Implementation of Behavior Based Robotics on Hexapod Legged Robot Based on Room Mapping

Zahra Salsabila [1], Nuryono Satya Widodo [2,*]
[1,2] Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
Email: [1] zahra1600022071@webmail.uad.ac.id, [2] nuryono.sw@ee.uad.ac.id
*Corresponding Author

***Abstract*—The Indonesian Fire Fighting Robot Contest (KRPAI) has a mission to extinguish fires quickly, with various kinds of points and bonuses to be taken. The robot used in this research is a 6-legged robot (Hexapod). The problem faced today is the robot's ability to navigate the room, the robot still has to enter the same room, especially in room 1 (a room with 2 doors) so that the Arbitrary Start bonus or Variable Door location which prohibits the robot from entering the same room cannot be obtained. There is also a Room Factor bonus obtained using the JTS (Segment Distance) method which is an additional bonus when the robot walks outside the room. It is necessary to develop a room mapping algorithm with behavior based so that the robot can get maximum points. The main sensor used is the IMU BNO055 sensor as a robot direction orientation sensor, as well as a proximity sensor as a wall search sensor, so that the robot can know the direction when leaving and exploring the room, knowing the starting room, and ensuring the next room entered is a different room. The results of the test successfully made the robot take maximum points in the race.**

***Keywords*—KRPAI, Hexapod, Mapping, Behaviour, IMU, BNO055, Sensor**

I. INTRODUCTION

The Indonesian Fire Fighting Robot Contest (KRPAI) is one of the regional and national robot contests held annually by the Directorate General of Learning and Student Affairs, and the Ministry of Research, Technology and Higher Education (Kemenristekdikti). The best robot will be submitted to Trinity as Indonesia's representative for the International championship. Trinity Collage Fire Fighting Home Robot Contest (TCFFHRC) is an international robot contest organized by Trinity Collage, Hartford, Connecticut, USA. The competition rules from TCFFHRC are a reference for KRPAI competitions both at the regional and national levels, because the national winner will get a ticket from DIKTI to represent Indonesia at TCFFHRC [1].

The problem faced at this time is the robot's ability to navigate the room, the robot still has to enter the same room, especially in room 1 (room with 2 doors) so that the Arbitrary Start or Variable Door location bonus that prohibits the robot from entering the same room cannot be obtained. The configuration of room 1 can be seen in Fig. 1.

In addition, there is also a Room Factor bonus obtained using the JTS (Segment Distance) method which is an additional bonus when the robot runs outside the room. From the existing problems, it is necessary to develop a room mapping algorithm with behavior based so that the robot can get maximum points. Behaviour based robotics is an approach in robotics that focuses on robots that are able to show behavior.

Fig. 1. Room configuration 1

In addition, there is also a Room Factor bonus obtained using the JTS (Segment Distance) method which is an additional bonus when the robot walks outside the room. From the existing problems, it is necessary to develop a room mapping algorithm with behavior based so that the robot can get maximum points. Behaviour based robotics is an approach in robotics that focuses on robots that are able to show behavior.

In this research, there are several behavior based used in the KRPAI robot application including: wandering, obstacle avoidance, search target and stop (find target) [2]. The main sensor used is the IMU BNO055 sensor as a robot direction orientation sensor [3], as well as a proximity sensor as a wall search sensor, so that the robot can know the direction when leaving and exploring the room, knowing the starting room, and ensuring the next room entered is a different room. So that the robot can achieve maximum points in the race.

II. METHODS

This research uses a hexapod robot (6 feet) that will explore each room to find a fire [4], so a behavior-based algorithm will be developed for the robot to map the room with reference to the IMU BNO055 sensor as a determinant of the robot's facing direction and ultrasonic proximity sensors and sharp gp that emit infrared [5] as sensors for the robot to explore the walls. The robot will determine a different algorithm for each different starting room. Here is the research method.

A. Robot Design

The robot design that will be used in this research is a 6-legged robot (Hexapod) spider type robot [6], the selection of this Hexapod type robot design is based on the robot's motion pattern which is more stable and faster in moving. The robot design can be seen in Fig. 2.

