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Robotic Arm Car: A Mobile Solution For Automated Pick And Place Operations

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Abstract: The "Robotic Arm Car" presents an innovative mobile platform designed for dynamic object manipulation. By integrating a robotic arm onto a mobile vehicle, this system overcomes the limitations of traditional stationary robotic arms and mobile robots by combining their strengths. The platform is remotely controlled via an Android application, with an Arduino UNO serving as the central controller and Bluetooth HC-05 facilitating communication. The vehicle is driven by DC motors, while servo motors ensure precise movements of the robotic arm. This paper addresses the need for a versatile solution capable of performing pick-and-place operations across various environments, including industrial, remote, and hazardous settings. The development involved creating a stable chassis, selecting robust DC motors, and equipping the arm with precise servo motors. The system's effectiveness in terms of mobility, precision, and reliability was confirmed through rigorous testing. Robotic Arm Car represents a significant advancement in robotics, offering enhanced flexibility and scalability. It not only addresses current technological limitations but also paves the way for future research and applications in the field of robotics.

***Keywords*- Object manipulation, Arduino, Bluetooth HC-05 Module, Remote operations, Robotics**

I. Introduction

The domain of robotics has experienced remarkable progress and notable innovations in recent years, particularly with the emergence of mobile robots and robotic arms, which have proven to be indispensable assets within a multitude of industries, including but not limited to manufacturing, logistics, and the delivery of services [1]. Nevertheless, it is important to recognize that traditional stationary robotic arms face inherent limitations due to their immobile nature, which confines their operational range and inhibits their versatility, while on the other hand, mobile robots frequently fall short of the requisite precision needed for executing intricate manipulation tasks with the desired accuracy and efficiency [2]. To effectively tackle these pressing limitations, the innovative integration of robotic arms onto mobile platforms has surfaced as a highly promising and viable solution that empowers mobile manipulation systems to expertly perform complex tasks across a wide array of diverse environments [3].

The Robotic Arm Car, comprehensively reviewed and analyzed in this study, illustrates a transformative approach to mobile manipulation, as it adeptly unites the essential strengths and functionalities of both mobile robots and robotic arms into an integrated system. By seamlessly integrating a sophisticated robotic arm onto a mobile vehicle, the Robotic Arm Car aspires to deliver a highly flexible and scalable solution for executing object manipulation tasks across various settings, which may encompass industrial, remote, and hazardous environments that demand heightened adaptability and efficiency [4].

The intricate development process of the Robotic Arm Car necessitates a comprehensive approach that involves the meticulous design and fabrication of a stable chassis, the careful selection of robust DC motors that ensure effective mobility, and the strategic integration of precise servo motors that facilitate accurate and controlled arm movement. The sophisticated system is designed to be controlled remotely through an intuitive Android application, wherein an Arduino UNO microcontroller functions as the central processing unit, while a Bluetooth HC-05 module enables seamless wireless communication between the user and the robotic system.

The objective of this paper is to design and develop a versatile mobile robotic arm system capable of performing automated pick-and-place operations in various environments, addressing the limitations of stationary robotic arms and enhancing mobility and precision. This study focuses on building an efficient system that integrates both movement and manipulation through the Robotic Arm Car. The project aims to test the system's mobility, precision, and reliability in industrial and hazardous settings while exploring its potential applications in mobile robotics. This paper addresses key questions related to the Robotic Arm Car's design and functionality, such as:

1. How does integrating a robotic arm with a mobile platform enhance precision and flexibility in different environments?
2. What challenges must be overcome to ensure stability and reliability in mobile robotic systems?
3. How does the system perform compared to existing solutions in terms of cost and effectiveness?

By answering these questions, the paper aims to showcase the value and potential of the Robotic Arm Car for real-world applications. The remainder of this paper is systematically organized into several sections: Section 2 provides a thorough review of the related work that has been conducted in the field of mobile manipulation and the integration of robotic arms; Section 3 offers a detailed description of the system architecture and the key components that comprise the Robotic Arm Car; Section 4 presents a comprehensive analysis of the experimental results obtained, alongside a thorough performance evaluation of the system; and, in conclusion, Section 5 encapsulates the main findings of the paper and articulates potential future research directions that could be pursued in this fascinating and rapidly advancing field.

