ISSN: 2977-0041

Review Article

Journal of Material Sciences and Engineering Technology

Simulation of Obstacle Avoidance Robots

Mukhtar Ibrahim Bello[1] and Muhammad Ahmad Baballe[2*]

[1]*Department of computer science, School of Technology, Kano state polytechnic, Kano, Nigeria*

[2]*Department of computer engineering technology, School of Technology, Kano state polytechnic, Kano, Nigeria*

[*]Corresponding author

Muhammad Ahmad Baballe, Department of computer engineering technology, School of Technology, Kano state polytechnic, Kano, Nigeria.

Received: October 04, 2023; **Accepted:** October 12, 2023; **Published:** October 20, 2023

ABSTRACT

The first function of the system is to detect the presence of obstacles. When the user activates the system using the power ON/OFF switch, the Arduino microcontroller will read the data. When the ultrasonic sensor detects the presence of an obstacle in the process of moving forward, the robot will move backward. If the robot does not sense any obstacle, that is, if the distance between an obstacle and it is wide, it will then move forward again until it senses an obstacle before it stops. C programming is used for Arduino board applications to develop the program for the whole system's operation. There are three light-emitting diodes; the first one shows the amount of charge in the batteries, while the remaining two show that if the robot is moving forward, one of the two LEDs will be on, and if it is moving backward, one of the LEDs will also be on. There is also a power source unit that is used to charge the batteries used in the system.

Keywords: Simulation, Arduino Uno, Ultrasonic Sensor, Robots

Introduction

Robotic navigation research is beginning to gain momentum on its own. Robotics experts started to create various free routes finding algorithms. The navigation system is regarded as being of paramount importance since the robot must be able to be securely controlled from the starting point to the target (destination). To avoid impediments, or to put it another way, the robot must be able to avoid them. The first of two elements that serve as a guide is this. The robot must also continually make sure that it reaches its goal (target). Making a decision from the different travel possibilities is the challenging part. When making decisions, like in the example, a driver is frequently nevertheless troubled by uncertainty in reality above. It will be interesting to see how this is implemented in a mobile robot (autonomous robot). Simple problems like these can turn into more complex ones if they are applied to autonomous mobile robots that must avoid obstacles. It would be difficult for a mobile robot to identify obstacles and decide how to avoid them, not to mention that the main target (goal) can disappear from the camera's field of view. All of these calls for a very difficult computational process. The light intensity is a factor that must be taken into account because the sensor that will be used is a camera sensor. The aforementioned factors will make it difficult for the robot to get where it is going. Obstacle avoidance has been the subject of numerous studies, starting with the presentation of fuzzy algorithms for reactive navigation of mobile robots in challenging environments [1-61]. This study shows that fuzzy logic is reasonably efficient and reacts rapidly to problems. This study only considers static workplace obstructions; moving obstructions caused by moving objects are not included. This study only considered unexpectedly appearing static obstacles, although model-based predictive controller (MBPC) using neural networks and ultrasonic sensors is also utilized to guide mobile robots around unexpectedly appearing static obstacles in their environment [62-77]. The Dynamic Artificial Neural Network (DANN) approach is used for motion planning for mobile robot paths through [78-80]. This research shows that on a flat surface, a mobile robot can be directed around both stationary and moving obstacles. In order to further enhance the robot's ability to overcome obstacle avoidance, generalized dynamic fuzzy neural networks (GDFNN), a blend of neural network and fuzzy approaches, were employed to construct real-time control autonomous mobile robots [81]. The experimental findings show that GDFNN outperforms conventional fuzzy logic control in terms of performance. The obstacle avoidance problem for mobile autonomous robots is also addressed by certain researchers using Reinforcement Learning with Neural Networks (RLNN) [82]. The simulation's results show that the robot can improve its capacity for learning and can complete the tasks assigned to it in a challenging setting [89-92]. By combining camera sensors with lasers, researchers are starting to invent new ways to identify obstructions instantly. These sensors are capable of precisely identifying both two- and three-dimensional objects [83]. Even in more recent studies, stereovision systems were developed using a combination of omnidirectional cameras and perspective cameras [84]. To estimate the locations of obstacles in three dimensions, this technique combines a wide field of view from a perspective camera with a 360°C field of view from an