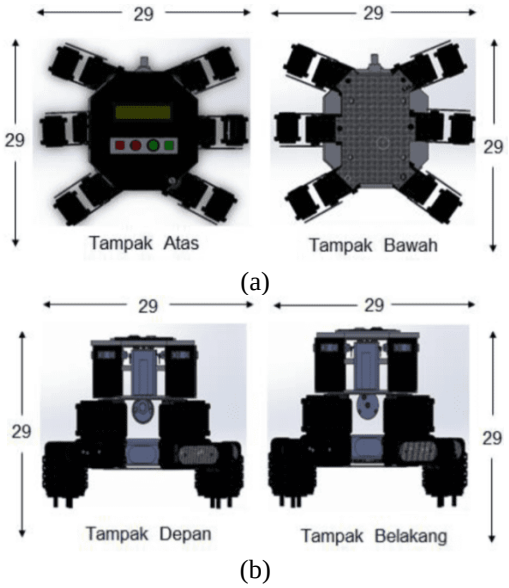


Fig. 2. Robot design, Tampak Atas (Top View), Tampak Bawah (Bottom View), Tampak Depan (Front View), Tampak Belakang (Rear View)

B. Control System Block Diagram

From Fig. 3, it can be seen that the design of the minisystem board on the robot consists of two main components, namely Arduino Due and Open Cm which work as master-slave, Arduino as the main controller that processes sensors which will then be sent to Open-Cm to drive the dynamixel Ax-18 servo [7] on the robot.

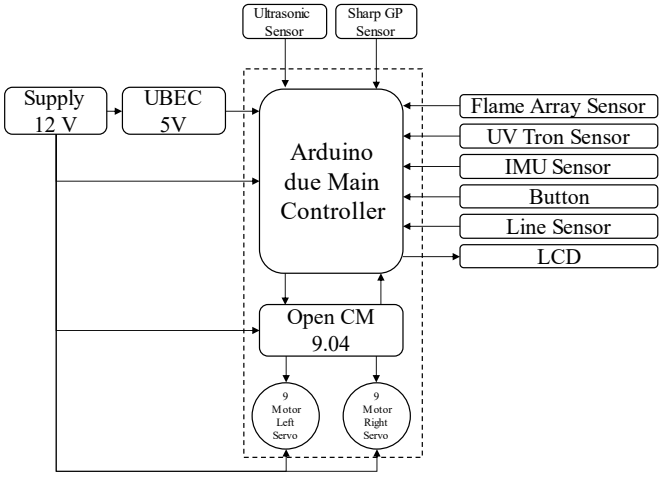


Fig. 3. Block diagram of the control system

C. Behaviour Based Robotic

An approach in robotics that focuses on a robot capable of exhibiting seemingly complex behaviors despite a small state of internal variables to model its immediate environment, mostly gradually refining its actions through sensory-motor links. Behavior-based robotics distinguishes itself from traditional artificial intelligence by using biological systems as models [8]. The incident in the arena of the Indonesian legged fire extinguisher robot contest, which is written in the diagram is a reference to behavior-based robotics in tracing the walls in the competition arena. The diagram of behavior based robotics can be seen in Fig 4.

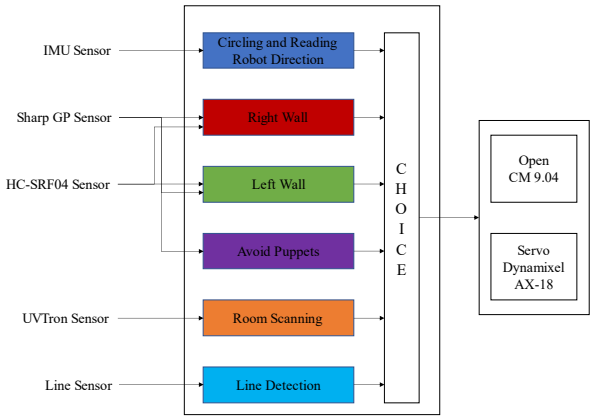


Fig. 4. Behaviour based robotic diagram

D. Room Identification Flowchart

Room identification is made to determine the position of the robot in the arena. The results of room identification are obtained from reading the robot's facing direction and reading the proximity sensors (srf04 sensor and sharp GP sensor) on the walls around the room. The result of room identification is that the robot will know every room visited. Room identification is divided into two, namely the home room and the fire room, where the results obtained will be stored by the robot, the purpose of this division is to make it easier for the robot to identify rooms in the KRPAI arena. Flowchart of room identification can be seen in Fig. 5.

