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Design and Fabrication of an Arduino-Based 5-DoF Robotic Arm for Pick-and-Place Applications

T. E. AMAKOROMO & O. E. OKOYE
Department of Physics/Electronics Technology,
University of Port Harcourt, Rivers State, Nigeria

ABSTRACT

The design, construction, control, and performance assessment of an Arduino-based, five-degree-of-freedom robotic arm intended for pick-and-place tasks are presented in this work. Using acrylic structural elements, six AD002 servo motors, an Arduino UNO R3 microcontroller, an Adept driver board, and Bluetooth-based control via an Android interface, the prototype was created as an inexpensive educational and testing platform. With consideration for payload capacity, structural stability, and convenience of use, the system was set up to offer synchronised motion at the base, shoulder, elbow, wrist, and gripper joints. Following assembly and calibration, three objects weighing 0.0245 kg, 0.0297 kg, and 0.0347 kg were used to test the robotic arm over a predetermined distance of 0.061 m. Higher payloads required more actuator effort and longer completion times, but the arm successfully finished all pick-and-place trials. The outcomes demonstrated that the system maintained adequate stability and repeatability during testing and operated dependably under modest loads. In addition to pointing up possibilities for future development in cargo handling, structural strengthening, and motion efficiency, the study shows that a basic microcontroller-based robotic arm can function as an efficient model for robotics education, embedded control, and small-scale automation.

Keywords: robotic arm, pick-and-place, Arduino UNO, servo motor, automation, 5-DoF, Bluetooth control

INTRODUCTION

Robotic arms are becoming more important in modern automation because they make processes that are repetitive, delicate, or physically demanding more precise, repeatable, and safe. Recent studies show that pick-and-place robots are still a major focus of research in manufacturing and automation since they are so important for moving materials, putting things together, and improving productivity (Rajesh *et al.*, 2024; Vagdevi & Harshitha, 2025). In 2026, people in the business talked about how artificial intelligence, advanced sensing, and autonomous control are all having an effect on robotics. This is making it possible for robotic systems to work in more settings (Burrus, 2026; ABI Research, 2025).

Intelligent production is growing; thus, robotic manipulators are now necessary for Industry 4.0 and the new Industry 5.0 procedures. In these settings, robots are used for more than just monotonous industrial tasks; they are used with data-driven control, sensing, and adaptive decision-making to boost productivity and consistency (Gökalp *et al.*, 2021; Aheleroff *et al.*, 2022). Manufacturers keep spending a lot of money on robotics because it can reduce the amount of labour that needs to be done by hand, improve quality control, and support flexible production systems, according to current research and industry publications (ABI Research, 2025; Burrus, 2026). This innovation has also helped make robotic prototypes that are cheaper and can be utilised for research and teaching.

Pick-and-place systems are a very useful way to use robots because they do normal industrial handling tasks in a small, easy-to-handle package. Recently conducted research on

Arduino-based robotic arms shows that people are still interested in low-cost embedded systems that can teach automation, mechatronics, and motion coordination (Lakshmi Vagdevi & Harshitha, 2025; Vinit *et al.*, 2025). These kinds of systems are especially helpful in places where advanced industrial robots are hard to get because of cost, technology, or lack of space. Because of this, a cheap robotic arm can be used as both a working prototype and a useful teaching tool for robots.

Even with these improvements, many of the robotic arm systems on the market are still too expensive or hard to use in teaching labs or for small-scale experiments. Because of this, we need a basic, low-cost, and dependable robotic arm that shows servo-based actuation, joint alignment, and pick-and-place control work. New research on Arduino-powered robot arms shows that microcontroller-based systems are still useful for making prototypes because they strike a good mix between usability and usefulness (Vagdevi & Harshitha, 2025; Vinit *et al.*, 2025). On the other hand, newer robotic research keeps focusing on pick-and-place uses with the main goals of better end-effector design, motion accuracy, and control reliability (Rajesh *et al.*, 2024; MIT News, 2024).

This research outlines the design, fabrication, and evaluation of a 5-degree-of-freedom robotic arm controlled by an Arduino UNO R3 and utilised through Bluetooth connectivity with an Android interface. The arm was made as a cheap teaching model for pick-and-place tasks, with a focus on choosing servos, building the structure, and doing basic functional tests. This work offers a realistic framework for understanding robotic motion control and demonstrates the deployment of cost-effective embedded systems to provide efficient automation tools for educational and prototypical purposes.

