Design and Development of an IoT-Enabled Omni-Directional Robot for Indoor Urban Area Delivery System

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Abstract. This paper presents the design and development of an IoT-enabled omni-directional robot for indoor urban delivery systems, addressing the challenges posed by confined spaces, frequent human interaction, and dynamic obstacles in urban indoor environments such as offices, malls, and hospitals. Traditional wheeled robots often lack the maneuverability needed to navigate efficiently in such spaces, which leads to operational inefficiencies and limits their practical use in automated delivery. To overcome these challenges, the proposed robot is equipped with omni-directional wheels, providing it with the ability to move in any direction without needing to rotate. This feature allows for enhanced mobility, especially in narrow or crowded areas. Additionally, ultrasonic sensors are integrated into the system for real-time obstacle detection and avoidance, ensuring the robot can autonomously navigate complex environments while avoiding collisions. The robot is controlled by an Arduino UNO microcontroller, and an ESP32 module provides IoT connectivity, enabling real-time monitoring, data transmission, and remote control of delivery operations. The robot's performance was evaluated in a simulated urban indoor environment, where it successfully navigated confined spaces, avoided obstacles, and completed delivery tasks efficiently. Experimental results demonstrated the robot's effectiveness in autonomous navigation and obstacle avoidance, making it a viable solution for indoor delivery applications. Future work will focus on improving the system's autonomy by incorporating advanced sensors such as LIDAR for more precise mapping and obstacle detection. Additionally, optimization of the power management system and the integration of machine learning algorithms for route optimization are proposed to enhance the robot's performance in larger and more complex environments.

Keywords: Omni-directional robot, indoor urban delivery, ultrasonic sensor, IoT-enabled robot

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1 Introduction

The rapid growth of automation in urban areas has led to the increasing use of autonomous robots for tasks such as indoor delivery. In environments such as office buildings, hospitals, and shopping malls, efficient and reliable delivery systems are essential to enhance operational productivity and reduce human labor. However, these indoor spaces often pose significant challenges for conventional mobile robots due to confined pathways, dynamic human interaction, and the need for precise navigation. Traditional wheeled robots struggle with maneuverability in narrow or crowded spaces, leading to inefficiencies and operational delays [1].

To address these challenges, omni-directional robots offer an effective solution by allowing movement in any direction without the need for rotation. This provides greater flexibility and mobility, especially in confined and dynamic indoor environments [2]. However, while the mechanical design of such robots can solve the problem of maneuverability, other challenges remain. The ability to detect and avoid obstacles in real time, particularly in environments with frequent human activity, is critical. Without effective obstacle detection and avoidance, the robot's ability to function autonomously in complex environments would be severely limited [3].

The integration of IoT technologies has further enhanced the capabilities of autonomous robots by enabling real-time monitoring, control, and data acquisition. By equipping the robot with IoT connectivity, it becomes possible to remotely track the robot’s status, manage delivery tasks, and intervene when necessary [4]. In this research, an Arduino UNO is used as the central microcontroller for controlling the robot’s movement, while an ESP32 module is employed for IoT communication. Ultrasonic sensors are incorporated for real-time obstacle detection, allowing the robot to autonomously navigate through the environment while avoiding collisions [5].

This paper aims to design and develop an IoT-enabled omni-directional robot specifically for indoor urban delivery systems. The proposed robot will utilize omni-directional wheels for improved mobility, ultrasonic sensors for obstacle detection, and IoT for real-time monitoring and control. The system will be evaluated in a simulated indoor urban environment to assess its effectiveness in completing delivery tasks efficiently while avoiding obstacles and navigating through dynamic spaces.

2 System Design and Architecture

The proposed omni-directional robot is designed for autonomous delivery in indoor urban environments, focusing on high maneuverability and efficient operation. It combines mechanical, electronic, and control subsystems, featuring omni-directional wheels for flexible movement, ultrasonic sensors for obstacle detection, an Arduino UNO for motor control, and an ESP32 for IoT communication. This integration enables the robot to navigate complex spaces autonomously while staying connected to a remote control system for real-time status updates and task management, as shown in Fig. .

