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Implementation of Grid Mapping Method for Firefighting Legged Robot

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ABSTRACT

The firefighting robot contest is an event to encourage high education students to explore electronics and robotic skill. The difficulty level of the contest increases from year to year though the arena layout is relatively similar. The field of arena consists of maze, detachable doors and distractors which requires smart idea to enable the robot to be well-performed. The combination of home position and random fire spot at each round of the game make each team have to find the most effective method to win the match. This paper presents an implementation the grid map method on the Azmi four legged robot using ultrasonic PING sensor, GPYA021 infrared sensor and GY-955 gyroscope. An ultrasonic sensor is attached on each of four sides of the robot. The data from each sensor will be interpreted as the distance of the front, right, left and back of the robot relative to the wall. Interpretation depends on the robot's current position. Virtual mapping technique was used by assuming that the arena consists of grids which have uniform size. Each grid was given a consecutive index numbering i.e a symbolic number which in practice be manifested in terms of distance unit. The results showed that the grid map method in this study worked well, tested on four randomized configurations, the robot successfully carried out the search task and returned to the home position with an acceptable execution time.

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1. INTRODUCTION

Firefighting robot contest has been emerged as an invitation to encourage the high education students in exploring robotics skill that refer to Trinity College Firefighting Robot Contest at Seattle, US. The firefighting robot is intended to locate a fire in a tiny floor plan of a house of a certain size, put out the fire using a fire extinguisher, and makes its way back to the front of the house [1]. The navigation of robot requires ability to detect walls, corners, rooms, and ramps. In this contest, there are two divisions, they are wheeled robot and legged robot.

The simulation of house is represented by 244 cm^2 walled floor by its height of 20 cm as shown in figure 1. It consists of four different size rooms and each room has its own door. There is certain area is used for robot start and back home area called as home base. The committee arranges the home base location and candle randomly to ensure the robot can work automatically based on sensing activity algorithm. In order in searching room, the robot requires method to mapping the arena. Various methods have been implemented using ultrasonic sensor, infrared sensor and laser sensor to detect the wall. Typically, bare algorithm use sensor signal directly to detect the walls and slowly feeding it to the actuators. However, smarter idea has been applied to add the abilities of robot to map the arena effectively which is involving grid map system. Thus, the processor artificially perceives the whole arena by scan the certain location. The common methods have been implemented in robot navigation such as wall following, state machine and grid map.

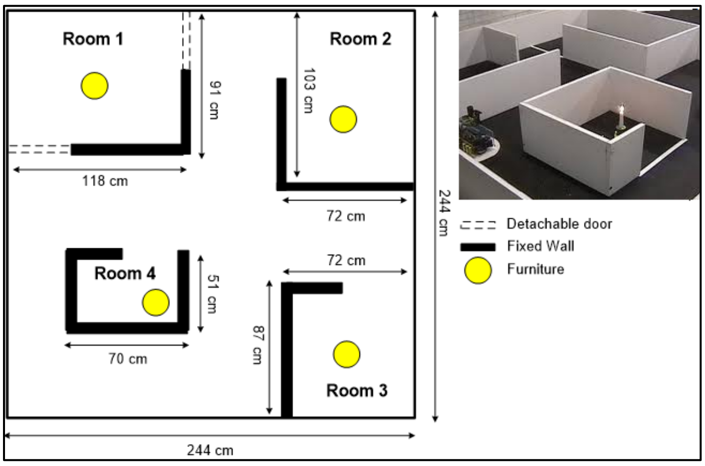


Figure 1. Firefighting robot contest arena size and real image (inset)

In this research, it has been successfully developed a legged robot using grid map in navigation, namely Robot Azmi. It has ability to reach the room destination by coordinate redundancy checking as arranged in grid system and memorize the steps to go back to home position.