RELATED WORK

Recent study on robotic arms shows that there are continuous improvements in mechanical design, control of trajectories, sensing, and optimisation for specific applications. The primary driver behind robotic arm technological developments in 2024 and 2025, according to research published by Ranjan *et al.* and Fucile *et al.*, is the need for more precise grabbing, stronger structures, and task adaptability in both industrial and educational settings. Improvements in actuators, materials, and kinematic configurations have substantially increased the employment of robotic manipulators in the manufacturing, medical, and service sectors, according to analyses of robotic arm manufacture (Ranjan *et al.*, 2024).

Because it instantly simplifies material handling, packaging, sorting, and assembly, pick-and-place robots remain a highly active application domain. Modern robotic arm fabrication systems are designed with improved dexterity and smaller control structures to maximise handling performance in semi-structured environments, according to a review published in 2024 (Ranjan *et al.*, 2024). In addition, recent research on trajectory optimisation has shown that precise route planning and motion smoothness are key factors in reducing vibration and improving end-effector precision during manipulation tasks (Li *et al.*, 2025; Zhang *et al.*, 2025).

Affordable embedded robotic systems persist in garnering interest due to their provision of accessible platforms for experimentation and education. Arduino-based robotic arms are extensively utilised in prototype development owing to their simplicity, cost-effectiveness, and compatibility with servo motor control (Vagdevi & Harshitha, 2025; Mahajan *et al.*, 2025). Recent studies indicate that smartphone and Bluetooth-controlled robotic arms are increasingly recognised as adaptable alternatives to more intricate industrial interfaces, particularly in contexts requiring user-friendly operation for laboratory or instructional purposes (Mahajan *et al.*, 2025). These developments endorse the utilisation of Arduino UNO-based control in the creation of small-scale robotic arms.

Structural design constitutes a significant focus in contemporary robotic arm research. Finite element analysis and structural optimisation are progressively employed to enhance stiffness, diminish vibration, and augment load-bearing capacity in robotic manipulators (Fucile *et al.*, 2024; Ranjan *et al.*, 2024). The mechanical design of a robotic arm significantly influences precision, stability, and payload performance in pick-and-place tasks. For economical arms constructed from lightweight materials, appropriate structural selection is crucial to prevent excessive flexing and motion inaccuracies.

Control systems have advanced significantly, with recent research concentrating on intelligent trajectory control, sensor fusion, and adaptive motion planning. Research released in 2025 indicates that enhanced control techniques can improve gripping precision and reduce response time in robotic arm movements (Li *et al.*, 2025; Zhang *et al.*, 2025). Simultaneously, industry reports from 2026 indicate an increased integration of AI-driven perception and vision-guided picking systems, especially in warehouse and logistics settings characterised by significant object variability (Burrus, 2026; ABI Research, 2025). Despite being more sophisticated than the prototype examined in this study, these systems serve as a valuable baseline for the trajectory of future robotic arm advancement.

In contrast to these more sophisticated platforms, the current study emphasises a straightforward, yet effective 5-DoF robotic arm constructed from readily available components for pick-and-place operations. The incorporation of an Arduino UNO, servo motors, and Bluetooth control categories the system as a low-cost instructional manipulator, while the integration of physical manufacturing and testing imparts practical value to the effort. This study so advances the endeavour to create cost-effective robotic systems that exemplify fundamental automation concepts while ensuring accessibility for academic and instructional purposes.

MATERIALS AND METHODS

Materials

To make a low-cost prototype of the robotic arm, multiple turns of readily available, lightweight parts were used. The main materials were acrylic structural pieces, an Arduino-compatible Adeept robotic arm driver board, six AD002 servo motors, a servo extension cable, a square bearing turntable, a battery holder, and a variety of bolts, nuts, screws, and wiring accessories. During the assembly process, they also used a winding pipe, suction cups, cross screwdrivers, a cross-socket wrench, and other tools. When choosing these materials, the three most important factors were mechanical stability, affordability, and ease of assembly. The servo motor that moves the joints is shown in Figure 1.