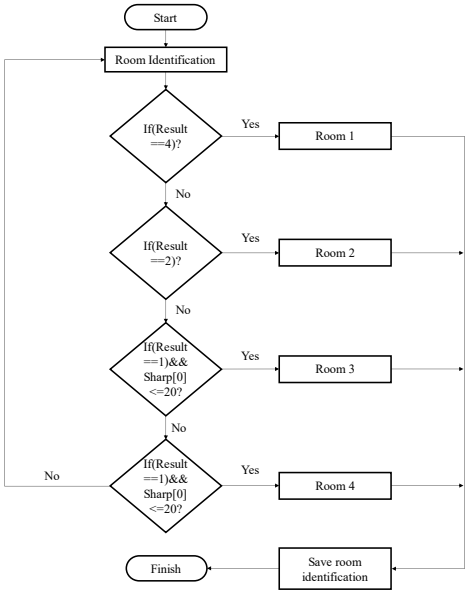


Fig. 5. Room identification flowchart

E. Robot Decision Flowchart

Robot decisions are part of behavior based robotics, when the robot can identify the home space and fire space the robot will have a decision, namely the right wall decision and the left wall decision. The robot decision is divided into 2 decisions, namely, the decision of the robot to move towards the fire room to the intersection of the home room and the decision of the robot to move towards the fire room after the intersection. The results of the robot decision can be seen in Fig. 6.

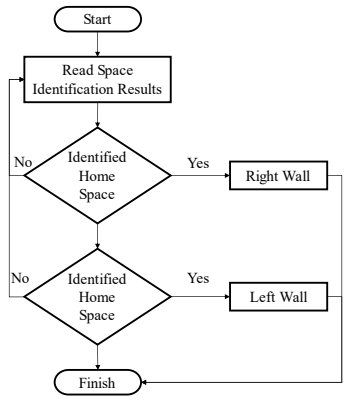


Fig. 6. Robot decision result flowchart

F. *Robot Direction Reading Flowchart*

The reading of the robot's facing direction is divided into 4 cardinal directions, it is used to determine the robot's facing direction in the arena using the IMU sensor value reading. The Robot Direction Reading Flowchart can be seen in Fig. 7.

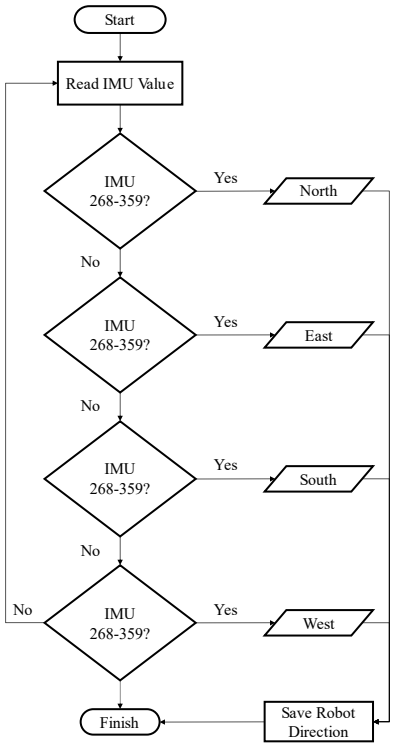


Fig. 7. Robot direction reading flowchart

G. *Robot Direction inverse Reading Flowchart with Adafruit BNO055*

The inverse reading of the robot's direction is the opposite of reading the robot's facing direction when the robot reads the direction of the intersection. The inverse reading of the robot's direction in the arena is done when detecting the intersection while running the room mapping. The inverse reading of the robot's facing direction functions to reverse the robot's facing direction so that the facing direction is opposite to the robot's departure direction at the intersection. The inverse direction of the robot The results of reading the inverse direction of the robot in the KRPAI arena can be seen in Fig. 8.