Citation: Mukhtar Ibrahim Bellom, Muhammad Ahmad Baballe. Simulation of Obstacle Avoidance Robots. J Mat Sci Eng Technol. 2023. 1(4): 1-7.
DOI: doi.org/10.61440/JMSET.2023.v1.16

omnidirectional camera. Several vision system implementations based on color sensors camera sensor Pixy 2 CMUcam5 and thermal cameras have been investigated in past studies [85-87]. Excellent outcomes are obtained from the aforementioned trials, particularly with regard to real-time obstacle detection. The earlier experiments, however, did not use movable barriers. The goal of this project is to develop a method for avoiding moving obstacles. Based on prior research, this project will develop an autonomous mobile robot that can navigate by itself to avoid moving obstructions caused by environmental changes in the robot's working environment. To recognize the environment, two webcams are used as stereo vision sensors. Because it is possible to detect pedestrians' upper bodies, they are used as impediments. Since the robot is operating in its genuine environment, this item was picked. The intelligence technique as a control system must be able to handle the issue of moving obstructions in the work area in order to send the robot to the objective (destination). The control system that is used to avoid obstacles is neurofuzzy. With the hope that it would be able to negotiate obstacles with ease and flexibility, a three-wheeled omnidirectional robot was deployed for this experiment. A robot behavior that can recognize the target object, recognize moving obstacles, and make flexible judgments to avoid them must be designed in order for the mobile robot to reach its predetermined target (goal). These actions will be used by the robot to navigate. With the help of stereo vision and the Neuro-Fuzzy algorithm, the robot is directed from its beginning point to its final location. In order to improve the robot's ability to adapt to changing environments, omnidirectional robotics and the Neuro-Fuzzy algorithm are employed to assist the robot in identifying obstacles and making decisions that the robot will avoid. The focus of this research is on robot navigation systems, which comprise locating the target (destination), which is assumed to always be in the robot's line of sight, spotting obstacles and avoiding them, and creating flexible and fluid movements. The impediment items employed are pedestrians, who are located via upper body detection. The robot's workstation consists of a corridor and an interior chamber that are each 4 meters long and 4 meters wide. This study is not focused on traveling the shortest distance because the robot does not walk along a path. To help omnidirectional mobile robots avoid obstacles, this research aims to develop a stereo vision-based navigation system. The proposed method employs the Neuro-Fuzzy algorithm to create a barrier-free path in real-time and to control the robot's movement in a flexible and fluid manner. To guide the mobile robot to a predetermined place, it is crucial to design a robot behavior that can recognize the target object, detect moving barriers, and make adaptive judgements to avoid them. This study aims to investigate the navigational behaviors of the robot. As shown, by using a stereo camera to detect a target and obstacles as input to ANFIS, this study advances the state-of-the-art in obstacle avoidance based on the visual sensor for robot navigation systems. The research technique for this work is divided into two primary sections. The first step is to create a technique for managing the angular and linear velocities of mobile autonomous robots [88].

How to Create a Robot That Avoids Obstacles Using Ultrasonic Sensors

Understanding the ultrasonic sensor's operation is crucial before beginning construction of the robot because it will be used to detect obstacles. The essential premise underpinning how an ultrasonic sensor operates is keeping track of how long it takes to broadcast ultrasonic beams and how long it takes to receive them after they have impacted a surface. The distance is then determined using the formula. Therefore, the trig pin of the HC-SR04 is raised for at least 10 us. Eight pulses at a frequency of 40 kHz are employed to transmit a sound beam. The signal is received by the HC-SR04 after it bounces off the surface and lands on the receiver echo pin. When the message was sent, the Echo pin had already risen significantly [94,95].

Materials and Method

The materials used in this research are shown in Table I below.

Table 1: Materials used in this Research

S/N	Name of components	Number used
1	Arduino Uno	1
2	Ultrasonic sensor	1
3	5 volt DC motor	2
4	LM298N Motor Driver Module	1

Method

This section of research handles the operation of the whole system. The first function of the system is to detect the presence of obstacles. When the user activates the system using the power ON/OFF switch, the Arduino microcontroller will read the data. When the ultrasonic sensor detects the presence of an obstacle in the process of moving forward, the robot will move backward. If the robot does not sense any obstacle, that is, if the distance between an obstacle and it is wide, it will then move forward again until it senses an obstacle before it stops. C programming is used for Arduino board applications to develop the program for the whole system's operation. There are three light-emitting diodes; the first one shows the amount of charge in the batteries, while the remaining two show that if the robot is moving forward, one of the two LEDs will be on, and if it is moving backward, one of the LEDs will also be on. There is also a power source unit that is used to charge the batteries used in the system.

Arduino Uno with Driver Motor

This is the pin configuration of how the Arduino Uno is connected with the motor driver, which is used to turn on the motor.