Figure 1: Servo motor used for joint actuation (Vagdevi & Harshitha, 2025)

Design Considerations

Because it has five degrees of freedom, the robotic arm can pick up and move objects in a small space. The design prioritised function at the arm's main joints while keeping it simple, inexpensive, and useful for learning. It was important to consider factors such as ease of control, structural weight, actuator torque, range of motion, and payload capacity. We focused on making the arm as light as possible so that the servomotors wouldn't have to work as hard and the movement would be more responsive. This was because the arm was going to be used as a teaching tool.

Mechanical Structure

The arm had a base, shoulder, elbow, wrist, and gripper assembly. To make the human arm move in an angular way, rotary joints were used at the main points of articulation. The square bearing turntable was put at the bottom to allow for rotation and make the machine more stable while it was running. Acrylic was chosen for the structural frame because it is strong enough for a tiny prototype, easy to work with, and light. The gripper was the end effector, and it was made to pick up and put down little things. Figure 2 shows how the arm is put together mechanically. The square bearing turntable that is used to rotate the base is shown in Figure 3. Figure 4 displays the end effector of the gripper.

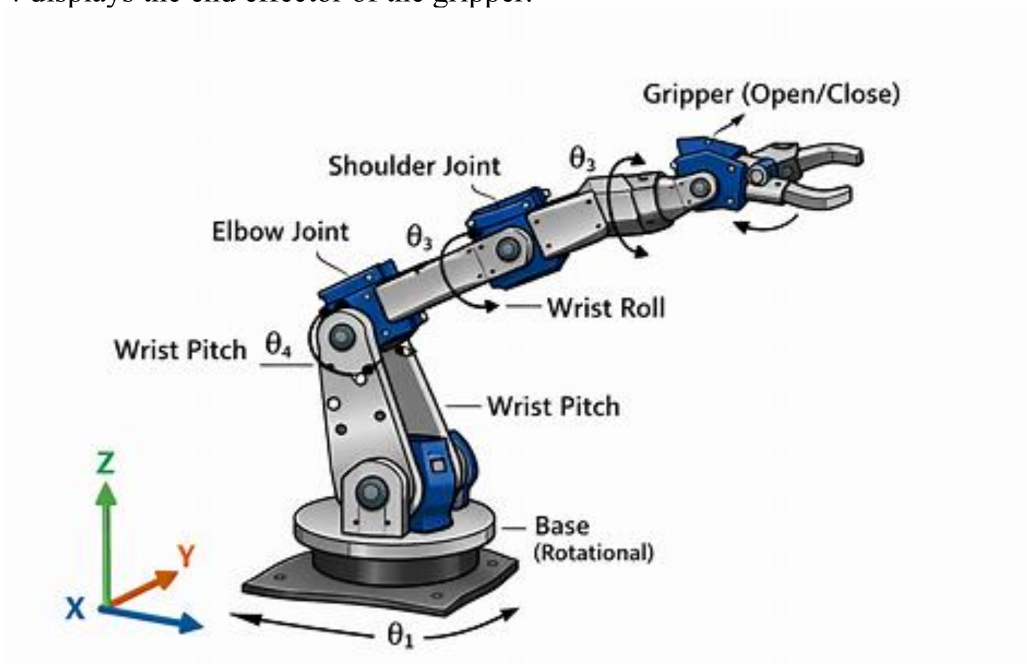

Figure 2: Mechanical layout of the robotic arm (Zhang *et al.*, 2025)

Figure 3: Square bearing turntable used for base rotation (Fucile *et al.*, 2024)

Figure 4: Gripper end-effector used for object handling (Fucile *et al.*, 2024)

Control System

The control system's main processing unit was an Arduino UNO R3 microcontroller made by Arduino. The servomotors' movements were controlled by this microprocessor. The servos were connected to the driver board, and the Arduino was used to send programmed signals that controlled the units. Bluetooth was used to allow the system to be controlled from a distance using an Android mobile. This made it easier to work with the system during the testing process. The driver board also had to handle power distribution and servo interface functions. Figure 5 shows how the whole system is put together. Figure 6 shows the electrical diagram for the robotic arm's control system.

