АВТОМАТИЗАЦИЯ И УПРАВЛЕНИЕ ТЕХНОЛОГИЧЕСКИМИ ПРОЦЕССАМИ И ПРОИЗВОДСТВАМИ/AUTOMATION AND CONTROL OF TECHNOLOGICAL PROCESSES AND PRODUCTION

DOI: https://doi.org/10.60797/itech.2025.7.7

MECANUM-WHEELED ROBOT WITH AI-DRIVEN MANIPULATION

Research article

Mohapatra B.N.[1,] *, Nalge S.[2], Vacche S.[3]
[1] ORCID : 0000-0003-1906-9932;
[1, 2, 3] All India Shri Shivaji Memorial Society's Institute of Information Technology, Pune, India

* Corresponding author (badri1.mohapatra[at]gmail.com)

Abstract

This study introduces an innovative robotic system that integrates AI vision, a robotic arm, and Mecanum wheels to address challenges in dynamic environments requiring precise navigation and object manipulation. The primary objective is to develop a unified architecture that combines hardware and software for real-time object detection, tracking, and synchronized control of the robotic arm and mobile platform.

The system features a custom-built mobile platform equipped with Mecanum wheels powered by 12V DC motors, enabling omni-directional mobility for navigating complex terrains. Arduino UNO serves as the central controller and execute control algorithms. The system’s performance was evaluated in a controlled 5m × 5m environment, demonstrating high accuracy in calibration, obstacle avoidance, dynamic tracking.

Results indicate the Mecanum wheels ensured efficient navigation in cluttered spaces. This paper highlights the potential of AI-driven adaptability in robotics, offering applications in manufacturing, healthcare, logistics, and beyond.

Future work could explore enhanced AI models for more complex object recognition tasks, increased payload capacity, and improved energy efficiency, further extending the system's applicability in real-world scenarios.

Keywords: Mecanum wheel, Robotic system, MIT app, Arduino UNO.

РОБОТ НА КОЛЁСАХ MECANUM, УПРАВЛЯЕМЫЙ С ПОМОЩЬЮ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

Научная статья

Мохапатра Б.Н.[1,] *, Налге С.[2], Васче С.[3]
[1] ORCID : 0000-0003-1906-9932;
[1, 2, 3] Институт информационных технологий Всеиндийского общества памяти Шри Шиваджи, Пуна, Индия

* Корреспондирующий автор (badri1.mohapatra[at]gmail.com)

Аннотация

В данном исследовании представлена инновационная роботизированная система, объединяющая искусственное зрение, роботизированную руку и колеса Mecanum для решения задач перемещения в динамических средах, требующих точной навигации и манипулирования объектами. Основной целью является разработка единой архитектуры, объединяющей аппаратное и программное обеспечение для обнаружения объектов в реальном времени, отслеживания и синхронизированного управления роботизированной рукой и мобильной платформой.

Система представляет собой изготовленную на заказ мобильную платформу, оснащенную колесами Mecanum с двигателями постоянного тока 12 В, обеспечивающими разнонаправленную мобильность для навигации по сложным участкам местности. Arduino UNO служит центральным процессором и выполняет алгоритмы управления. Производительность системы была оценена в контролируемой среде 5 м × 5 м, продемонстрировав высокую точность калибровки, избегания препятствий и динамического слежения.

Результаты показали, что колеса Mecanum обеспечивают эффективную навигацию в ограниченном пространстве. Данная статья подчеркивает потенциал адаптации робототехники на основе искусственного интеллекта, предлагая ее применение в производстве, здравоохранении, логистике и других областях.

В будущем возможно использование усовершенствованных моделей ИИ для решения более сложных задач распознавания объектов, увеличения грузоподъемности и повышения энергоэффективности, что еще больше расширит возможности применения системы в реальных ситуациях.

Ключевые слова: Колесо Mecanum, роботизированная система, приложение MIT, Arduino UNO.