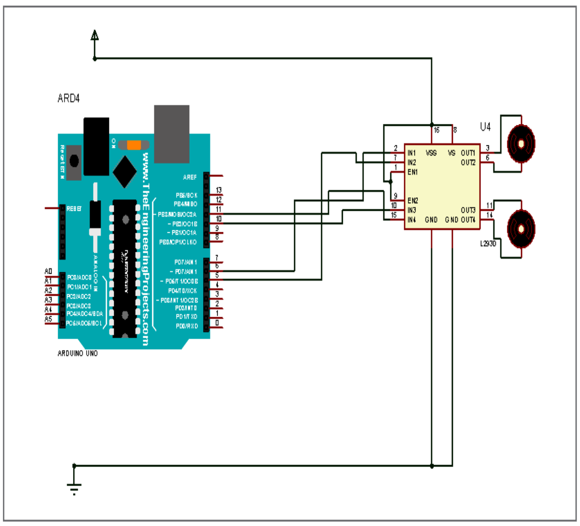

Figure 1: Pin configuration of the Arduino and driver motor

Pin Configuration of the Arduino with Servo Motor

The below diagram shows how the Arduino Uno is connected to the 5-volt servo motor. The ultrasonic sensor is mounted on the servo motor. This motor helps rotate the sensor to detect obstacles.

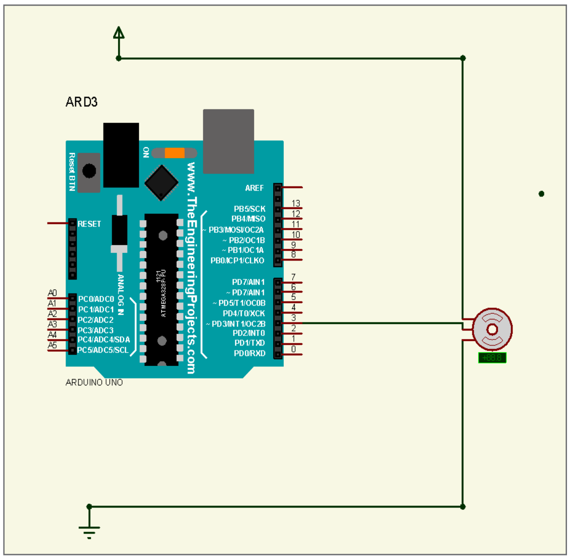

Figure 2: Pin configuration of the Arduino to 5v dc motor

Pin Configuration of the Arduino to Ultra Sonic Sensor

The image below shows how the pin of the Arduino Uno is connected to the ultrasonic sensor. This ultrasonic sensor is used to detect an obstacle that is in front of the robot.

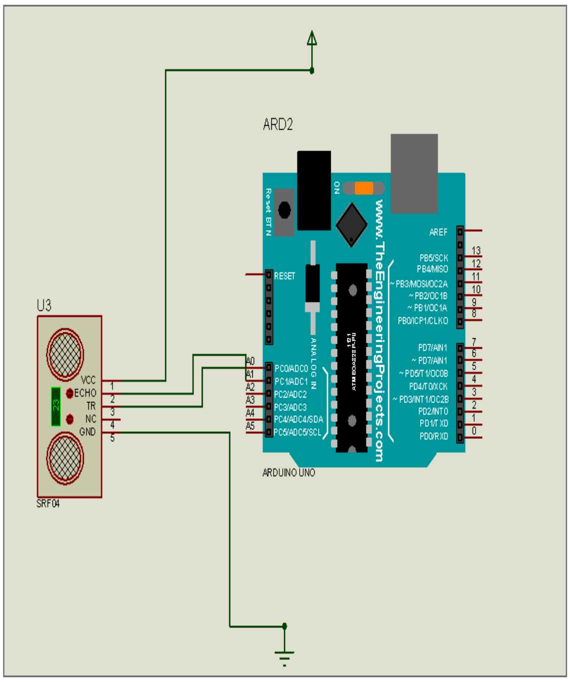

Figure 3: Pin configuration of the Arduino to the ultra-sonic sensor

Result

The simulation's results are produced, and they also demonstrate how the robot's entire circuit is implemented. The Arduino IDE integrated development environment was used to write the software, which was then translated from the C language into machine code (a hex file) for debugging. Then it is tested and simulated on the PROTEUS ISIS professional. The program was determined to be functional, albeit with a few small flaws that were fixed before the project was finished. Based on a dimension, plastic rubber was used to create the casing, and gum rubber was used to attach the pieces.