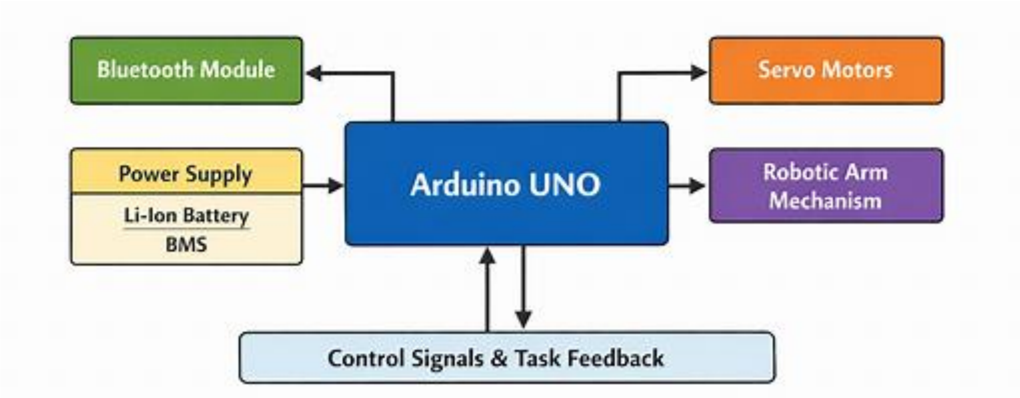

Figure 5: Block diagram of the Arduino-based 5-DoF robotic arm system

Fabrication Procedure

The process of fabricating the arm components commenced with their design and precise cutting to the appropriate dimensions and contours. The acrylic components were fabricated sequentially, commencing with the foundational structure and progressing to the shoulder, elbow, wrist, and gripper elements. They positioned the servo motors appropriately and utilised screws and standoffs to secure them. To ensure the turntable operated smoothly, a square bearing was installed at the base. Subsequent to assembling the mechanical components, the electronic elements were interconnected, and the control system was linked to the actuators. The completed prototype of the robotic arm is depicted in Figure 7.

