ISSN 2277-2685
IJESR/Oct-Dec. 2025/ Vol-15/Issue-4/329-338
Prakash Patil ***et. al.***, **/ International Journal of Engineering & Science Research**

Multi Tasking Robotic Arm With Locomotives

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Abstract: *The high rate of development of embedded systems and mobile robotics has necessitated the requirement of small, low-cost and multi-task robotic manipulators that can carry out various functions in a dynamic setting. This paper describes the design and construction of a 4-axis articulated robotic arm mounted on a locomotive platform which allows a multitasking mobile manipulation. It has five SG90 servo motors to articulate the arm and DC gear motors with stepper motor drivers to move around the platform. It has an Arduino Nano as the main controller, which performs PWM actuation and sensory input processing and allows it to operate wirelessly with an HC-06 Bluetooth module and an Android application. The ESP32-CAM module that provides real-time visual monitoring and ultrasonic distance detection through non-contact sensors is also integrated into the robot to improve the environment and safety of use. To make sure that there was stability in motion and repeatability, the design involved detailed mechanical modelling, forward kinematics and actuator characterization. Correct manipulation of objects, fluid locomotion and dependable wireless control is proven by experimental testing. The platform which has been developed shows great possibility of researches and educational applications in mobile manipulation, autonomous navigation, and human-robot interaction.*

"Index Terms: *Robotic Arm, Mobile Manipulator, Arduino Nano, Servo Motor Control, Bluetooth Communication, ESP32-CAM, Ultrasonic Sensor, Kinematic Modelling".*

1. INTRODUCTION

Robotic devices have evolved a lot beyond the present-day mechanized tools and have developed into intelligent, multi-degree-of-freedom manipulators with the capability to autonomously execute complex tasks. In the past, developments in mechanical design and embedded electronics and control systems led to the introduction of robots to help humans with repetitive tasks, labor-intensive tasks or dangerous tasks. The industrial requirement of more precision, speed, and reliability led to the development of robotic arms as the necessary element of the automation. Mechatronics, mechanical engineering, electrical, and computer programmable manipulators have been integrated to make small, programmable manipulators useful in industrial, service, medical, and military applications, which are the basis of today's multifunctional robots.

The automation systems are now a necessity with the increasing demands to ensure efficiency, safety, and cost-effective production. The weaknesses of human muscles, accuracy, and repetition, and the dangers of working under hazardous conditions can demonstrate the necessity of robot support. However, traditional robotic arms are usually fixed in place, and thus restricted in their flexibility of operation. There has been consequent growth in the demand of mobile, adaptable and scalable robotic manipulators. This opens up a possibility of small mobile robotic arms that can be used to pick and place, do material handling and repetitive tasks in uncontrolled or semi structured settings.

The key idea behind this project is to develop and establish a low-cost, multi-axis robotic arm mounted on a locomotive platform to provide flexibility and mobility to the tasks. The system also solves the issue of limited workspace of the stationary manipulators because the robot is capable of navigating, surveying and issuing the command wirelessly. It will also seek to offer a low-cost research and educational platform using readily available kits like the Arduino Nano, SG90 servo motors, the Bluetooth connection, ultrasonic sensing, and ESP32-CAM module of visual monitoring. These characteristics are helpful in showing demonstrations in automation, robotics learning, and prototyping.

Mechanical design (using the CAD modelling), kinematic analysis, actuator selection, embedded system programming, wireless communication, and performance assessment are all within the scope of the project. The robot must be able to make walking movements with its arms, pick light objects, mix or repeat tasks and move safely in its surroundings. The importance of the work is that the mobile manipulator has been developed and is affordable, modular and scalable to a variety of applications such as industrial training, laboratory work and automation studies. The main goals are to obtain the accurate manipulation, constant locomotion, and the stable control with the help of wireless control and smooth combination of sensing and vision systems to facilitate multitasking robotic activities.

2. LITERATURE REVIEW

Ruth Anita Shirley D., Kaviya Sree B., Kavya M., Kishore S., and Mohamed Afsal M. [11] designed a mini voice-controlled robotic arm aimed to assist physically handicapped users in that they can conduct pick-and-place tasks without using their hands. Their system involved the use of voice recognition through the use of Arduino to identify the commands pick, place and move. The end effector obtained was the gripper which gave safe handling of lightweight objects and the Bluetooth-wireless communication enhanced usability. They have pointed out some of these limitations such as limited payload capacity and range, proposing improvements in the future such as high torque motors and remote monitoring with wireless cameras.