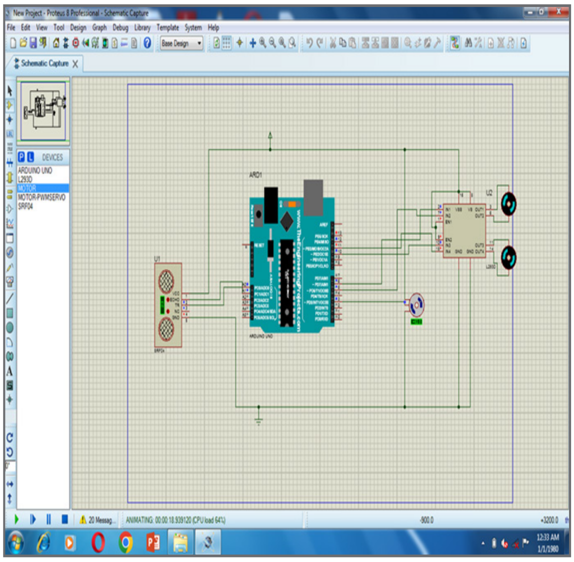

Figure 4: Simulation result of the whole system

Conclusion

This research has been successfully completed and tested. The obstacle avoidance robot was tested to sense the presence of an obstacle. Whenever this robot senses the presence of an obstacle, it will move backward until it is far away from the object it senses, then it will move forward again towards this object. This device is useful, and it finds application in diverse areas of life.

References

1. Mora TE, Sanchez EN. Fuzzy logic-based real-time navigation controller for a mobile robot in Proceedings. IEEE/RSJ International Conference on Intelligent Robots and Systems. Innovations in Theory, Practice and Applications (Cat. No.98CH36190). 1998. 1: 612-617.
2. Waghmare LM, Tallapragada P, Bidwai N. Reactive Navigation of Autonomous Vehicle using Neuro-Fuzzy Controller in 2006. IEEE International Conference on Industrial Technology. 2006. 2681-2685.
3. Seghour S, Tadjine M. Consensus-based approach and reactive fuzzy navigation for multiple no-holonomic mobile robots in 2017 6th International Conference on Systems and Control (ICSC). 2017. 492-497.
4. Shen T, Zhai J. Reactive Obstacle Avoidance Strategy Based on Fuzzy Neural Network and Arc Trajectory in 2019 Chinese Automation Congress (CAC). 2019. 4792-4796.
5. Wang Y, Yuan Y. A dynamic reactive power compensation method for high-power and high-voltage electronic motors based on self-adaptive fuzzy PID control in 2016 IEEE Chinese Guidance, Navigation and Control Conference (CGNCC). 2016. 10-15.
6. Ruiz E, Acuña R, Véélez P, Fernández-López G. Hybrid Deliberative Reactive Navigation System for Mobile Robots Using ROS and Fuzzy Logic Control in 2015 12th Latin American Robotics Symposium and 2015 3rd Brazilian Symposium on Robotics (LARSSBR). 2015. 67-72.