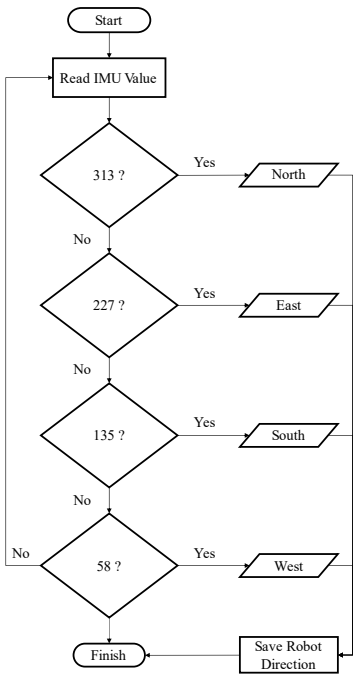


Fig. 8. Robot inverse direction reading flowchart

H. *Robot Decision Main Flowchart*

In this flowchart, the robot searches the walls in the room to find a line to get out of the room. When the robot detects a line, the robot will know the direction it is going by calling the IMU sensor, the robot will also know the numbering of the room lines by using the line sensor as a reference. The main robot decision flowchart can be seen in Fig. 9.

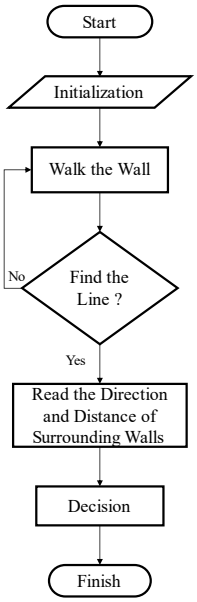


Fig. 9. Robot decision main flowchart

I. *Adafruit BNO055 Sensor*

The Adafruit BNO055 algorithm is used to determine where the robot is facing, if the direction is known, it can be used as a reference to determine the starting position and determine the direction of the robot in the hallway. In this study the author gave his own code for naming the home room, namely by numbering the space lines. The space line

is determined by knowing the direction of the robot out of the room using Adafruit BNO055 as a direction determinant and a distance sensor as a reference for conditions around the room. The goal is to facilitate robot decision making. The placement of the BNO055 sensor can be seen in Fig. 10.

Fig. 10. BNO055 sensor placement on the robot

J. *Departure Algorithm with Room Mapping*

The definition of an algorithm is logic, methods, and systematic stages (sequences) used to solve a problem. Algorithms can also be interpreted as a systematic and logical sequence of steps [9]. In this study, the algorithm used is an algorithm to determine the starting position and an algorithm to determine the direction of the robot's search based on the starting position.

III. RESULT AND DISCUSSION

A. *BNO055 IMU Sensor Calibration Testing*

Testing the imu calibration tool is used to get the imu value and setpoint value in the KRPAI arena, the way the tool works is reading the direction at the intersection to get the imu value which will be entered into the program and used by the robot to navigate. The imu calibration tool can be seen in Fig. 11.

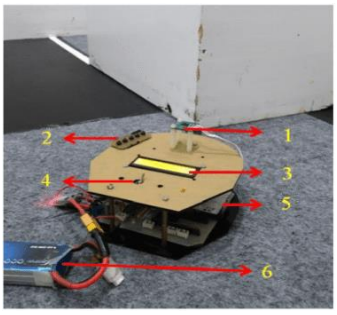


Fig. 11. IMU calibration tool

The use of the calibration tool is done by placing the tool right in the middle of the KRPAI arena intersection, then the IMU sensor will read the angle value of each direction at the intersection. The coverage angle of each direction has an average width of 90 degrees. In addition to reading the average angle of 90 degrees, testing is carried out to find a narrow angle or middle value in each direction which will be a benchmark for the robot when crossing the intersection. The use of the calibration tool can be seen in Fig. 12.

All calibrated values will become the robot's reference when navigating [10], either in the hallway or determining the direction when leaving the room. The IMU reading results can be seen in Table 1.

