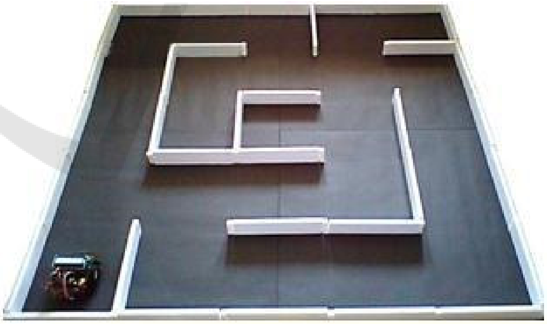
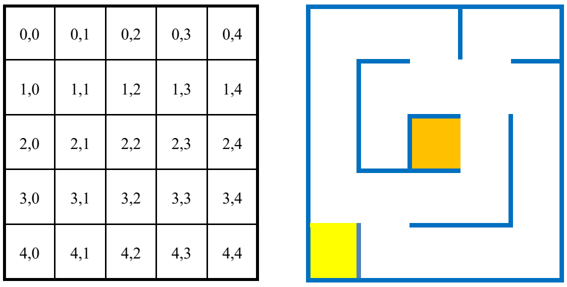


Figure 33: Another maze for the second experiment.



0,0	0,1	0,2	0,3	0,4
1,0	1,1	1,2	1,3	1,4
2,0	2,1	2,2	2,3	2,4
3,0	3,1	3,2	3,3	3,4
4,0	4,1	4,2	4,3	4,4

Figure 34: Coordinate cell and maze arena layout.

The other experiment journey of this robot using another layout can see table 2. Figure 33 shows another maze for the second experiment and figure 34 shows the coordinate and maze layout. The robot journey from starting point to the destination point has been shown in table 2.

The robot in the second experiment still prioritized the smallest Trémaux value and if the Trémaux value was the same, the closest Manhattan distance value would be used. The results of the second experiment showed that the robot can choose the closest route using a combination of the Trémaux algorithm and the Manhattan distance value. Combining the Trémaux algorithm with the Manhattan distance has proven to be better than using the Trémaux algorithm alone.

Table 2: Second Robot Experiment with another maze layout.

	Routes	Number of steps
Run	(4,0) → (3,0) → (3,1) → (3,2) → (3,3) → (2,3) → (2,2)	6
Return back	(2,2) → (2,3) → (3,3) → (3,2) → (3,1) → (3,0) → (4,0)	6

This experiment was carried out using a real robot with a design as shown in Figure 2. Based on all experiments, the use of infrared sensors has proven to be effective in detecting obstacles. So, the robot can explore the maze without any problems.

4 CONCLUSIONS

The design and implementation of robots using the Trémaux algorithm can run a mobile robot to explore the maze and map the existing paths. The use of the Manhattan Distance algorithm can improve the performance of the Trémaux algorithm to determine the direction of travel, compared to only using the Trémaux algorithm.

For further research, the use of the Trémaux method can be improved by a combination of more algorithms and also applications in larger mazes. This research is expected to produce an effective algorithm to operate in a wide unknown environment.

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