7. Chand P. Fuzzy reactive control for wheeled mobile robots in 2015 6th International Conference on Automation, Robotics and Applications (ICARA). 2015. 167-172.
8. Zerfa H, Nouibat W. Fuzzy reactive navigation for autonomous mobile robot with an offline adaptive neuro fuzzy system in 3rd International Conference on Systems and Control 2013. 950-955.
9. Melendez, Castillo O. Optimization of type-2 fuzzy reactive controllers for an autonomous mobile robot in 2012 Fourth World Congress on Nature and Biologically Inspired Computing (NaBIC). 2012. 207-211.
10. Baklouti E, Jallouli M, Ben Amor N, Titi S, Nafti A. Autonomous mobile robot navigation coupling fuzzy logic and reactive DVZ 3D obstacle avoidance control in 2015 International Symposium on Innovations in Intelligent Systems and Applications (INISTA). 2015. 1-6.
11. Lv Y, Jiang P. The Design of Indoor Mobile Robot Navigation System Based on UWB Location in 2018 Eighth International Conference on Instrumentation & Measurement, Computer, Communication and Control (IMCCC). 2018. 334-338.
12. Itta A, Attolico G, Distante A. Combining reactive behaviors using a hierarchy of fuzzy controllers in Ninth IEEE International Conference on Fuzzy Systems. FUZZ-IEEE. 2000. 2: 1041-1044.
13. Mendez MAO, Madrigal JAF. Fuzzy Logic User Adaptive Navigation Control System For Mobile Robots In Unknown Environments in 2007 IEEE International Symposium on Intelligent Signal Processing. 2007. 1-6.
14. Ismail II, Nordin MF. Reactive navigation of autonomous guided vehicle using fuzzy logic in Student Conference on Research and Development. 2002. 153-156.
15. Zhang N, Beetner D, Wunsch DC, Hemmelman B, Hasan A. An Embedded Real-Time Neuro-Fuzzy Controller for Mobile Robot Navigation in The 14th IEEE International Conference on Fuzzy Systems, 2005. FUZZ. 2005. 05: 319-324.
16. Castellano G, Attolico G, Stella E, Distante A. Reactive navigation by fuzzy control in Proceedings of IEEE 5th International Fuzzy Systems. 1996. 3: 2143-2149.
17. Xu WL, Tso SK. Sensor-based fuzzy reactive navigation of a mobile robot through local target switching IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews). 1999. 29: 451-459.
18. Joshi MM, Zaveri MA. Fuzzy Based Autonomous Robot Navigation System in 2009 Annual IEEE India Conference. 2009. 1-4.
19. Alwan M, Cheung PYK, Saleh A, Obeid NEC. Combining goal-directed, reactive and reflexive navigation in autonomous mobile robots in 1996 Australian New Zealand Conference on Intelligent Information Systems. Proceedings. ANZIIS. 1996. 96: 346-349.
20. Al-Jumaily AAS, Amin SHM. Fuzzy logic-based behaviors blending for intelligent reactive navigation of walking robot in ISSPA 99. Proceedings of the Fifth International Symposium on Signal Processing and its Applications (IEEE Cat. No.99EX359). 1999. 1: 155-158.
21. Skubic M, Graves S, Mollenhauer J. Design of a two-level fuzzy controller for a reactive miniature mobile robot in Third International Conference on Industrial Fuzzy Control and Intelligent Systems. 1993. 224-227.
22. Overholt JL, Hudas GR, Cheok KC. A modular neural-fuzzy controller for autonomous reactive navigation in NAFIPS 2005 Annual Meeting of the North American Fuzzy Information Processing Society. 2005. 121-126.
23. Li W. Fuzzy logic-based robot navigation in uncertain environments by multisensor integration in Proceedings of 1994 IEEE International Conference on MFI "94. Multisensor Fusion and Integration for Intelligent Systems. 1994. 259-264.
24. Melik N, Slimane N. Autonomous navigation with obstacle avoidance of tricycle mobile robot based on fuzzy controller in 2015 4th International Conference on Electrical Engineering (ICEE). 2015 1-4.
25. Aycard O, Charpillet F, Haton J-P. A new approach to design fuzzy controllers for mobile robots' navigation in Proceedings 1997 IEEE International Symposium on Computational Intelligence in Robotics and Automation CIRA"97. Towards New Computational Principles for Robotics and Automation. 1997. 68-73.
26. Arrue BC, Cuesta F, Braunstingl R, Ollero A. Fuzzy behaviors combination to control a nonholonomic mobile robot using virtual perception memory in Proceedings of 6th International Fuzzy Systems Conference. 1997. 3: 1239-1244.
27. Li W, Feng X. Behavior fusion for robot navigation in uncertain environments using fuzzy logic in Proceedings of IEEE International Conference on Systems, Man and Cybernetics. 1994. 2: 1790-1796.
28. Al-Jumaily AAS, Amin SHM. Behaviors blending for intelligent reactive navigation of climbing robot in 2000 26th Annual Conference of the IEEE Industrial Electronics Society. IECON 2000. 2000 IEEE International Conference on Industrial Electronics, Control and Instrumentation. 21st Century Technologies. 2000. 2: 795-799.
29. Yang X, Moallem M, Patel RV. A fuzzy logic-based reactive navigation algorithm for mobile robots. in Proceedings of 2005 IEEE Conference on Control Applications. CCA. 2005. 197-202.
30. Duan Y, Xin-Hexu. Fuzzy reinforcement learning and its application in robot navigation. in 2005 International Conference on Machine Learning and Cybernetics. 2005. 2: 899-904.
31. Xu WL, Tso SK, Fung YH. Sensor-based reactive navigation of a mobile robot through local target switching in 1997 8th International Conference on Advanced Robotics. Proceedings. ICAR. 97: 361-366.
32. Anvar AM. Intelligent navigation process for autonomous underwater vehicles (AUVs) using time-based fuzzy temporal reasoning in 10th International Symposium on Temporal Representation and Reasoning, 2003 and Fourth International Conference on Temporal Logic. Proceedings. 2003. 56-61.
33. Maaref H, Barret C. Fuzzy help in mobile robot navigation. in Proceedings IEEE Conference on Industrial Automation and Control Emerging Technology Applications. 1995. 387-390.
34. Barret C, Benreguieg M, Maaref H. Fuzzy agents for reactive navigation of a mobile robot. in Proceedings of 1st International Conference on Conventional and Knowledge Based Intelligent Electronic Systems. KES. 1997. 2: 649-658.