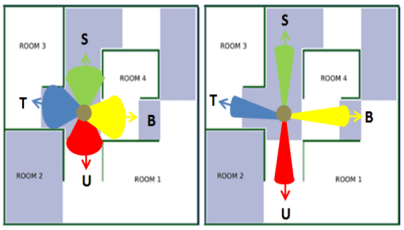


Fig. 12. Use of IMU calibration tool

Table 1. IMU value reading results

No	Robot Direction (Code)	IMU Value	Inverse Value
1	North (1)	268-359	313
2	West (2)	181-267	227
3	South (3)	91-181	135
4	East (4)	0-90	58

B. *Testing the Robot Mechanical Design Results*

Robot design testing is in the 2019 KRPAI legged match regulations, where the maximum dimensions of the robot are 31 x 31 x 27 (length x width x height). With dimensional restrictions, the al-jazari robot is made with dimensions of 25 x 25 x 27 (length x width x height). The mechanical constituent of the robot consists of a robot head frame and a leg frame. The robot head frame is divided into 2 pieces, namely, the upper and lower frames made of acrylic material. The robot head frame is used to arrange sensors and minisitems on the robot. While the leg frame is made of aluminum material with a thickness of 3mm called the foot frame. The foot frame is used as a connector between servos, which are arranged and assembled to become 6 legs that can support the entire robot body. The results of the robot mechanics can be seen in Fig. 13. The description of the robot mechanics test results can be seen in Table 2.

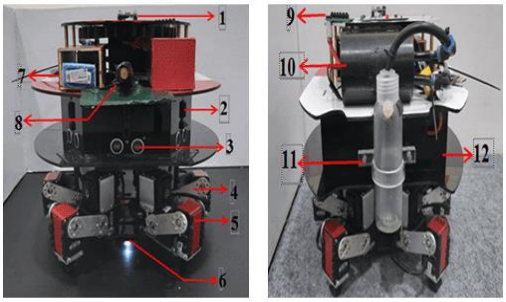


Fig. 13. Robot mechanical design result

Table 2. Description of robot mechanical testing

No	Name of Component
1	IMU Sensor
2	Sharp GP Sensor
3	HC-SRF04 Sensor
4	Leg Frame
5	Servo Dynamixel Ax-12
6	Line Sensor
7	Battery
8	Button
9	Head Frame

C. *Testing the IMU Value of the Robot*

The test begins by exposing the robot to one direction of the intersection point which is the reference point is point 0 “Zero” (north), after that press the setpoint button, to read the direction of the reference value used is the original value [11].

imu is referred to as the setpoint value, because the original imu value is based on point 0 "Zero" which is considered the north direction. The test can be seen on the LCD whether the robot is correct in reading the direction of the intersection in the KRPAI competition arena, the calibration on the robot is done before the robot is run. The results of the reading of the value of the robot can be seen in Table 3.

D. Home Room Recognition Testing

This test was conducted to recognize each room in the KRPAI competition arena. The test results are obtained from reading the direction of the robot's face, and the distance between the robot and the surrounding walls. The results of the home room recognition test can be seen in Table 4.

E. Testing Room Factor Results Using the JTS Method

Testing segment travel distance and real travel time is done by calculating the total distance and travel time from home to the point of fire by summing up the distance segments of the robot when passing through the rooms visited during its journey. The results of the segment distance calculation will later be calculated to become the room factor value and the real travel time obtained will later be multiplied by the room factor value to get the final time value. This test only uses 1 configuration, out of 4 configurations in the KRPAI race. Configuration 4 that will be tested can be seen in Fig. 14.

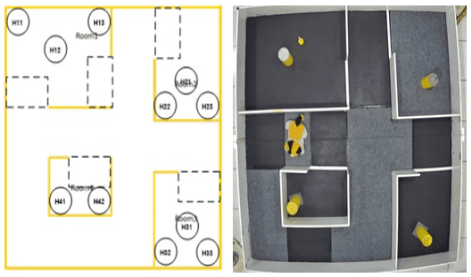


Fig. 14. Configuration 4 to be tested

F. Testing Home (start) R1 and Fire R2 Configurations

Configuration testing is done with the home room in room 1 and the fire room in the room that will be visited last, namely room 2. The test was conducted 5 times. The distance traveled by all robots is mapped by segment, as shown in Fig. 15.