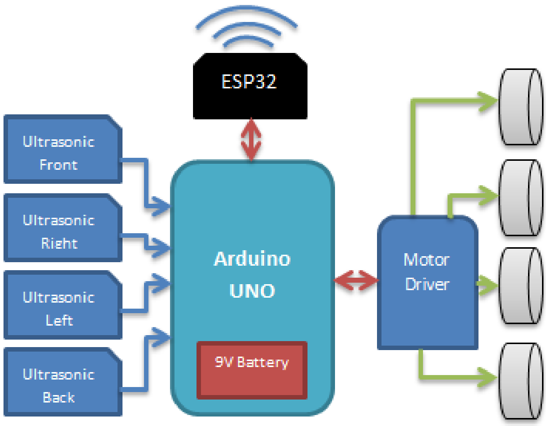
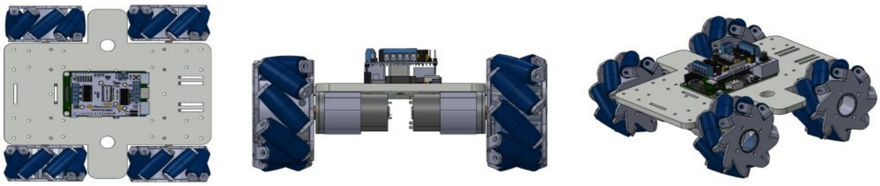


Fig. 1. Omni-directional robot system design.

2.1 Mechanical Design

The robot's mechanical design features omni-directional wheels, enabling movement in any direction such as forward, backward, sideways, or diagonally without changing orientation. This flexibility is crucial in indoor environments with narrow corridors and tight corners. The seamless direction changes improve efficiency in navigating complex spaces, speeding up delivery tasks and enhancing system flexibility. The SolidWorks model (see Fig.), highlights this design, ensuring stability even in cluttered environments.



(a) (b) (c)

Fig. 2. (a) Top view, (b) Side view, (c) Orthogonal view of the omni-directional robot design.

2.2 Electronics and Sensors

The robot's electronic system is powered by a 9V battery, with the Arduino UNO processing sensor data and controlling the motors. Four ultrasonic sensors positioned at the front, sides, and back provide 360-degree real-time obstacle detection. The Arduino UNO, connected to a motor driver shield, controls the four omni-directional wheels for precise movement. Additionally, the ESP32 module enables IoT connectivity for remote monitoring and control. Table 1 describes the components, including the Arduino, sensors, motor driver shield, and ESP32 module.

Table 1. Electronic system specifications.

Components	Types	Power Supply
Microcontroller	Arduino UNO	5~9V
Sensor	Ultrasonic HCSR04	5V
Motor Driver	DK Electronic v1.0	5V
IoT module	ESP Lolin32	5V

2.3 Control System

The control system processes data from the ultrasonic sensors to make real-time decisions for movement and obstacle avoidance. When an obstacle is detected, the sensors send distance data to the Arduino UNO, which calculates the appropriate response based on the robot's position. For example, if an obstacle is ahead, the robot can quickly change direction to avoid a collision. This ensures smooth navigation in dynamic environments. The Arduino UNO communicates with the ESP32 module to transmit real-time data to a remote system, allowing users to monitor the robot, adjust tasks, and troubleshoot remotely, enhancing its reliability for indoor delivery.

3 IoT integration and Remote Control

The robot's IoT integration provides essential remote monitoring and control, ensuring efficient management of indoor delivery tasks. Using the ESP32 module, the systems enables real-time communication with operators, allowing them to check if the robot is online or offline and make necessary adjustments remotely.

3.1 IoT Architecture

The ESP32 module handles wireless communication, connecting the robot to a cloud platform for real-time control and monitoring. It provides basic online/offline status feedback, ensuring the system remains active and responsive to operator commands. This straightforward architecture allows for seamless integration with the IoT interface while minimizing potential connectivity issues. Its focus on reliability and ease of use makes it well-suited for indoor delivery applications, where consistent communication is critical.

3.2 Data Monitoring and Remote Operation

Operators manage the robot through a user-friendly HMI system built with Kodular IO, accessible on mobile devices. These interfaces allow remote monitoring and control, letting users start, stop, or adjust delivery tasks efficiently. The Kodular IO dashboard simplifies remote operation, making it easy to integrate into delivery workflows. Figure 3 shows the designed HMI system.

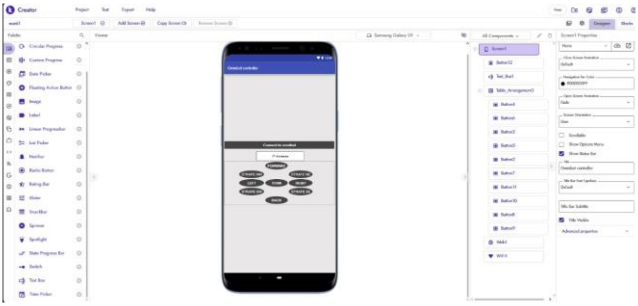


Fig. 3. HMI design using Kodular IO.