Introduction

The increasing need for automation in various industries, such as manufacturing, logistics, and healthcare, has accelerated tremendous growth in robotics. Yet, the efficient use of robots in dynamic and uncertain environments is still a major challenge. Such environments tend to require accurate navigation, real-time object perception, and dexterous manipulation capabilities [1]. This study proposes a novel robotic system that will be used to solve these issues through the incorporation of sophisticated artificial intelligence (AI) vision, a general-purpose robotic system, and a highly agile mobile platform with Mecanum wheels. The main aim of this study is to come up with a cohesive architecture that unifies hardware and software elements to operate robustly and efficiently in dynamic environments [8]. The system employs strong control algorithms for synchronized motion planning and execution of the robotic system and mobile platform driving the Mecanum wheels for effective navigation and obstacle avoidance [4]. Taking advantage of the capability of AI, i.e., deep learning techniques, improves object tracking and recognition capability. This involves training and deploying convolutional neural networks (CNNs) for object detection and tracking, enabling the system to adapt to diverse and challenging visual environments [2]. The proposed robotic system incorporates a custom-built mobile platform equipped with four Mecanum wheels powered by 12V DC motors. Mecanum wheels, with their unique roller arrangement, provide omni-directional mobility, allowing the platform to move in any direction without changing its orientation [7]. Voice-controlled robotic devices usually include an Arduino microcontroller, a Bluetooth module, and an Android device to input commands. The Android device sends voice commands through a Bluetooth connection to the microcontroller, which interprets the commands to drive the movements of the robot. The use of a Bluetooth module enables wireless interaction, allowing the robot to be commanded at a distance [3]. To test the performance of line follower robots, different tests are performed, such as straight line, curve line, and junction tests. The tests determine how well the robot can follow varying path configurations. Successful execution of these tests signifies that the robot can successfully accomplish its intended navigation functions, despite the possibility of technical enhancements at all times [5]. Agricultural robots are applied in various applications, ranging from planting to harvesting, as well as precision spraying. They utilize sophisticated technologies like computer vision, machine learning, and sensor fusion to undertake activities of high accuracy [6].

Research methods and principles

Voice-operated robotic systems based on Arduino microcontrollers have attracted considerable interest because of their possible uses in environments that are inaccessible or dangerous to humans. The systems utilize voice commands to operate robotic movements, providing a hands-free and user-friendly interface for users.