2. METHOD

2.1 Hardware

Figure 2(a) depicts block diagram of legged robot system which consist of sensors and actuators. The robot use two pairs leg that are controlled by three servo motors each. Microcontroller Teensy 3.5 is assigned to captive sensor signal, processing the algorithm and make decision via actuators. Teensy 3.5 is the fifth generation 32-bit microcontroller board with ARM CORTEX-M4 and running at 120 MHz. It has 256 KB of RAM and 512 KB of flash memory which allows for the storage and execution of more substantial programs and data. It features wide range I/O pins of 34 digital pins, 21 analog pins, and multiple serial communication interfaces (UART, I2C, SPI) and PWM outputs.

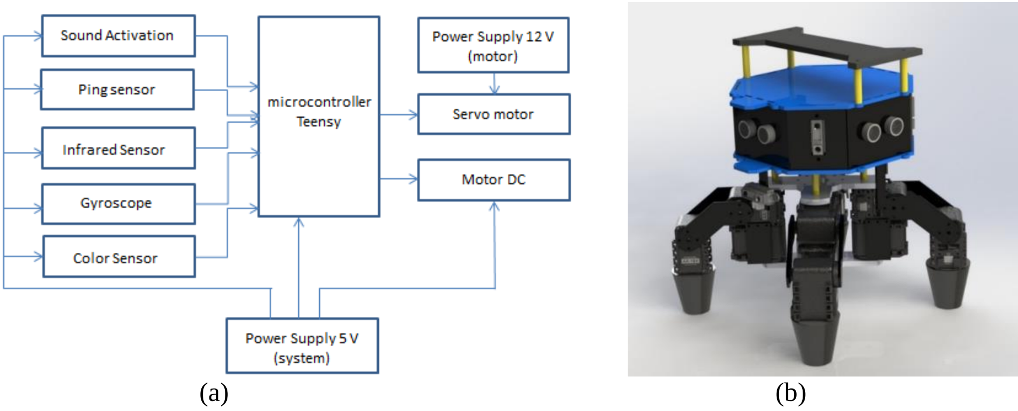


Figure 2. (a)Diagram block of robot system and (b) 3D design of Robot Azmi

The 3D robot design is shown in figure 2(b) which has four mechanical legs and the main body for sensors and controller installation. This system uses ping ultrasonic sensor which has trigger burst of 200 microsecond. It also uses Sharp GP2Y0A21YK infrared sensor which has range of 10-80 cm with linear voltage output 0-3 V and current consumption of 35 mA. Figure below depicts the flowchart of the mapping program. Color Sensor TCS230 is applied for sensing the color of the path and to detect obstacle.

The PING ultrasonic sensor acts as a provider of information on the robot's distance to the arena wall, allowing the robot to navigate along the aisle or the edge of the wall without crashing into it or making contact. The robot reads data from the ultrasonic sensor and combines it with data from the GY-955 gyroscope sensor for calculations. The TCS230 color sensor is used to anticipate and detect the gray carpet deliberately placed by the organizers to confuse the robots. As the robot approaches the fire point, the GPYA021 infrared sensor plays a crucial role in positioning the robot most effectively for extinguishing the fire. The front of the robot is oriented on one side so that the reading data from the ultrasonic sensor, which includes front, back, right, and left distances, depends on the robot's front side, as shown in Figure 3(a). Data from each ultrasonic sensor is translated flexibly, enabling each one to function as a front sensor.