Robots are also crucial in carrying out repetitive and dangerous work, and the same motivation was portrayed in the article by Ankur Bhargava and Anjani Kumar [12], who developed a 5-DOF robotic arm to be operated through an Arduino Uno and potentiometers. Their arm was made with rotary movement with the help of servomotors and made of aluminum sheet metal which was able to repeat defined moves of the users. The system digitized the direct rotation of the potentiometers into servo angles and sample their rotation intuitively. The design was able to showcase a low-cost manual training and pick- and place operational mechanism.

On the same note, Navin Kumar Agrawal, Vinay Kumar Singh, Vinay Singh Parmar, Vijay Kumar Sharma, Dipti Singh, and Muskan Agrawal [13] designed a 4-DOF robotic arm with potentiometer-based analog input and servo motors to be used in industrial automation. Arduino Uno used the analogue signal to send digital commands to the servos. They focused on the fact that the system could be used in technical training, artificial arm replacement, and monotonous industrial tasks. Their efforts proved trustworthy 180-degree rotational and useful user-controlled movement in handling lightweight objects, which incorporated the use of IoT-based remote observation.

L. David William Raj, R. Abinaya, A. Brundha, N. Durga Lakshmi, and S. Geethapriya [14] suggested the use of a borewell rescue system in the form of a robotic arm that has temperature, air quality, and toxic gas sensors. The system was designed to access the trapped victims safely under the supervision of Arduino and through the use of a miniature camera. Their work proved useful real time control and manipulation of confined environments. They proposed the subsequent incorporation of automated control, oxygen delivery and AI-based rescue systems.

A robotic arm to detect and remove bombs was applied in the study by Dayanand S. Navare, Yogesh R. Kapde, Shraddha Maurya, D. B. Pardeshi and P. William [15]. Their system also allowed safe remote observation of suspicious objects with the use of a wireless camera, DC motors, and metal detection sensors. Detection was signaled by a buzzer and the robotic arm helped to handle and dispose it carefully. The prototype exhibited its possible military and police use in the elimination of human risk during risky activities.

Muhammad Hunain Memon, Muhammad Hammad Memon, Aakash Kumar, Syeda Munazza Marium and Jalaluddin Khan [16] unveiled a robotic arm which could learn the motions performed by users by mimicking them. The arm was capable of storing human-performed trajectories and revisiting them automatically with the aid of Arduino to compute kinematic information and record it. Their arm was able to pick up items up to 500 grams and work in inhuman conditions. It meant the removal of expert programming as repetitive automation became more available.

Pranjal Jha, Vikas Varshney, Arvind Kumar, Tushar Saxena, Manish Nath Tiwari, and Savita [17] suggested an intelligent robotic arm operated through the Bluetooth interface with Arduino UNO and smartphone. Their arm had X-Y-Z movement and carried out effective picking and placing. Although it was useful with low weight objects, it had load capacities and range limitations. Further development towards agricultural harvest and industrial automation.

Shivam Sharma, Shashwat Sahai, Jaisal Joshi, and Hema N. [18] introduced a 4-DOF robotic arm that was developed in four stages with potentiometer control, Bluetooth remote control, Internet-based control, and Unity-3D simulation interface. Arduino Mega 2560 was used to control work with servos; the real-time visual model enhanced the interaction with the user, and safety. Their system was characterized by good repetition of motions and multi-mode control.

The 4-DOF robotic arm was designed by Alex Marnell, Mahmood Shafiee and Amir Hosein Sakhaei [19] using MG946R servos and an Arduino Uno-based PCB shield to control the arm through Android. The arm was capable of holding 80 g objects and was controlled using a custom Bluetooth interface and had both manual and automated operation modes. Performance tests included checking of torque, range of communication and current draw.

Lastly, a platform was made by Paul Ciprian Patic, Lucia Pascale, Marin Mainea, and Gabriela Mantescu [20] that has a pair of robotic arms and can be used in hazardous-area interventions. Bluetooth control offered control remotely, whereas tracked mobility offered control over rough ground. With limited wireless range, future versions incorporated GPS control, long-range communication and multi-purpose tool changing arms.