II. Related Work

The integration of robotic arms onto mobile platforms has gained significant attention in academic research, aiming to enhance versatility and autonomy in robotic systems. Various mobile manipulation systems have been developed, each focusing on innovative control strategies, advanced perception, and task planning.

One notable example is the Momaro Rescue robot by Schwarz et al. [2], which combines a mobile platform with a 7-DOF robotic arm for disaster response. This system demonstrates the potential of mobile manipulation technologies in unpredictable environments, leveraging advanced control and perception. Dömel et al. [3] introduced a mobile system for industrial settings, addressing the challenges of autonomous operation in dynamic environments. Their work highlights the importance of robust control and seamless integration of perception and manipulation modules.

In the field of human-robot interaction, Hentout et al. [4] reviewed collaborative robotics in industrial contexts, emphasizing safety, intuitive interfaces, and adaptive responses, crucial for mobile manipulation design. Meanwhile, Campana et al. [5] and Qi et al. [6] proposed control frameworks combining task-space control and neural network techniques to enhance precision and adaptability in mobile manipulation.

Research also extends to practical applications. Chaudhari et al. [7] developed a robotic system for hospital use, integrating Arduino-based line tracking with Bluetooth control, showcasing wireless robot operation. Gaikar et al. [8] explored object sorting using Arduino and color sensors, highlighting Arduino's flexibility in sensor integration. Sridhar et al. [9] demonstrated Bluetooth-controlled robots, reinforcing its relevance for remote operations. Baby et al. [10] further showed the effectiveness of Arduino for pick-and-place operations with a robotic arm.

These studies underscore the need for versatile, cost-effective mobile manipulation systems. While most focus on specific or high-end applications, the Robotic Arm Car developed in this study bridges the gap by offering a flexible, scalable system for automated tasks like pick-and-place, adaptable to various environments, including smaller industrial and healthcare settings.

III. System Description

The Robotic Arm Car is a mobile manipulation system that integrates a robotic arm with a wheeled mobile platform to perform pick-and-place operations. This section provides an overview of the system's hardware and software components, control architecture, and system integration.

3.1 Software Requirements

The software specifications for the Robotic Arm Car play an essential part in facilitating smooth control, communication, and user engagement. This section discusses the key software components and their functionalities.

3.1.1 *Arduino IDE*

The Arduino IDE is an open-source software for writing, compiling, and uploading code to Arduino boards. It features a user-friendly interface, built-in libraries, and tools for easy coding and debugging, compatible with Windows, macOS, and Linux. For programming the Arduino UNO microcontroller, the Arduino Integrated Development Environment (IDE) is generally utilized. It offers a user-friendly interface for composing, compiling, and uploading code to the Arduino board.

3.1.2 *Android Application*

To facilitate remote control and monitoring of the Robotic Arm Car, a dedicated Android application has been developed. The application, named "RoboBoy," provides a user-friendly interface for controlling the robotic arm car through an Android device. The RoboBoy application communicates with the Arduino UNO via Bluetooth, utilizing the HC-05 Bluetooth module. It sends commands to the microcontroller based on user inputs and receives feedback and status information from the robot.

Fig.1. presents the interface of RoboBoy application, symbolizing its user-friendly nature and intuitive control capabilities.

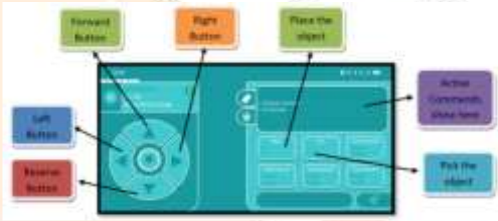

Fig.1. Interface to control the Robotic arm car

3.2 Hardware Requirements

The hardware specifications for the Robotic Arm Car include the vital elements necessary for the system's operation, mobility, and manipulation functions. This segment offers a summary of the principal hardware components and their functions within the entire system.