35. Al-Jumaily AAS, Amin SHM, Khalil M. A fuzzy multi-behavior reactive obstacle avoidance navigation for a climbing mobile robot in Proceedings of IEEE International Conference on Intelligent Engineering Systems. 1997. 147-152.
36. A hybrid neuro-fuzzy system for sensor-based robot navigation in unknown environments in Proceedings of 1995 American Control Conference - ACC. 1995. 4: 2749-2753.
37. Mester G. Obstacle Avoidance of Mobile Robots in Unknown Environments in 2007 5th International Symposium on Intelligent Systems and Informatics. 2007. 123-127.
38. Benreguieg M, Maaref H, Barret C. Fusion of fuzzy agents for the reactive navigation of a mobile robot in Proceedings of the 1997 IEEE/RSJ International Conference on Intelligent Robot and Systems. Innovative Robotics for Real-World Applications. IROS. 1997. 1: 388-394.
39. Dupre M, Yang SX. Two-Stage Fuzzy Logic-Based Controller for Mobile Robot Navigation in 2006 International Conference on Mechatronics and Automation. 2006. 745-750.
40. Jayasiri A, Mann GKI, Gosine RG. Supervisory control of Fuzzy Discrete Event Systems and its application to mobile robot navigation in 2009 Canadian Conference on Electrical and Computer Engineering. 2009. 1147-1151.
41. Shi D, Selekwa MF, Collins EG, Moore CA. Fuzzy behavior navigation for an unmanned helicopter in unknown environments in 2005 IEEE International Conference on Systems, Man and Cybernetics. 2005. 4: 3897-3902.
42. Mondelli G, Castellano G, Attolico G, Stella E, Distante A. Self-tuning fuzzy logic controller for reactive navigation. in Proceedings of Conference on Intelligent Vehicles. 1996 87-92.
43. Selekwa MF, Dunlap DD, Collins EG. Implementation of Multi-valued Fuzzy Behavior Control for Robot Navigation in Cluttered Environments in Proceedings of the 2005 IEEE International Conference on Robotics and Automation. 2005. 3688-3695.
44. Reddy BBK, Kimiaghalam B, Homaifar A. Reactive real time behavior for mobile robots in unknown environments in 2004 IEEE International Symposium on Industrial Electronics. 2004. 1: 693- 697.
45. Kundu S, Parhi DR. Behavior-based navigation of multiple robotic agents using hybrid-fuzzy controller in 2010 International Conference on Computer and Communication Technology (ICCCT). 2010. 706-711.
46. Safiotti A. Fuzzy logic in autonomous robotics: behavior coordination in Proceedings of 6th International Fuzzy Systems Conference. 1997. 1: 573-578.
47. Maaref H, Barret C. Progressive optimization of a fuzzy inference system in Proceedings Joint 9th IFSA World Congress and 20th NAFIPS International Conference (Cat. No. 01TH8569). 2001. 1: 47-52.
48. Vega Oliver JC, Huamaní Navarrete PF. Fuzzy control to simulate 4 autonomous navigation behaviors in a differential-drive mobile robot in 2017 IEEE International Conference on Aerospace and Signals (INCAS). 2017. 1-4.
49. Yung-Jen Hsu J, Lo D-C, Hsu S-C. Fuzzy control for behaviorbased mobile robots. in NAFIPS/IFIS/NASA "94. Proceedings of the First International Joint Conference of The North American Fuzzy Information Processing Society Biannual Conference. The Industrial Fuzzy Control and Intelligent. 1994. 209-213.
50. Zhu A, Yang SX. A goal-oriented fuzzy reactive control for mobile robots with automatic rule optimization in 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems. 2010. 3688-3693.
51. Zhu A, Yang SX. A fuzzy logic approach to reactive navigation of behavior-based mobile robots. in IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA. 2004. 5: 5045-5050.
52. Kundu S, Parhi DR. Fuzzy based reactive navigational strategy for mobile agent. in 2010 International Conference on Industrial Electronics, Control and Robotics. 2010. 12-17.
53. Goodridge SG, and Luo RC. Fuzzy behavior fusion for reactive control of an autonomous mobile robot: MARGE. in Proceedings of the 1994 IEEE International Conference on Robotics and Automation. 1994. 2: 1622-1627.
54. Tan KC, Tan KK, Lee TH, Zhao S, Chen YJ. Autonomous robot navigation based on fuzzy sensor fusion and reinforcement learning in Proceedings of the IEEE International Symposium on Intelligent Control. 2002. 182-187.
55. Sotelo MA. Vehicle fuzzy driving based on DGPS and vision in Proceedings Joint 9th IFSA World Congress and 20th NAFIPS International Conference (Cat. No. 01TH8569). 2001. 3: 1472-1477.
56. Howard A, Werger B, Seraji H. Integrating terrain maps into a reactive navigation strategy in 2003 IEEE International Conference on Robotics and Automation (Cat. No.03CH37422). 2003. 2: 2012- 2017.
57. Liu H, Hu P, Luo Y, Li C. A goal-oriented fuzzy reactive control method for mobile robot navigation in unknown environment in 2009 IEEE International Symposium on Industrial Electronics. 2009. 1950-1955.
58. Hagras HA. A hierarchical type-2 fuzzy logic control architecture for autonomous mobile robots IEEE Transactions on Fuzzy Systems. 2004. 12: 524-539.
59. Kundu S, Dayal RP. A fuzzy approach towards behavioral strategy for navigation of mobile agent in INTERACT-2010. 292-297.
60. Shim B-K, Kim J-H, Park I-M, Han S-H. An intelligent control of non-holonomic mobile robot based on fuzzy perception in ICCAS 2010. 2111-2114.
61. Al-Jumaily AAS, Amin SHM. Blending multi-behaviors of intelligent reactive navigation for legged walking robot in unstructured environment in 2000 TENCON Proceedings. Intelligent Systems and Technologies for the New Millennium (Cat. No.00CH37119). 2000. 2: 297-302.
62. Ortega JG, Camacho EF. Mobile robot navigation in a partially structured static environment, using neural predictive control Control Eng Pract. 1996. 4: 1669-1679.
63. Zarate LE, Becker M, Garrido BDM, Rocha HSC. An artificial neural network structure able to obstacle avoidance behavior used in mobile robots in IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON. 2002. 2: 2457-2461.
64. Gamal O, Cai X, Roth H. Learning from Fuzzy System Demonstration: Autonomous Navigation of Mobile Robot in Static Indoor Environment using Multimodal Deep Learning in 2020 24th International Conference on System Theory, Control and Computing (ICSTCC). 2020. 218-225.