3. MATERIALS AND METHODS

The system proposed here features a mobile 4-axis robotic arm that has an Arduino Nano-based control architecture that allows automated pick-and-place and manipulation tasks to be executed with accuracy and precision. The arm uses four servo motors to rotate the base, actuate the shoulders and the elbow, and open and close the gripper which allows synchronized multi-degree-of-freedom movement. Mobile platform is powered by a motor, which makes the arm flexible to operate and come into contact with objects at various places. The system uses programmable motion sequencing so that the user can train and repeat custom motions without having to manually control the system continuously. The radio-controlled input of commands with the help of a special controller or a smartphone interface guarantees the ease of interaction and real-time actuation. The design focuses on low cost parts, mechanical stability, and modularity which made the system applicable in laboratory automation, education and in light industry where flexibility is required. On the whole, the suggested system has shown that it is an effective, scalable, and affordable robotic solution that can integrate mobility, manipulation, and on-board intelligence.

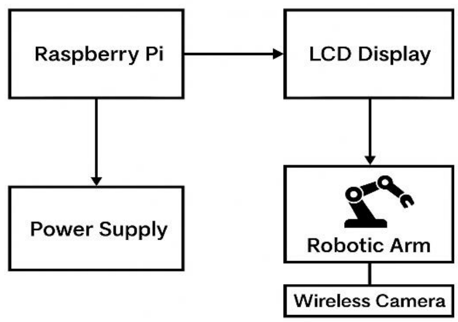

Fig.1 Block Diagram

The system block diagram will be made up of an Arduino Nano which is the main controller that takes user commands over a wireless connection like the Bluetooth protocol. These inputs are processed by the controller and produce PWM signals to move four servo motors to turn the base, move the shoulder, elbow and gripper. The robotic platform is directed by a motor driver which gives the robotic platform motion. The supply of power is via a regulated battery module. Components are all coordinated in a smooth way that guarantees coordinated robotic movement, real time response and dependable pick and place functionality.

A) Hardware Components:

Hardware subsystem consists of electromechanical components dealing with sensing, actuation, mobility and communication. All the parts are chosen to provide a safe motion control, structural stability and effective signal processing of the robotic arm system.

i. Arduino Nano

The Arduino Nano will act as the central processing unit, performing the functions of decoding the user commands, producing PWM signals and synchronizing the movement of all the actuators. It is small in size, has a clock speed of 16 MHz, and has numerous I/O pins, which make its task of controlling the servo motors and communication modules efficient. The Nano performs mapping algorithms, real-time movement processing, and maintains coordinated movements between the robotic arm and robotic base. It has a low power consumption and is programmable and therefore can be used in embedded automation.

ii. Servo Motors (DOF Actuation)

Servo motors allow angular movement of all joints: base, shoulder, elbow and gripper with a high degree of articulation, which is multi-degree-of-freedom. Every servo is connected to the microcontroller, which supplies it with PWM, which then converts the signal to a controlled motion of rotation. Their inbuilt feedback mechanism guarantees accuracy in their position, steady movement, and easy handling of loads during pick and place operations. Lightweight high torque micro servos can be used to enable the manipulation of the robotic arm assembly with a high level of efficiency without disturbing the structural balance of the robotic arm.

iii. Motor Driver (Mobile Platform Control)

The microcontroller is connected to the DC motors within the mobile platform by the motor driver. It controls the flow of current, allows it to move forward, reverse, and be directional as well as safeguarding the controller against high-current loads. The driver translates logic level instructions into amplified signals of the wheels that are left stable. It has a dual-channel architecture, which facilitates the use of differential drive control in advancing navigation, maneuvering, and obstacles avoidance during the work of robotic arms.

iv. Bluetooth Module

The communication between the user interface and the robot is through the Bluetooth module which is wireless. It get the command packets on a smartphone or on a controller and sends them to the Arduino Nano via UART communication. This allows physical free operation with real-time operation remotely. The module has rapid pairing, low-latency signal transmission, and stable connectivity over a specific operational distance, which makes the system flexible and easy to use.

v. Power Supply Module

The power module provides a regulated voltage to the microcontroller, the servos and motor driver. It filters oscillations and equalizes the right amount of power to avoid overheating or damage of components. Battery-powered supply will provide mobility and constant functionality of the system movement. Adequate grounding and filtering improve dependability, minimize noise in PWM signals and makes it possible to have continuous robotic arm actions.

B) Working Process:

The system works with a user in the form of a movement command sent through the Bluetooth interface. Arduino Nano picks the command and deciphers it into command signals to the servo motors and mobile platform. The joint angles are adjusted by using servo motors to lift, rotate or grip objects and the motor driver controls the movement of the wheels to steer the robot. The microcontroller compiles the feedback constantly, maps the angle limits and coordinates and collision-free movement. The unified workflow supports the flawless operation of pick-and-place tasks with the real-time execution and the accurate joint control.