The results of the calculation of segment travel distance and real travel time can be seen in Table 5.

Table 5. Calculation results of segment travel distance and real travel time

No	Experiment	JTS	Travel Time Real
1	Experiment 1	1523 cm	68 Second
2	Experiment 2	1523 cm	71 Second
3	Experiment 3	1523 cm	70 Second
4	Experiment 4	1523 cm	74 Second
5	Experiment 5	1523 cm	66 Second

From the test results of Table 5, the results of the calculation of segment travel distance will be calculated to become the room factor value and the real travel time obtained will be multiplied by the room factor value to get the final time value. The calculation results are obtained from:

a) Real Time
b) Room Factor = 200/JTS cm
c) End Time = WR x RM = 8.90 seconds
d) Bonus Visiting Room:
   - 1 room = (1)
   - 2 rooms = (0.85)
   - 3 rooms = (0.5)
   - 4 spaces = 0.35
e) Arbitrary Start Bonus = 0.8
f) Variable Door Location Bonus = 0.45
g) Total Points = WA x Visiting Rooms x AS x VDL = seconds

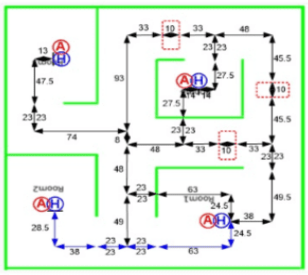


Fig. 15. Distance traveled by the whole robot

The results of the overall bonus calculation and the final score can be seen in Table 6. From Table 6 we can see the results of the final value obtained by the robot from the five experiments. Testing is done with an image processing system, namely object marking to help make robot movement patterns [12]. The first step taken is to take a video by installing the camera as high as possible, so that the entire arena and robot are clearly visible in the video. Then the video obtained is processed using the Python application and open cv to get a robot movement plot [13]. In the segment mileage test, the green and red lines indicate the movement of the robot through the room from home to the fire point, then the results of the robot's journey will be displayed with the plotting results. The plotting function is used to draw lines or as markers on the image plane [14]-[16]. The results of the robot travel time test can be seen in Table 7.

Successful Room Factor (JTS) in home room 1 and fire room 2 configurations:

$$\text{Percentage of Success} = \frac{Number\ of\ Success}{Number\ of\ Success} \text{ x } 100\%$$

$$= \frac{5}{5} \text{ x } 100\%$$
$$= 100\ \%$$

So the percentage of Room factor success using the Segment Travel Distance method on the five trials of testing home R1 and fire R2 is 100% successful [17]-[20].

IV. CONCLUSIONS

In previous studies, robots have not been able to get maximum points so that in this research, the authors succeeded in developing a robot algorithm to not enter the same room and maximize Room Factor bonuses using the JTS (Segment Travel Distance) method to get maximum points in the KRPAI race. After developing the algorithm, the author succeeded in making the robot reach the maximum point in the race by taking all the bonuses contained in the match rules.

Table 3. Results of IMU value readings on the robot, Arah hadap robot (Robot facing direction), derajat (Degree)

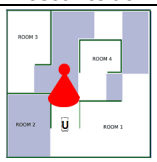
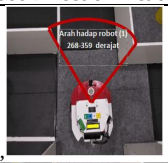
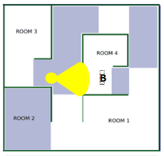
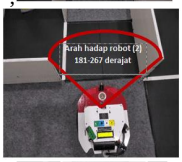
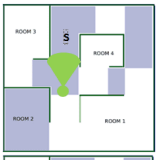
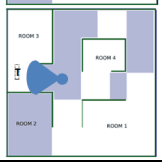
No	Robot Position	Robot Direction Reading	Result
1			North (1) 268-359 Degrees
2			West (2) 181-267 Degrees
3			South (3) 91-180 Degrees
4			East (4) 0-90 Erajat