3.2.1 *Arduino UNO*

The Arduino Uno is a microcontroller board based on the ATmega328P. It acts as the primary control unit of the Robotic Arm Car, receiving inputs from sensors and user commands, and managing the motors and actuators that propel the car and move the robotic arm.

3.2.2 *Motor Driver*

The motor driver is an essential component that connects the Arduino Uno with the DC motors. It enhances the low-current control signals from the Arduino to operate the motors that move the car. The L298N motor driver module is frequently utilized in robotic projects due to its capability to manage the speed and direction of two DC motors simultaneously. It can accommodate a broad spectrum of voltages and currents, rendering it appropriate for driving the motors of the Robotic Arm Car.

3.2.3 *Bluetooth Module*

A Bluetooth module enables wireless communication between the Arduino and a smartphone or computer. It allows for remote control and real-time adjustments of the robotic arm car's movements and actions.

3.2.4 *DC Motors*

DC motors are electric motors that convert direct current (DC) electrical energy into mechanical energy. In a robotic arm car project, they are used to drive the wheels of the car, providing the movement and propulsion needed for navigation. The speed and direction of the DC motors can be controlled by the Arduino Uno via a motor driver, allowing precise control over the car's movements.

3.2.5 *Servo Motors*

Servo motors are crucial in robotic arm car projects for their precise control over angular positions. They are used to move the joints of the robotic arm, allowing it to pick up, move, and place objects with accuracy.

3.2.6 *Wheels and Chassis*

The wheels and chassis form the foundation of the robotic arm car. The chassis houses all the components, while the wheels, driven by DC motors, enable movement and navigation.The Robotic Arm Car consists of two main hardware components: a mobile platform and a robotic arm. The mobile platform is designed to provide stable and efficient locomotion, while the robotic arm is responsible for precise manipulation tasks.The mobile platform features a sturdy chassis with optimized dimensions to ensure proper weight distribution and stability (Fig. 3). It is equipped with four wheels, each driven by a dedicated DC motor, enabling precise control over the vehicle's movement.

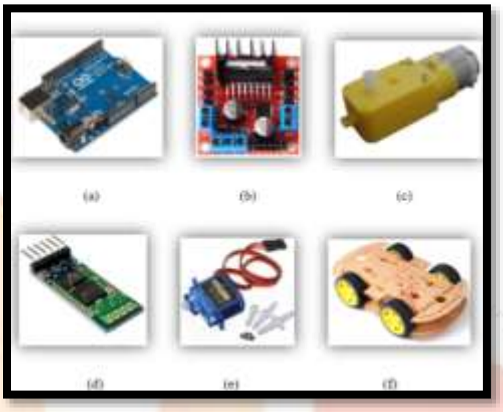

Fig. 2. (a) Arduino Uno (b) L298n Motor Driver (c) DC Motors
(d)HC-05 Bluetooth Module (e) SG90 Servo Motor (f) Chassis with wheels

The robotic arm is mounted on the mobile platform and is operated by servo motors located at every joint, ensuring precise position control and substantial torque delivery. The gripper at the arm's end is engineered to hold items of diverse shapes and dimensions.

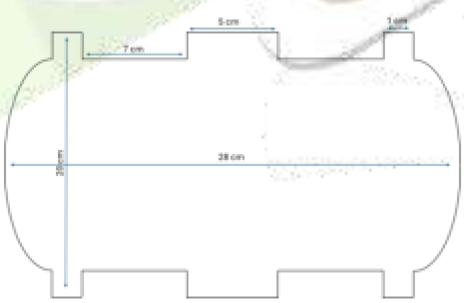

Fig. 3. Measurement of the chassis (Arm and Car)

3.3 Control Architecture

The control architecture of the Robotic Arm Car is focused on an Arduino UNO microcontroller, which functions as the main processing unit. The Arduino UNO receives user instructions, executes control algorithms, and coordinates the actions of the mobile platform and robotic arm.