3.3 Autonomous Navigation and Obstacle Avoidance

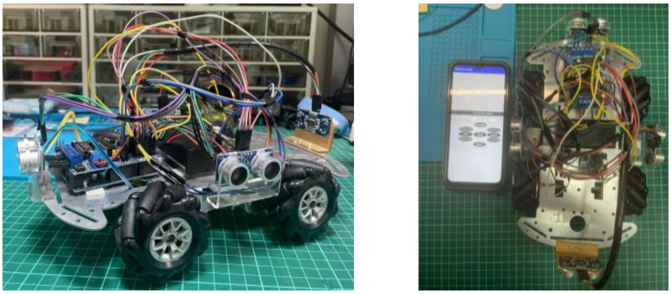
Autonomous navigation and obstacle avoidance are programmed in the Arduino IDE. Ultrasonic sensors provide real-time data to the Arduino UNO (see Figure 4), which processes it to detect obstacles and adjust the robot's path. While IoT connectivity enables remote monitoring, navigation is fully autonomous, ensuring smooth operation in complex environments.

Fig. 4. Arduino IDE program for autonomous navigation and obstacle avoidance.

4 Experimental and Performance Evaluation

4.1 System Implementation

The omni-directional robot was implemented in a controlled indoor environment to evaluate its maneuverability, obstacle detection, and IoT capabilities. The hardware, including the Arduino UNO, ESP32 module, ultrasonic sensors, and omni-directional wheels, was assembled and programmed according to the system architecture. The robot was tested in a simulated indoor urban area, where it autonomously navigated through narrow corridors and avoided dynamic obstacles, such as moving objects and people. The IoT connectivity was also tested by remotely controlling the robot and monitoring its status via the Kodular IO interface. The implemented overall system is shown in Figure 5.

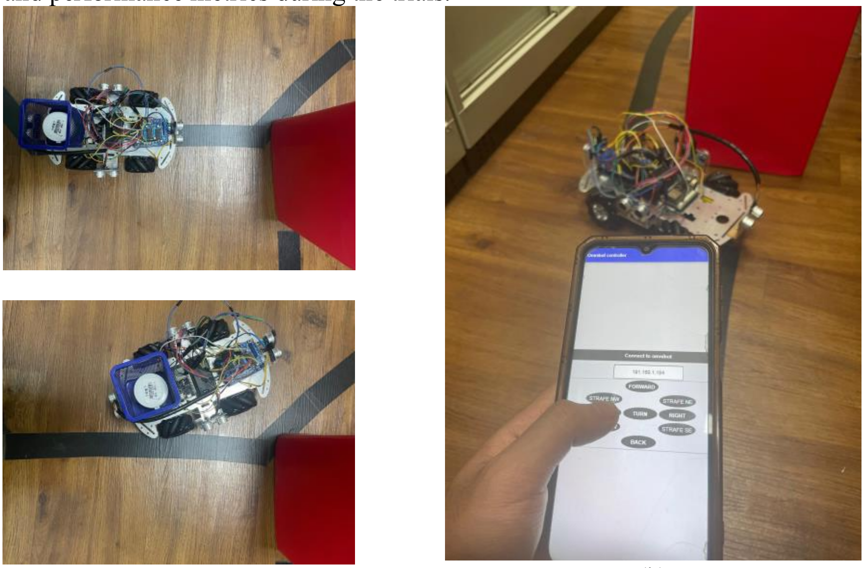


(a) (b)

Fig. 5. (a) Omni-directional robot implementation, (b) IoT connectivity with robot.

4.2 Experimental Results

The experimental results demonstrated the robot's ability to successfully navigate confined spaces and avoid obstacles with high accuracy. The ultrasonic sensors provided reliable 360-degree coverage, enabling the robot to detect and respond to obstacles in real-time. The IoT system functioned smoothly, allowing for efficient remote monitoring and control without significant delays. In repeated trials, the robot consistently completed the tasks within the expected route, demonstrating its effectiveness as an autonomous delivery solution for indoor environments. Figures 6 present the test setup and performance metrics during the trials.



(a) (b)

Fig. 6. (a) The robot automatically avoid obstacle, (b) The robot controlled remotely using IoT.

5 Conclusion

The design and implementation of the IoT-enabled omni-directional robot successfully addressed the challenges of confined spaces and dynamic obstacles often encountered in indoor urban environments. By integrating omni-directional wheels for enhanced mobility and ultrasonic sensors for real-time obstacle detection, the robot demonstrated smooth navigation and efficient task completion. The experimental results validated its capability to autonomously avoid obstacles and execute delivery tasks, proving its potential as a practical solution for automated indoor deliveries. Additionally, the integration of IoT through the ESP32 module allowed for seamless remote monitoring and control, further improving operational efficiency. Future work will focus on enhancing the system's autonomy by incorporating advanced sensors, such as LIDAR, for more precise navigation and obstacle detection. Improvements in power management and the use of machine learning for route optimization will also be explored to expand the robot's capabilities in more complex and larger environments, ensuring it can adapt to broader applications.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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