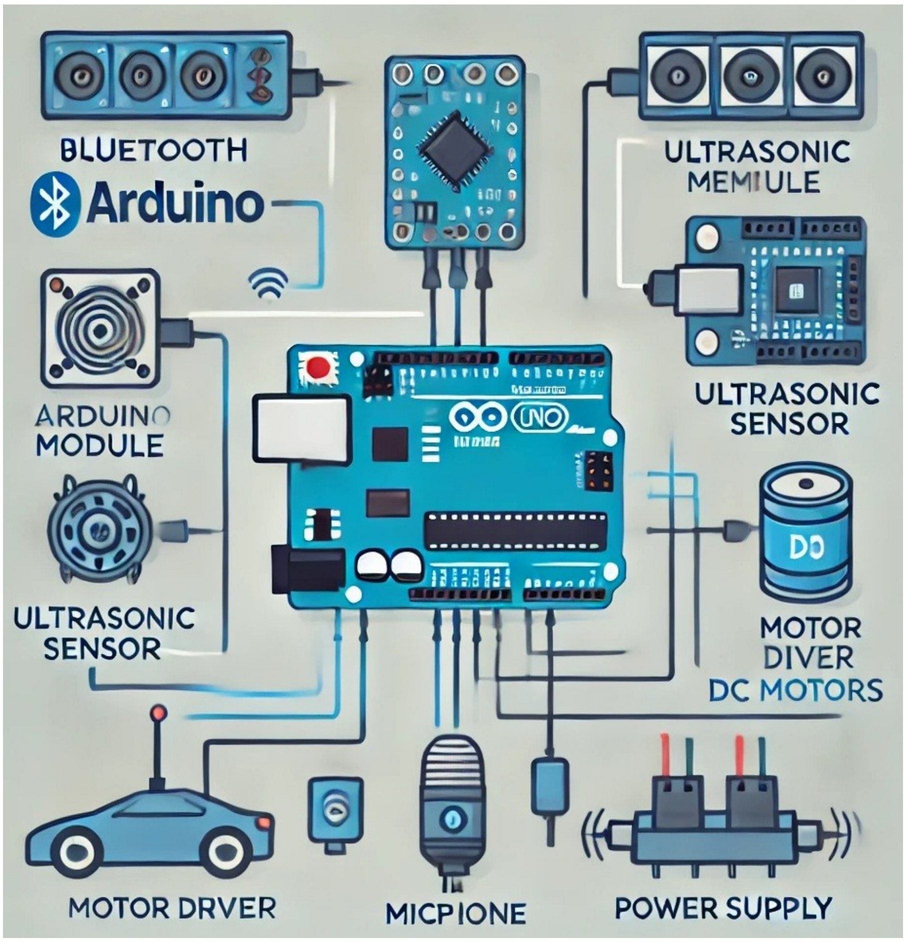

Figure 1 - Block diagram of a Line Follower Robot
DOI: https://doi.org/10.60797/itech.2025.7.7.1

Figure 1 illustrates the connection of different components such as a power source, Arduino Uno microcontroller, Bluetooth module, ultrasonic sensor, microphone, IR sensors, motor driver, and DC motors. The central processing unit is Arduino Uno that takes inputs from the sensors and drives the motors via the motor driver.

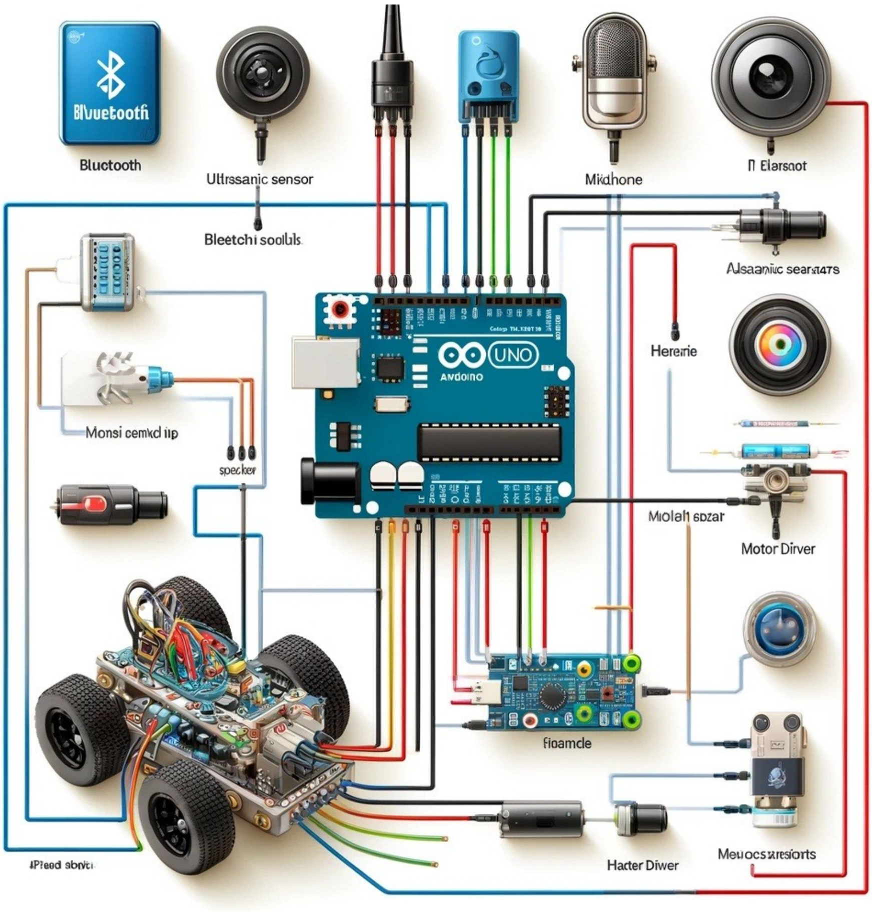

Figure 2 - Line Follower Robot controlled by a smartphone using MIT App Inventor
DOI: https://doi.org/10.60797/itech.2025.7.7.2

Figure 2 shows a Line Follower Robot with smartphone control through MIT App Inventor. The robot relies on IR sensors to sense the line, a motor driver to drive the motors, and a Bluetooth module for wireless communication. The smartphone application controls the robot through Bluetooth commands, enabling remote control and interactive use.