Table 4. Home room testing results

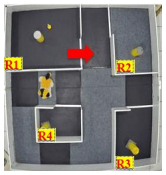
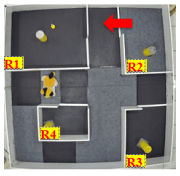
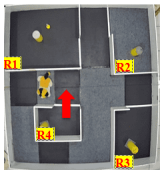
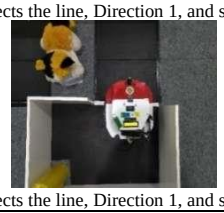
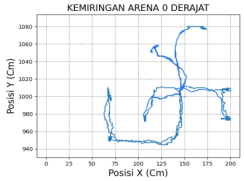
No	Robot Positioning in the Arena	Readings Robot Trigger	Result
1		 Robot detects lines and reads directions (east)	R. Home = 1
2		 Robot detects lines and reads directions 2 (west)	R. Home = 2
3		 The robot detects the line, Direction 1, and sharp [1] <= 20	R. Home = 3
4		 The robot detects the line, Direction 1, and sharp [1] >= 20	R. Home = 4

Table 6. Overall bonus calculation and final score

No	Experiment	Room Factor	End Time	Visiting Room	Arbitrary Start	Variable Door Location	Total Points	Description
1	Experiment	0.131	8.90	0.5	0.8	0.45	1.60	Succes
2	Experiment	0.131	9.30	0.5	0.8	0.45	1.67	Succes
3	Experiment	0.131	9.17	0.5	0.8	0.45	1.65	Succes
4	Experiment	0.131	9.69	0.5	0.8	0.45	1.74	Succes
5	Experiment	0.131	8.64	0.5	0.8	0.45	1.55	Succes

Table 7. Test results of robot turnaround time, Kemiringan arena 0 derajat (Arena slope 0 degrees), Posisi (Position)

Configuration	Testing Distance Traveled Segment										Plotting
R.Home = 1 R.Api = 2											
	Experiment 1		Experiment 2		Experiment 3		Experiment 4		Experiment 5		
	Result	Time (s)	Result	Time (s)	Result	Time (s)	Result	Time (s)	Result	Time (s)	
	V	68 Second	V	71 Second	V	70 Second	V	74 Second	V	66 Second	

ACKNOWLEDGEMENT

Thanks to the entire academic community of Electrical Engineering at UAD who have supported this research directly or indirectly. Especially to Bimawa UAD who has provided both moral and material assistance.

REFERENCES

[1] N. Subramanian, M. N. Shanju Shri, V. Rohitram and K. C. Sriharipriya, "IoT based Voice Controlled Home Assistance Hexapod," *2022 IEEE International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE)*, pp. 1-6, 2022, https://doi.org/10.1109/ICDCECE53908.2022.9792856.

[2] A. Banos, Y. Verbelen, S. Kaluvan, C. Hutson, M. R. Tucker and T. B. Scott, "Hexapod robotic system for indoor neutron and gamma radiation mapping and inspection," 2022 25th International Symposium on Design and Diagnostics of Electronic Circuits and Systems (DDECS), pp. 48-53, 2022, https://doi.org/10.1109/DDECS54261.2022.9770114.

[3] J. Menezes, S. Das, B. Panchal, N. P. Yelve, P. Kumar, "Mapping, trajectory planning, and navigation for hexapod robots using ROS," *International Conference on Energy, Materials Sciences & Mechanical Engineering*, pp. 851-866, 2020, https://doi.org/10.1007/978-981-16-2794-1_76.

[4] J. Truong, D. Yarats, T. Li, F. Meier, S. Chernova, D. Batra, A. Rai, "Learning navigation skills for legged robots with learned robot embeddings," *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 484-491, 2021, https://doi.org/10.1109/IROS51168.2021.9635911.

[5] J. Truong *et al.*, "Learning Navigation Skills for Legged Robots with Learned Robot Embeddings," *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 484-491, 2021, https://doi.org/10.1109/IROS51168.2021.9635911.

[6] N. D. Kent, D. Neiman, M. Travers and T. M. Howard, "Improved Performance of CPG Parameter Inference for Path-following Control of Legged Robots," *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 11963-11970, 2022, https://doi.org/10.1109/IROS51168.2021.9635911.