65. Lafmejani AS, Berman S, Fainekos G. NMPC-LBF: Nonlinear MPC with Learned Barrier Function for Decentralized Safe Navigation of Multiple Robots in Unknown Environments 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). 2022. 10297-10303.
66. Chen G. Robot Navigation with Map-Based Deep Reinforcement Learning 2020 IEEE International Conference on Networking, Sensing and Control (ICNSC). 2020. 1-6.
67. Pan Y, Wang J. A neurodynamic optimization approach to nonlinear model predictive control in 2010 IEEE International Conference on Systems, Man and Cybernetics. 2010. 1597-1602.
68. Hirose N, Xia F, Martín-Martín R, Sadeghian A, Savarese S. Deep Visual MPC-Policy earning for Navigation IEEE Robot Autom Lett. 2019. 4: 3184-3191.
69. Ono T, Kanamaru T. Prediction of pedestrian trajectory based on long short-term memory of data in 2021 21st International Conference on Control, Automation and Systems (ICCAS). 2021. 1676-1679.
70. Kim T, Lee H, Hong S, Lee W. TOAST: Trajectory Optimization and Simultaneous Tracking Using Shared Neural Network Dynamics IEEE Robot Autom Lett. 2022. 7: 9747-9754.
71. Guo Y, Jena R, Hughes D, Lewis M, Sycara M. Transfer Learning for Human Navigation and Triage Strategies Prediction in a Simulated Urban Search and Rescue Task in 2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN). 2021. 784-791.
72. Polevoy A, Knuth C, Popek KM, Katyal KD. Complex Terrain Navigation via Model Error Prediction 2022 International Conference on Robotics and Automation (ICRA). 2022. 9411-9417.
73. Lai S, Lan M, Chen BM. Model Predictive Local Motion Planning with Boundary State Constrained Primitives IEEE Robot Autom Lett. 2019. 4: 3577-3584.
74. Gauthier-Clerc F, Hill A, Laneurit J, Lenain R, Lucet E. Online velocity fluctuation of off-road wheeled mobile robots: A reinforcement learning approach in 2021 IEEE International Conference on Robotics and Automation (ICRA). 2021. 2421-2427.
75. Ferreira EP, Miranda VM. Development of static neural networks as full predictors or controllers for multiarticulated mobile robots in backward movements - new models and tools in 2011 9th IEEE International Conference on Control and Automation (ICCA). 2011. 985-990.
76. Weerakkodi Mudalige ND. DogTouch: CNN-based Recognition of Surface Textures by Quadruped Robot with High Density Tactile Sensors in 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring). 2022. 1-5.
77. Zou X, Sun B, Zhao D, Zhu Z, Zhao J, et al. Multi-Modal Pedestrian Trajectory Prediction for Edge Agents Based on Spatial Temporal Graph IEEE Access. 2020. 8: 83321-83332.
78. Engedy I, Horvath G. Artificial neural network based mobile robot navigation in 2009 IEEE International Symposium on Intelligent Signal Processing. 2009. 241-246.
79. Bugeja MK, Fabri SG, Camilleri L. Dual Adaptive Dynamic Control of Mobile Robots Using Neural Networks IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics). 2009. 39: 129-141.