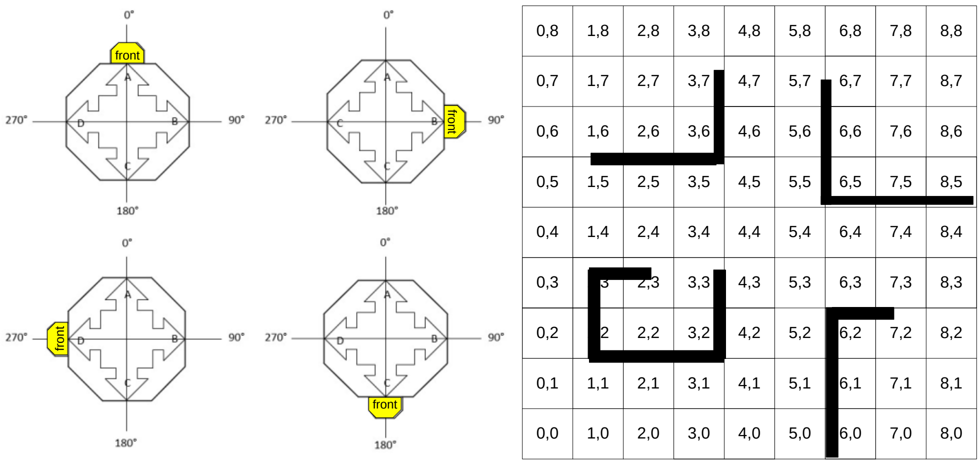
2.2 Grid Map

The layout of the firefighting robot contest arena is shown in figure 1. The arena comprises various rooms shaped like booths, each having distinct areas. Inside each room, furniture is intentionally placed to serve as a distraction for the robot. Due to the varying booth sizes, the arena's layout is asymmetrical. To enable effective navigation, the grid map method is employed, which calculates the usable area for the robot in addition to the clearance or minimum distance between the robot and the arena wall. The number of grids on each side is determined using Equation 1.

$$\text{Total grid} = (\text{Arena Perimeter}) / (\text{Robot Perimeter} + \text{Clearance}) \quad (1)$$

Given that the arena perimeter is 244 cm, the robot perimeter is 20 cm, and the clearance is 6 cm, substituting these values into (1) yields 9 grids for each side. Figure 3(b) illustrates the grid map, where each grid is assigned an index number following a column-row pattern sequentially, with the lower-left corner as the origin.

While the robot maneuvers within the arena, it stores and updates data for each occupied grid. This data includes five pieces of information: the distance to the front wall, the distance to the right wall, the distance to the back wall, the distance to the left wall, and the presence or absence of carpet.



(a) (b)

Figure 3. (a) Front side of robot arrangement and (b) grid map design of the arena by coordinates

2.3 Programming

After the robot gathers data from all four ultrasonic sensors, it can determine its current position on the grid map based on the obtained coordinates. If there is a redundancy of coordinates, meaning the robot remains at the same position (x, y) after reading the ultrasonic sensors, it will initiate movement away from the wall. The robot's movement vector always aligns with the front side of the robot. Until the robot locates a fire point, the back of the robot serves as a reference for moving away from the wall. This means that the robot will keep the back side oriented away from the wall while navigating through the arena. By doing so, the robot can effectively explore the environment and avoid collisions with obstacles or walls.

In summary, the robot utilizes data from the ultrasonic sensors to determine its position on the grid map, and if there is any redundancy, it starts moving away from the wall. The robot's movement vector always aligns with the front side, while the back of the robot is used as a reference for moving away from the wall until a fire point is detected.

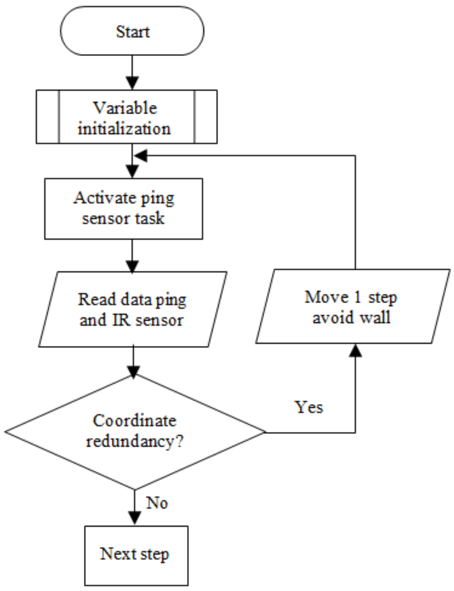


Figure 4. Grid map algorithm flowchart

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3. RESULTS AND DISCUSSIONS

The robot Azmi implemented the grid map method and underwent testing for search and fire extinguishing tasks in firefighting robot contest arena. The robot initial position (home position) and the location of the hotspot were varied in each experiment to assess the robot reliability in performing its duties. The trajectory of the robot for each experiment is visualized in Figure 5. In Figure 5, the red line represents the path the robot took when searching for hotspots, while the blue line shows the path the robot followed after extinguishing the fire and returning to its home position. In all four combinations of home position and hotspots tested, the robot successfully located, extinguished the fire, and returned to its home position. Notably, the robot efficiently navigated without exploring all the rooms individually, indicating its effective use of time. The duration for the robot to complete the entire trip, from leaving the home position to returning to it, was recorded as 22 seconds, 32 seconds, 31 seconds, and 24 seconds for configurations a, b, c, and d, respectively.