[7] N. S. Szczecinski, C. Goldsmith, W. Nourse, R. D. Quinn, "A perspective on the neuromorphic control of legged locomotion in past, present, and future insect-like robots," *Neuromorphic Computing and Engineering*, vol. 3, no. 2, 2023, https://doi.org/10.1088/2634-4386/acc04f.

[8] T. Azayev, K. Zimmerman, "Blind hexapod locomotion in complex terrain with gait adaptation using deep reinforcement learning and classification," *Journal of Intelligent & Robotic Systems*, vol. 99, pp. 659-671, 2020, https://doi.org/10.1007/s10846-020-01162-8.

[9] P. Manoonpong *et al.*, "Insect-Inspired Robots: Bridging Biological and Artificial Systems," *Sensors*, vol. 21, no. 22, p. 7609, 2021, http://dx.doi.org/10.3390/s21227609.

[10] R. Buchanan, L. Wellhausen, M. Bjelonic, T. Bandyopadhyay, N. Kottege, M. Hutter, "Perceptive whole-body planning for multilegged robots in confined spaces," *Journal of Field Robotics*, vol. 38, no. 1, pp. 68-84, 2020, https://doi.org/10.1002/rob.21974.

[11] K. Huang *et al.*, "Telelocomotion—Remotely Operated Legged Robots," *Applied Sciences*, vol. 11, no. 1, p. 194, 2020, http://dx.doi.org/10.3390/app11010194.

[12] M. Thor, T. Kulvicius and P. Manoonpong, "Generic Neural Locomotion Control Framework for Legged Robots," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 32, no. 9, pp. 4013-4025, 2021, https://doi.org/10.1109/TNNLS.2020.3016523.

[13] J. Faigl, P. Čížek, "Adaptive locomotion control of hexapod walking robot for traversing rough terrains with position feedback only," *Robotics and Autonomous Systems*, vol. 116, pp. 136-147. 2019, https://doi.org/10.1016/j.robot.2019.03.008.

[14] R. Kaushik, P. Desreumaux, J. B. Mouret, "Adaptive prior selection for repertoire-based online adaptation in robotics," *Frontiers in Robotics and AI*, vol. 6, p. 151, 2020, https://doi.org/10.3389/frobt.2019.00151.

[15] P. Čížek, J. Faigl, "Self-supervised learning of the biologically-inspired obstacle avoidance of hexapod walking robot," *Bioinspiration & biomimetics*, vol. 14, no. 4, p. 046002, 2019, https://doi.org/10.1088/1748-3190/ab1a9c.

[16] C. Cruz Ulloa, L. Sánchez, J. Del Cerro, and A. Barrientos, "Deep Learning Vision System for Quadruped Robot Gait Pattern Regulation," *Biomimetics*, vol. 8, no. 3, p. 289, 2023, http://dx.doi.org/10.3390/biomimetics8030289.

[17] A. Bouman *et al.*, "Autonomous Spot: Long-Range Autonomous Exploration of Extreme Environments with Legged Locomotion," *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 2518-2525, 2020, https://doi.org/10.1109/IROS45743.2020.9341361.

[18] T. Kim, S. Lee, S. Chang, S. Hwang, Y. L. Park, "Environmental Adaptability of Legged Robots with Cutaneous Inflation and Sensation," *Advanced Intelligent Systems*, p. 2300172, 2023, https://doi.org/10.1002/aisy.202300172.

[19] B. Qin, Y. Gao and Y. Bai, "Sim-to-real: Six-legged Robot Control with Deep Reinforcement Learning and Curriculum Learning," *2019 4th International Conference on Robotics and Automation Engineering (ICRAE)*, pp. 1-5, 2019, https://doi.org/10.1109/ICRAE48301.2019.9043822.

[20] A. Bouman *et al.*, "Autonomous Spot: Long-Range Autonomous Exploration of Extreme Environments with Legged Locomotion," *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 2518-2525, 2020, https://doi.org/10.1109/IROS45743.2020.9341361.