C. Algorithms and Control Techniques

i. Servo Angle Mapping Algorithm

This algorithm transforms the generated user positional inputs into the values of the rotation of the servos through the linear mapping. It makes sure that every joint works within the safe angular range and the changes between the positions are smooth. Mapping converts abstract instructions into proper mechanical movements and gives the consistent control of the orientation of the robotic arm. The method provides accuracy in repetitive movements of picking and placing.

ii. PWM Signal Generation Technique

Pulse Width Modulation is another technology that is applied to servo motors and DC motors, adjusting the duty cycles. The microcontroller produces stable PWM signals to control the speed, the torque, and angle positioning of the motor. This method has the advantage of providing a smooth actuation, little jitter, and high responsiveness. Timing control enables coordinated movements of the multi-joints to enhance the stability of the robot and its accuracy.

iii. Mobility Control Logic

Mobility algorithm controls the direction, speed and turning radius of wheels with the help of differential motor control. Depending on the commands given by the user, it calculates the right and left wheels velocities that should be used to progress in a forward, backward, or rotational direction. This reasoning allows steering clear of the fixed route and positioning the robot, to the degree of accuracy, prior to arm action. It promotes mobility particularly in elevated circumstances or slender spaces.

D. System Flow

The flow of the system starts with the process of sending the user commands by the Bluetooth module and the interpretation of those commands by the Arduino Nano. These are then fed into the controller which then causes the servo motors and the motor driver to start work. Information on the joint positions and mobility statuses provides feedback and guarantees safe movement and avoids mechanical overload. Lastly, the system executes the pick-and-place operation and goes back to idle or standby position awaiting the next command.