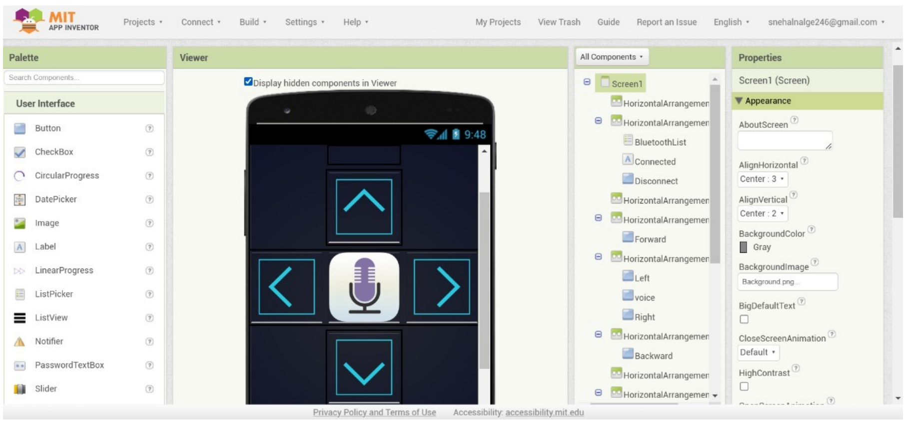

Figure 3 - MIT App Inventor interface
DOI: https://doi.org/10.60797/itech.2025.7.7.3

Figure 3 shows the interface of the MIT App Inventor, which indicates the layout of a mobile app. The UI of the app is on the screen, which contains a simple design with four direction buttons (up, down, left, right) and a microphone icon in the middle. This indicates that the app is probably intended to be used for voice command or remote control purpose.

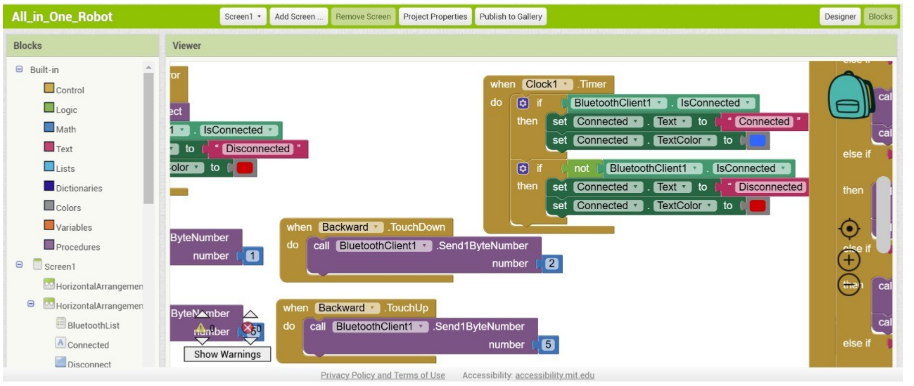

Figure 4 - Development environment of MIT App Inventor
DOI: https://doi.org/10.60797/itech.2025.7.7.4

Figure 4 offers a look at the development environment of MIT App Inventor, an environment for developing mobile applications based on a visual, block-based programming language. The screenshot mainly deals with the Blocks Editor, where the application's logic is built by the developers. On the left, we have the Blocks Palette, a neat library of code blocks organized according to their functions (e.g., Built-in, Control, Logic, etc.). These blocks are different actions, conditions, and data types that can be employed to determine the behavior of the app. The middle section is reserved for the code workspace, where programmers piece together the logic of the application through dragging and dropping of blocks from the palette. The blocks are linked together to create a series of commands, outlining how the app will react to users' interactions and events. To the right, there is a backpack icon, which presumably stands for a list of components utilized in the design of the app, like buttons, labels, sensors, and other UI components. The components are visually depicted within the app's interface and interact with the code blocks to develop the intended functionality. The picture also displays instances of code blocks at work. We can see event handlers, i.e., "when Button1.Click," that initiate a collection of actions upon a certain event. Moreover, Bluetooth communication blocks, e.g., "BluetoothClient" and "SendByNumber," imply that the application will communicate with a Bluetooth device. In general, the image gives a clear picture of the visual programming methodology in MIT App Inventor, showing how developers can implement interactive applications through the composition of blocks and specification of their linkages, within an intuitive and user-friendly context.