80. Yuan J, Wang H, Lin C, Liu D, Yu D. A Novel GRU-RNN Network Model for Dynamic Path Planning of Mobile Robot IEEE Access. 2019. 7: 15140-15151.
81. Er MJ, Tan TP, Loh SY. Control of a mobile robot using generalized dynamic fuzzy neural networks Microprocess Microsyst. 2004. 28: 491-498.
82. Huang B-Q, Cao G-Y, Guo M. Reinforcement Learning Neural Network to the Problem of Autonomous Mobile Robot Obstacle Avoidance in 2005 International Conference on Machine Learning and Cybernetics. 2005. 85-89.
83. Soumare S, Ohya A, Yuta S. Real-time obstacle avoidance by an autonomous mobile robot using an active vision sensor and a vertically emitted laser slit In Intelligent Autonomous Systems. 2002. 7: 301-308.
84. Lauer M , Schönbein M, Lange S, Welker S. 3D-objecttracking with a mixed omnidirectional stereo camera system Mechatronics. 2011. 21: 390-398.
85. Tahmasebi M, Gohari M, Emami A. An Autonomous Pesticide Sprayer Robot with a Color-based Vision System. International Journal of Robotics and Control Systems. 2: 115-123.
86. Perkasa SD, Megantoro P, Winarno HA. Implementation of a camera sensor pixy 2 cmucam5 to a two wheeled robot to follow colored object. Journal of Robotics and Control (JRC). 2: 496-501.
87. Rusydi MI. Autonomous Movement Control of Coaxial Mobile Robot based on Aspect Ratio of Human Face for Public Relation Activity Using Stereo Thermal Camera. Journal of Robotics and Control (JRC). 3: 361-373.
88. Umam F, Fuad M, Suwarno I, Ma'arif A, Caesarendra W. Obstacle Avoidance Based on Stereo Vision Navigation System for Omni-directional Robot. Journal of Robotics and Control (JRC). 2023. 4.
89. Baballe MA, Adamu AI, Bari AS, Ibrahim A. Principal Operation of a Line Follower Robot. Global Journal of Research in Engineering & Computer Sciences. 2023. 03.
90. Çavaş M, Ahmad MB. A REVIEW ON SPIDER ROBOTIC SYSTEM. International Journal of New Computer Architectures and their Applications (IJNCAA). 2019. 9: 19-24.
91. Ahmad MB, Muhammad, A general review on advancement in the robotic system. Artificial & Computational Intelligence. 2020. 1-7.
92. Baballe MA, Bello MI, Hussaini A, Musa US. Pipeline Inspection Robot Monitoring System. Journal of Advancement in Robotics. 2022. 9.
93. Ahmad MB. The Various Types of sensors used in the Security Alarm system. International Journal of New Computer Architectures and their Applications (IJNCAA). 2019. 9: 50-59.
94. https://circuitdigest.com/microcontroller-projects/arduino-obstacle-avoding-robot.

95. Adamu AI, Bari AS, Ibrahim A, Baballe MA. The Several uses for Obstacle-Avoidance Robots. Global Journal of Research in Engineering & Computer Sciences. 3.
96. Baballe MA. A Look at the Different Types of Servo Motors and Their Applications. Global Journal of Research in Engineering & Computer Sciences. 2022.
97. Abdulkadir SB, Muhammad AF, Amina I, Mukhtar IB, Baballe MA. Elements needed to implement the Obstacle-Avoidance Robots. Global Journal of Research in Engineering & Computer Sciences. 2023. 3: 18-27.