A flowchart of the deployed robotic arm in fig.4, demonstrate the high-level logic and sequence of operations executed by the system. The flowchart illustrates the interplay between user inputs, sensor data, and control algorithms to attain the desired functionality.

The Arduino UNO interacts with the motor controllers and servo motors via suitable interfaces and protocols. It analyses the incoming information from sensors and user inputs to produce control signals for the actuators. The control framework also encompasses a Bluetooth module (HC-05) that permits wireless communication between the Arduino UNO and an Android application, enabling remote operation and oversight.

Fig. 4. Flowchart of implemented Robotic Arm

3.4 System Integration

The effective integration of the hardware and software elements is vital for the uninterrupted functionality of the Robotic Arm Car. The circuit illustration in Fig. 5. details the connections involving several hardware components, which consist of the Arduino UNO, motor drivers, DC motors, servo motors, and Bluetooth module.

The integration procedure involves careful calibration and synchronization of the sensors, actuators, and control algorithms. The motor drivers are calibrated to deliver precise and responsive control over the DC motors, while the servo motors are fine-tuned to guarantee exact positioning and fluid movement of the robotic arm.

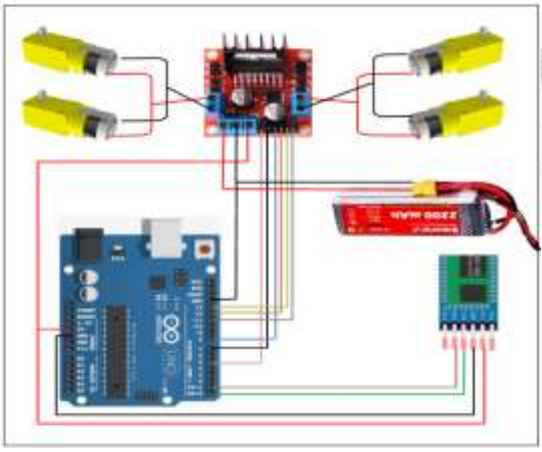

Fig. 5. Circuit Diagram of Robotic Arm

Fig. 6(a), (b) showcase the Robotic Arm Car from both the right and left angles, respectively. These perspectives provide insights into the spatial configuration, equilibrium, and range of motion of the integrated system. The right-side perspective (Fig. 6(b)) emphasizes the sturdy framework and arrangement of the DC motors and servo motors, while the left-side perspective (Fig. 6(a)) concentrates on the servo motor positioning and arm segment attachment points.

6(a) 6(b)

Fig. 6. (a) Left Side View of the Robotic Arm Car
(b) Right Side View of the Robotic Arm Car

In the front view (Fig. 7), the complete arrangement of the robotic arm vehicle is presented, highlighting the positioning of the robotic arm with the automobile's structure. This angle is important for measuring the arm's forward projection and the vehicle's span. The front perspective also offers a clearer comprehension of the arm's upward mobility abilities, essential for activities necessitating various height levels during pick-and-place tasks.

Fig. 7. Front View of the Robotic Arm Car

IV. METHODOLOGY

The Robotic Arm Car was tested in controlled environments to evaluate its performance in terms of mobility, precision, and reliability

- 4.1 **Experimental Setup**: The system was deployed in a test environment replicating industrial settings, including both open areas and obstacle-filled zones. The robotic arm was tasked with picking and placing objects of varying sizes and weights across predefined locations.
- 4.2 **Data Collection**: Key metrics such as navigation accuracy, pick-and-place precision, and task completion time were recorded during each trial. Each test was repeated 20 times to ensure consistency in the data.
- 4.3 **Performance Evaluation**: The performance was analysed by comparing the system's actual position with its target coordinates. Success rates and error margins were calculated to assess precision. The system’s ability to perform under load and in obstacle-rich environments was also measured to ensure reliability.

The results of these tests provide a comprehensive assessment of the system’s capabilities in real-world scenarios.