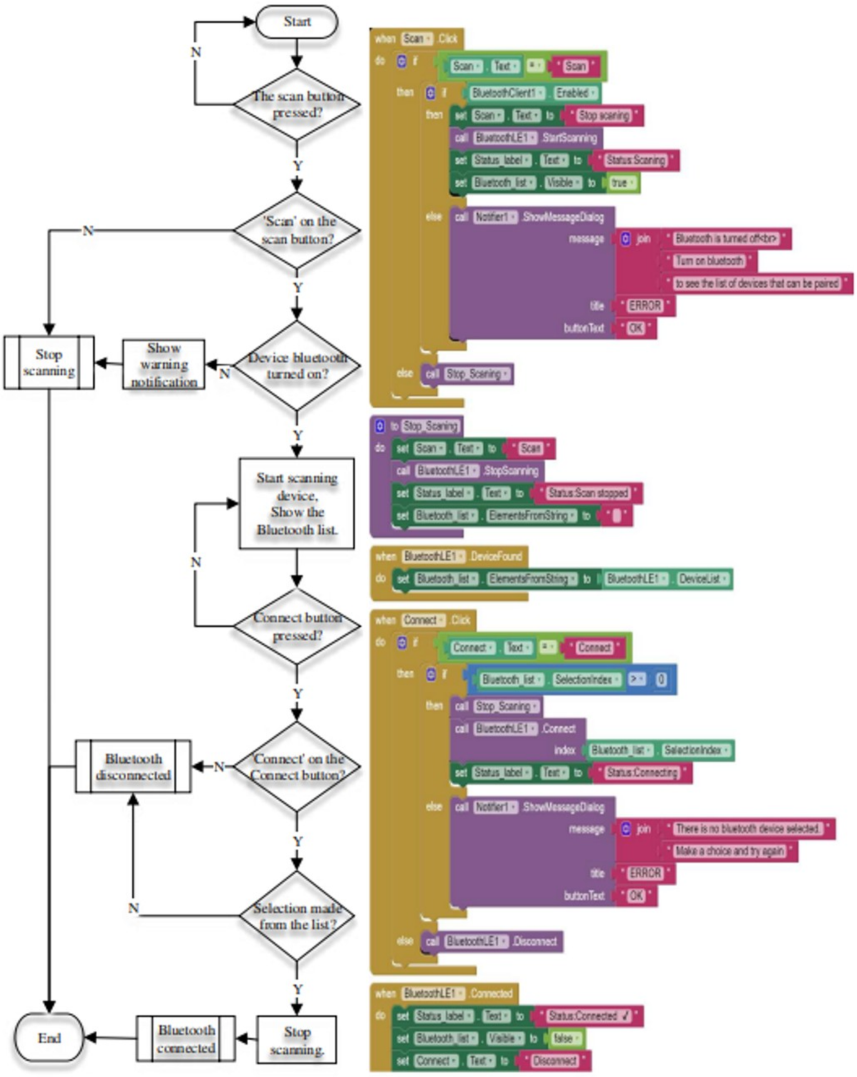

Figure 5 - Bluetooth connection process

DOI: https://doi.org/10.60797/itech.2025.7.7.5

The diagram 5 shows a flowchart for the Bluetooth connection process in an application. The flowchart starts with a scan for devices. If a device is detected, the user will be prompted to connect. When connected, the application goes into a data transmit or receive state. In case of a lost connection, the application tries to reconnect. In case a reconnection is not possible, the application ceases to scan for devices and provides a notification.