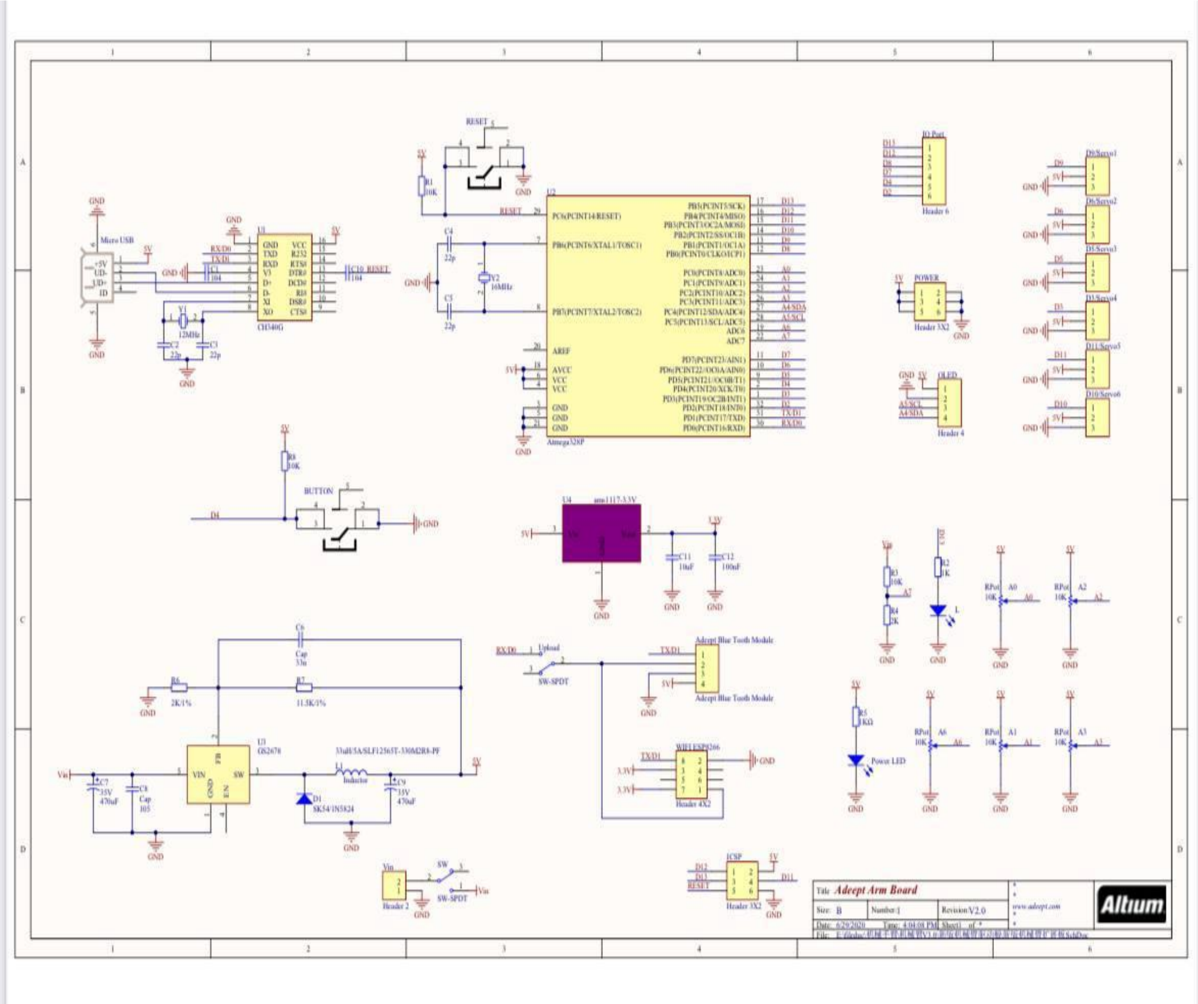

Figure 6: Electrical schematic of the robotic arm control system

Figure 7: Completed robotic arm prototype after assembly

Assembly and Wiring

The driver board that works with Arduino was connected to the servo motors using the correct connections and extension cords. Because they were close to the central control unit, the gripper servos needed longer wires. The battery holder provided power to the arm while it was moving, and the microcontroller, which had control input, sent signals to the servos. To make sure that the electrical contact was safe and the pins were connected correctly, a lot of care was taken. We also made sure that all the cables were in the right positions so that everything worked well when the joints moved.

Calibration and Testing

To make sure that the joints moved in sync after construction, the robotic arm was calibrated. Software changes and checking the positions of the servos by hand made sure that the motion was correct at each degree of freedom. After then, tests were done utilising objects of different weights in a series of pick-and-place trials. The arm was told to pick up things from one place and put them in a specific place. The performance was judged based on how well it could handle different loads, how stable it was, how quickly it responded, and how accurately it moved.

Data Collection

The mass of each test object, the distance traversed, the time taken, and the arm's movement behaviour were all recorded during the testing phase. These results were utilised to see how well the prototype worked under different loading conditions. The data collected formed a basis for assessing the arm's reliability in executing pick-and-place operations within its design limitations.

RESULTS

The constructed robotic arm was put together without a hitch and ran like clockwork when it came to pick-and-place operations. Each servo motor responded to the control signals after wiring and programming, enabling coordinated motion across all five degrees of freedom. The arm reliably and consistently transported things from their starting point to their intended destination. The prototype proved, all things considered, that a cheap robotic arm based on Arduino can successfully execute simple manipulation operations.

Three pick-and-place tests were done with objects of varied weights. The initial test went well, as an object weighing 0.0245 kg was lifted and moved. The arm also finished the job with an object that weighed 0.0297 kg in the second trial. The object mass was raised to 0.0347 kg for the third experiment, and the arm still did the job, but the servomotors had to work harder to move it. These tests proved that the arm could lift light loads within its range of motion.

The measurements acquired during testing are contained in Table 1. The robotic arm lifted all three objects a distance of 0.061 m. The duration escalated with the augmentation of the object's mass, indicating that greater weights necessitated additional exertion from the servomotors. The computed velocity diminished little with the augmentation of mass, whereas the projected acceleration likewise declined as the load intensified.

Table 1: Performance data for the pick-and-place trials of the fabricated robotic arm

Parameter	Object A	Object B	Object C
Mass (kg)	0.0245	0.0297	0.0347
Distance (m)	0.0610	0.0610	0.0610
Time (s)	20.0	25.0	31.0
Speed (m/s)	0.00305	0.00244	0.00197
Acceleration (m/s²)	0.000305	0.000195	0.000127

The results showed that the robotic arm moved faster and with less pressure on the servos when it was holding lighter things. When it was holding heavier objects, it moved more slowly and with more strain on the servos. The longer duration for the third trial showed that the payload influences how well a low-cost robotic system moves. The arm worked well during the test, and there were no serious mechanical problems during the trials.