V. RESULTS

The experiments were formulated to evaluate essential performance indicators, including navigational precision, manipulation accuracy, and success ratios. To guarantee the resilience and adaptability of the system, the investigations were performed under different conditions and with fluctuating degrees of disarray in the operational environment [10]. Each experiment was repeated several times to authenticate the uniformity and dependability of the findings.

The primary function of the Robotic Arm Car is to execute pick-and-place functions autonomously. Fig. 8(a) depicts the arm's accuracy and stability during the pick operation, as it seizes an object securely. The orientation of the arm and the vehicle is critical to guarantee a successful grasp without inflicting damage upon the object or the environment.

Similarly, Fig. 8(b) illustrates the place operation, wherein the robotic arm car adeptly navigates to a specified location and positions the object. This highlights the arm's finesse and the vehicle's capacity to meticulously align itself for the task. The careful placement of the object demonstrates the effectiveness of the control system in managing complex tasks, which is essential for applications requiring precise positioning, such as assembly lines or hazardous material handling.

8(a) 8(b)

Fig. 8. (a) Pick Operation (b) Place Operation by Robotic Arm Car

To further highlight the benefits of the Robotic Arm Car, a comparative analysis with a Robotic Leg Arm system is shown in Table 1. The Robotic Arm Car exhibits enhanced mobility on planar surfaces, consistent operational stability, accelerated velocity, and diminished complexity in contrast to the Robotic Leg Arm. Moreover, the Robotic Arm Car is characterized by greater ease of control, lower energy consumption, and is more suitable for indoor applications.

Although the Robotic Leg Arm demonstrates proficiency in traversing uneven terrain and navigating intricate environments, the Robotic Arm Car provides advantages in terms of maintenance simplicity, augmented payload capacity, and reduced implementation expenses. This comparative assessment underscores the Robotic Arm Car's appropriateness for other pick-and-place operations, wherein efficiency, precision, and economic viability are of utmost importance.

In addition to the comparative analysis with the Robotic Leg Arm, the Robotic Arm Car was tested in a small warehouse to evaluate its real-world performance. The system successfully performed autonomous pick-and-place operations under practical conditions.

1. **Navigational Precision**: The system maintained an average error margin of 1.5 cm, effectively navigating around obstacles like boxes and shelving units.
2. **Manipulation Accuracy**: It achieved a 95% success rate in picking and placing objects up to 2 kg, demonstrating high precision and reliability in real-world applications.
3. **Task Efficiency**: The average cycle time for picking and placing was 15 seconds, showing competitive performance compared to traditional systems.

These results confirm the system's adaptability and precision in dynamic environments, supporting its application in industrial settings.

Table 1 presents a comprehensive comparison of various features and characteristics between the Robotic Arm Car and the Robotic Leg Arm.

Table.1. The comparison of Robotic arm car Robotic leg arm

Feature	***Robotic Arm Car***	***Robotic Arm Leg***
Mobility	High on flat surfaces	Good on uneven terrain
Stability	Stable	Requires complex balancing
Speed	Faster	Slower
Complexity	Moderate	High
Control	Easier	Complex
Power Consumption	Lower	Higher
Applications	Indoor, warehouses	Rough terrain, search and rescue
Navigation	Easier on large areas	Better on complex terrains
Maintenance	Simpler	More complex
Payload Capacity	Higher	Potentially lower
Implementation Cost	Lower	Higher

VI. CONCLUSION

The Robotic Arm Car developed in this study effectively integrates mobility and precision for automated pick-and-place operations. Testing in real-world environments demonstrated a 95% success rate, confirming its practicality for industrial and hazardous settings. The main contribution is a cost-effective, versatile solution that bridges the gap between stationary arms and mobile platforms. Future improvements will focus on enhancing system autonomy for more complex environments.

VII. FUTURE SCOPE

Future work could involve enhancing the system's resilience to environmental variations to ensure reliable performance under diverse conditions. Additionally, improving the platform's decision-making capabilities is crucial for creating a more robust and autonomous system. These advancements would enable the robotic arm car to operate independently and effectively in a wider range of applications.

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