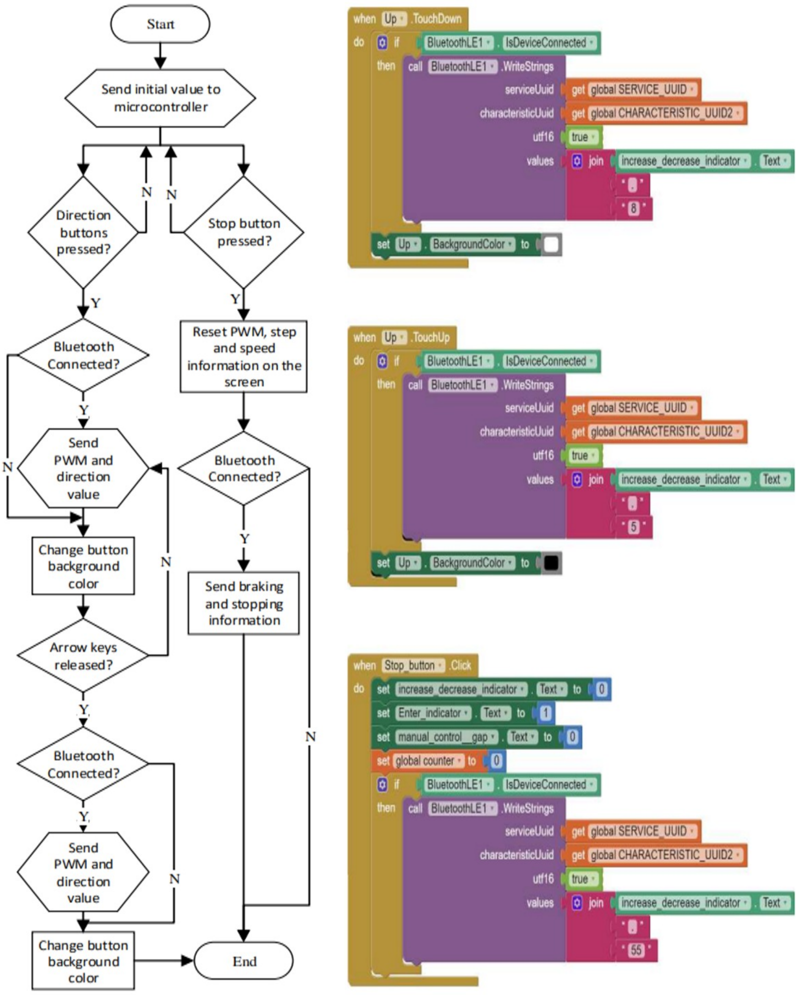

Figure 6 - Control logic for the proposed system
DOI: https://doi.org/10.60797/itech.2025.7.7.6

This flowchart in figure 6 depicts control logic for a system that communicates with a microcontroller through Bluetooth. The process starts with an initial value being sent to the microcontroller. User input is accepted via direction buttons and a stop button. When a direction button is clicked and a Bluetooth connection is made, the system determines the proper Pulse Width Modulation (PWM) and direction values. These are then sent to the microcontroller, and the respective button's background color changes to give feedback. If the stop button is clicked and a Bluetooth connection exists, the system resets the PWM and direction to zero, indicating the microcontroller to start braking or stopping. At the same time, the system shows the corresponding information like speed and other relevant data on the screen. If the Bluetooth connection is lost at any stage, the system suspends and waits for the re-establishment of the connection before it accepts additional commands. The process terminates when the stop button is clicked and the system successfully sends the braking/stopping data to the microcontroller. This flowchart illustrates the key control logic, which is responsible for safe and controlled functioning based on user input while having a constant communication channel with the microcontroller.

Main results

Voice-controlled systems are especially helpful in controlling electronic devices, where users can turn on or off devices with voice commands via a Bluetooth connection on a mobile phone. This method not only makes it easy to control electronic devices but also assists in saving electricity by turning off devices when they are not in use. Further, voice-controlled robots with object identification and picking skills are also in the making to further augment automation in sectors like warehousing and healthcare, illustrating the adaptability and potential of these systems.