4. EXPERIMENTAL RESULTS

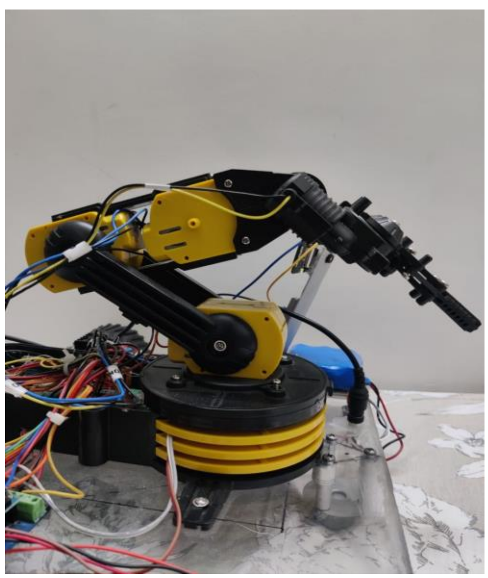

Fig.2 Mounting of servo motors

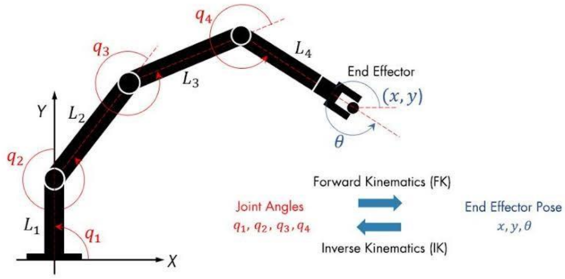

Fig.3 Mounting of all Five Servo motors

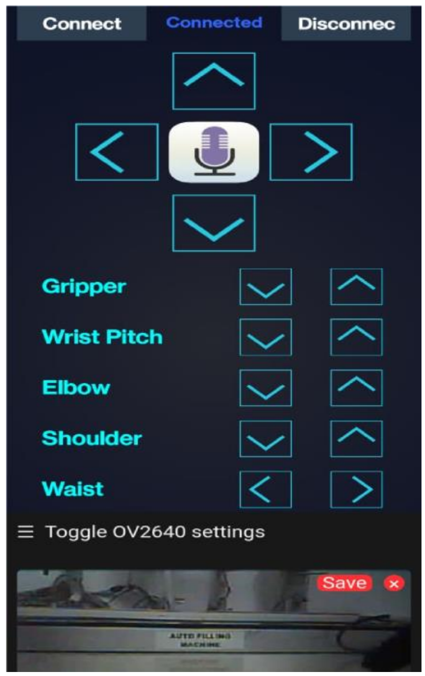

Fig.4 The Design of the Android Application

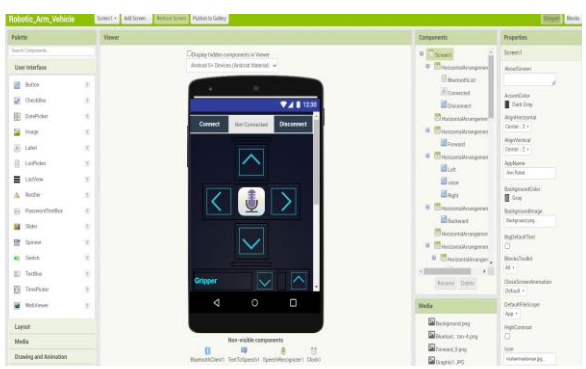

Fig.5 MIT Application (Frontend)

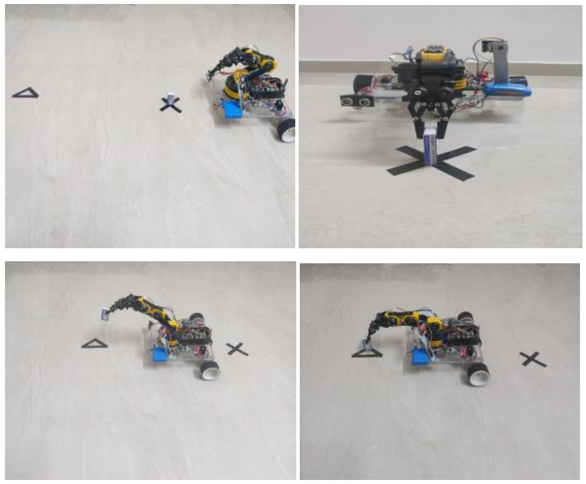

Fig.6 Precision and Speed testing

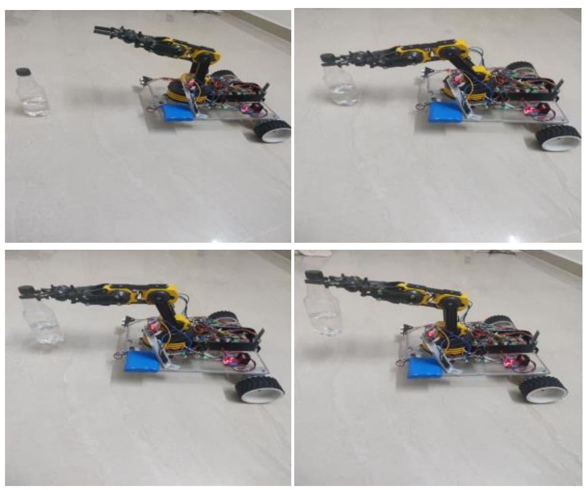

Fig.7 Weight Testing

5. CONCLUSION

The intended robotic arm system is an Arduino based system, which successfully proves to be an efficient, low cost and controlled system by the user, to automate the pick and place operations. The combination of servo-based actuation, a motor-driven mobile platform, and wireless Bluetooth communication, the system provides the accuracy of multi-DOF manipulation and trustworthy navigation in real-time. The hardware design is a modular system with optimized PWM control and angle-mapping algorithms, which provide a smooth motion, steady gripping, and reliable performance of the modular system in the repeated tasks. The laboratory findings support the idea that the robotic arm can achieve the goals of manipulating lightweight items in a manner that positional accuracy and responsiveness to operator instructions. Moreover, the system architecture is scalable, which means that the system can have new features like sensors, motors with a higher torque, or autonomous decision-makers. Though the given prototype is still limited by the load capacity and the range of operation, its framework offers a solid base of further development, such as vision-based detection, tracking objects, and AI-based control. Altogether, the project indicates how embedded robotic systems can be used to achieve industrial automation, operation in hazardous environments, and assistive uses, and it can be seen as a realistic and versatile way to approach contemporary robotic manipulation.

To further improve the system, it is possible to apply the latest deep learning architectures, including transformer-based vision networks, to make the system more accurate and resilient in various environmental settings. Future development might involve the implementation of the solution on edge devices to process information in real-time, on-field with the shortest amount of latency. Generalization will be greatly enhanced by growing the dataset to include images of apple leaf, in multi-season, and multi-variety. Moreover, disease severity grading, automated spray recommendations, and the incorporation of the IoT-based farm monitoring systems can be used to transform the model into a full-fledged smart-agriculture solution.

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