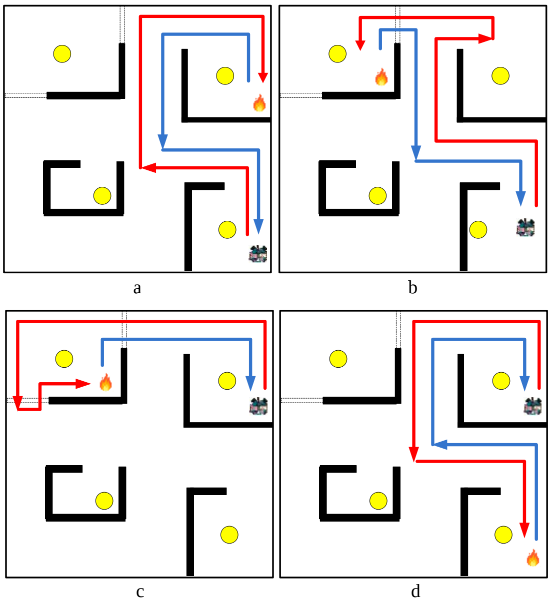

Figure 5.Visualization of robot pathways, a) home posisiton at room 4 and candle at room 2, b) home posisiton at room 4 and candle at room 1, c). home posisiton at room 2 and candle at room 1, d).home posisiton at room 2 and candle at room 4.

The time taken for carrying out tasks by the robot is affected by the complexity of the robot's initial position or home position and the presence of hotspots. Additionally, the number of vector direction changes used as directions for the robot to move also affects the duration of the robot's task execution. This applies to both fire search trips and return trips. From the test results, when the robot has entered a chamber that is not the target (there are no hotspots), the robot must perform a U-turn maneuver. The U-turn maneuver causes the magnitude of the robot's trajectory to become longer. To account for the additional trajectory due to the U-turn, the robot requires time to re-recognize the surrounding space, make rotational movements, and move forward. As a result, the time required for the robot becomes longer.

Table 1 shows a comparison between this study and several other existing studies. In this study, the robot has been tested on four variations of the home position-hotspot combination and has successfully carried out a return trip. The results in this study differ from other studies that have not been tested for two parameters simultaneously.

Table 1. Comparison of previous works

Researcher	Method	Sensor	Tipe Robot	Variation of *home position* – candle position	Return trip
[2][3]	*Wall following/tracking*	Ultrasonic PING	Legged robot	No	No
[4]	*State machine*	Ultrasonic PING	Legged robot	No	No
[5]	*Grid map*	Ultrasonic PING, Magnetic compass CMPS03	Wheeled robot	No	Yes
This paper	*Grid map*	Ultrasonic PING, Gyroscope GY-955	Legged robot	Yes	Yes

4. CONCLUSION

The grid map method has been designed and implemented in the robot Azmi with results that have proven effective as a solution for robot navigation facing an arena consisting of maze. Robots can optimally locate hotspots without having to explore all the rooms. The robot can also maneuver around immediately when it has entered a non-target room. The time record that the robot managed to achieve is still quite rational. The characteristics of the ultrasonic sensor used and its placement on the robot are important to note because the ultrasonic sensor has a field of view that is wide enough so that a minimal difference in slope can result in a significant interpretation of the reading results.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Author1: Conceptualization, Methodology, Software, Project administration. **Author2**: Software, Writting – original draft. **Author3**: Writing – review & editing. **Author4**: Validation**.**

DECLARATION OF COMPETING INTERESTS

There is no competing financial interests

DATA AVAILABILITY

Data will be made available on request.

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