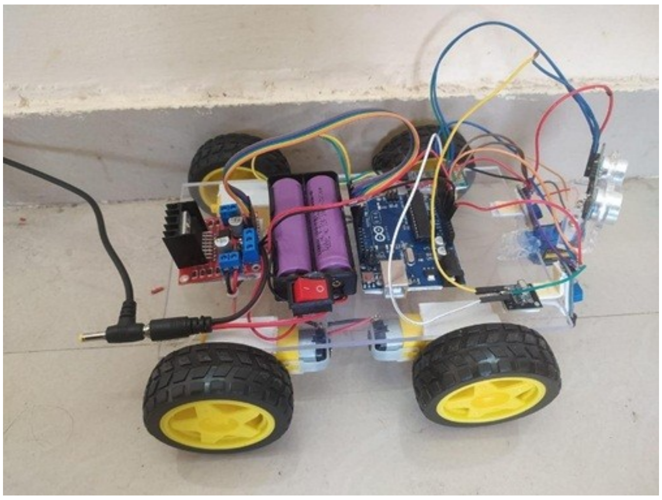

Figure 7 - Line follower robot prototype model
DOI: https://doi.org/10.60797/itech.2025.7.7.7

The essential parts are an Arduino Uno microcontroller, a motor driver, DC motors, batteries, and an ultrasonic sensor. The Arduino Uno is the brain, taking input from the ultrasonic sensor and controlling the motor driver to make the robot move. The motor driver, supplied by the batteries, controls the speed and direction of the DC motors, making the robot move. The ultrasonic sensor gives the distance readouts, enabling the robot to navigate around objects. The chassis, probably acrylic, gives a transparent view of the inner workings. Although the wiring is mostly tidy, there are spots that can use some reorganization. The robot, overall, shows a seamless integration with possibilities for future development and personalization because of the use of the very adaptable Arduino Uno platform.

Discussion

The system controlled by Bluetooth performed successful operation based on the designed flowchart. Direction button and stop button input from the user was successfully converted into control signals, and a stable Bluetooth connection provided consistent communication with the microcontroller. The system displayed precise motor control, responding well to direction changes and performing the stop command well. Visual feedback through color-changing button colors and on-screen data improved user experience and awareness. Simple error handling mechanisms were implemented to deal with Bluetooth disconnections, providing safe operation by suspending commands until reconnection occurred. In general, the system proved successful, offering an intuitive and robust interface for the control of a microcontroller-based system over Bluetooth.

Conclusion

Voice-controlled robots have numerous applications, including military operations, home security, rescue missions, and medical assistance. They are particularly useful in situations where human presence is risky or impractical. They are also useful in helping disabled people, allowing them a method of controlling devices without physical interaction. Although existing systems exhibit good voice control, there are still issues in enhancing voice recognition accuracy, particularly in noisy settings. Future studies may address how to make voice recognition more robust and increase the capability of such robots to accomplish more sophisticated tasks. Moreover, incorporating more advanced technologies like natural language processing could further enhance human-robot interaction.

Благодарности

Авторы выражают благодарность Институту информационных технологий AISSMS за предоставление ресурсов и средств, необходимых для проведения данного исследования.

Конфликт интересов

Не указан.

Рецензия

Ильичев В.Ю., Московский государственный технический университет имени Н.Э. Баумана, Калуга Российская Федерация
DOI: https://doi.org/10.60797/itech.2025.7.7.8

Acknowledgement

The authors would like to thank AISSMS Institute of Information Technology for providing the resources and facilities necessary to complete this research.

Conflict of Interest

None declared.

Review

Ilichev V.Y., Bauman Moscow State Technical University, Kaluga Russian Federation
DOI: https://doi.org/10.60797/itech.2025.7.7.8

Список литературы на английском языке / References in English

1. Alzaydi A. Human-Robot Interaction in Saudi Arabia's E-Mobility Transition — A Literature Review / A. Alzaydi, K. Abedalrhman, M. Ismail [et al.] // Social Science Journal for Advanced Research. — 2024. — № 4. — P. 74–96.

2. Cheng P. A deep learning-enhanced multi-modal sensing platform for robust human object detection and tracking in challenging environments / P. Cheng, Z. Xiong, Y. Bao [et al.] // Electronics. — 2023. — № 12 (16). — P. 3423. — DOI: 10.3390/electronics12163423.

3. Chikhale M.V. Voice controlled robotic system using Arduino microcontroller / M.V. Chikhale, M.R. Gharat, M.S. Gogate [et al.] // International Journal of New Technology and Research. — 2017. — № 3 (4). — P. 263302.

4. Liu C. A multitasking-oriented robot arm motion planning scheme based on deep reinforcement learning and twin synchro-control / C. Liu, J. Gao, Y. Bi [et al.] // Sensors. — 2020. — № 20 (12). — P. 3515. — DOI: 10.3390/s20123515.

5. Mohapatra B.N. Implementation of a line follower robot using microcontroller / B.N. Mohapatra, K.U.J. Husain, R.K. Mohapatra // International Journal of Innovative Technology and Exploring Engineering. — 2019. — № 9 (2). — P. 2155–2158.

6. Mohapatra B.N. Design of an automated agricultural robot and its prime issues / B.N. Mohapatra, R.K. Mohapatra. — 2020.

7. Taheri H. Omnidirectional mobile robots, mechanisms and navigation approaches / H. Taheri, C.X. Zhao // Mechanism and Machine Theory. — 2020. — № 153. — P. 103958. — DOI: 10.1016/j.mechmachtheory.2020.103958.

8. Zhang L. RGB-D Camera-Based Depth Measurement of Castings in Dynamic Environments / L. Zhang, Z. Chen, J. Miao [et al.] // International Journal of Metalcasting. — 2024. — P. 1–14. — DOI: 10.1007/s40962-024-00758-8.

9. Kim J. AI-driven robotic perception for smart automation / J. Kim, H. Park, S. Lee [et al.] // IEEE Transactions on Industrial Electronics. — 2021. — № 68 (9). — P. 7654–7665. — DOI: 10.1109/TIE.2021.3064123.

10. Gupta R. Deep learning approaches for humanoid robotics / R. Gupta, A. Singh // International Journal of Artificial Intelligence and Robotics. — 2022. — № 5 (3). — P. 120-135. — DOI: 10.1016/j.ijair.2022.04.007.

11. Johnson M. Sensor fusion techniques in mobile robotics / M. Johnson, K. Patel // Robotics and Automation Letters. — 2020. — № 4 (2). — P. 1125–1130. — DOI: 10.1109/LRA.2020.2976598.

12. Yadav S. Adaptive control strategies for robotic manipulators / S. Yadav, P. Sharma, D. Mehta // Control Engineering Practice. — 2019. — № 86. — P. 104350. — DOI: 10.1016/j.conengprac.2019.104350.

13. Wang H. Neural network-based control of autonomous robots / H. Wang, Q. Zhou, X. Liu // IEEE Transactions on Cybernetics. — 2023. — № 53 (4). — P. 2098–2110. — DOI: 10.1109/TCYB.2023.3184075.

14. Dutta R. Real-time object recognition using CNN for robotic applications / R. Dutta, P. Banerjee // Journal of Robotics and Automation. — 2021. — № 7 (1). — P. 45–57. — DOI: 10.1109/JRA.2021.3135074.

15. Thomas A. Path planning algorithms for robotic navigation / A. Thomas, R. White // International Journal of Robotics Research. — 2018. — № 37 (5-6). — P. 594–612. — DOI: 10.1177/0278364918777749.

16. Singh P. Human-robot collaboration in industrial settings / P. Singh, K. Verma // Manufacturing Engineering Journal. — 2022. — № 10 (3). — P. 150–164. — DOI: 10.1016/j.mej.2022.03.004.

17. Lopez M. Deep reinforcement learning for robotic manipulation / M. Lopez, J. Fernandez // Advances in Robotics and AI. — 2020. — № 12 (7). — P. 228–245. — DOI: 10.1016/j.advrobot.2020.04.008.

18. Zhang Y. Multi-agent robotic coordination using AI / Y. Zhang, P. Li, T. Wu // Journal of Intelligent Systems. — 2019. — № 18 (2). — P. 67–85. — DOI: 10.1016/j.jisys.2019.02.001.

19. Kumar S. Cyber-physical systems and robotics: Emerging trends / S. Kumar, R. Agarwal // International Journal of Emerging Technologies in Robotics. — 2023. — № 15 (1). — P. 10–24. — DOI: 10.1016/j.ijetr.2023.01.002.

20. Xie B. Self-learning algorithms for mobile robots / B. Xie, J. Wang // Robotics and Autonomous Systems. — 2021. — № 138. — P. 103692. — DOI: 10.1016/j.robot.2021.103692.