In general, the test results showed that the system worked as it was supposed to by picking up and placing things. The made-up arm could dependably move things around the fixed workspace and show rudimentary control, positioning, and gripper action. The results also demonstrate that the arm is good for teaching and doing basic automation tasks, but the servo torque and light weight of the arm limit how much weight it can carry.

DISCUSSION

The results show that the built robotic arm could perform pick-and-place tasks satisfactorily with a low-cost Arduino-based control system. This shows that simple servo-driven manipulators can still work well for fundamental automation tasks, provided the mechanical structure, actuator choice, and control logic are compatible. Similar studies indicate that the performance of robotic arms improves when the design balances load capacity, joint stability, and control accuracy, particularly in compact prototype systems (Ranjan et al., 2024; Ogunbiyi et al., 2025).

The increase in completion time with greater object mass shows that the payload directly affects how efficiently the arm moves. This is typical of a light robotic arm, where the servomotors have to work harder as the load increases. Studies on optimising robotic arms have demonstrated that minimising vibration, enhancing stiffness, and choosing appropriate actuator configurations are crucial for sustaining accuracy under load (Alshihabi et al., 2025; Ranjan et al., 2024). The arm functioned effectively throughout all three trials in this study, indicating that the construction and servo configuration were sufficient for handling lightweight objects.

The arm's success shows that robotic systems that use microcontrollers can be useful for both making prototypes and educating. People appreciate systems that use the Arduino platform because they are cheap, easy to develop, and flexible enough for basic motion control and experimentation (Mahajan *et al.*, 2025; Pandit *et al.*, 2025). Bluetooth control made things a lot more handy by letting you operate them from a distance with an Android interface. This means that the system can be used to show students how automation, robotics, and embedded systems work.

Choosing lightweight acrylic reduced the stress on the servomotors as a whole and probably made the stability better during testing. But lightweight materials limit how much the arm can carry and may make it less durable when it is under more stress. Recent studies on robotic arms have underscored the importance of structural optimisation and modal analysis in improving reliability and reducing vibration, especially for arms expected to handle heavier loads or more complex tasks (Alshihabi *et al.*, 2025; Fucile *et al.*, 2024). As a result, future versions of the arm may benefit from better materials or stronger joints.

The results also demonstrate that the system works effectively for minor pick-and-place operations, but not yet for heavy industrial jobs. This prototype doesn't have the torque, accuracy, advanced sensing, or consistency that most industrial robotic arms need. But the current study does contribute a valuable and cheap model that explains how basic robotic handling works. It's useful since it's easy to use, available, and teaches people, especially in places where strong industrial robots aren't available.

In general, the results show that the prototype worked as it was supposed to within the limits of its design. The arm was able to pick and place things, respond to control inputs, and show significant differences in performance between different payloads. These results show that making low-cost robotic arms for teaching purposes is possible. They also set the stage for future advancements in structural design, control accuracy, and payload handling.

CONCLUSION

This work designed, developed, and tested a 5-DoF pick-and-place robotic arm. The prototype demonstrated that the amalgamation of the mechanical structure, servo selection, and control system enables a cost-effective microcontroller-based system to reliably manage simple objects.

The arm did pick-and-place tests with different weights and was able to move steadily. The results showed that the system works best with light loads because heavier things make the servomotor work harder and slow down the motion.

Additionally, the inquiry demonstrated that robotic arms that make use of Arduino software might still be useful for the production of prototypes and for learning. As a result of the utilisation of common components, such as servo motors, acrylic structural components, and Bluetooth control, it was both inexpensive and convenient to put together. A fundamental understanding of how robots operate and how to automate various processes was also imparted.

The prototype performed as expected; however, it is not very sturdy and cannot support a significant amount of weight due to the fact that it is relatively lightweight and the servomotors do not have a great deal of torque. In order to make things more accurate, stable, and capable of holding greater weight in the future, they might use materials that are more durable, motors that have a higher torque, joint designs that are more advanced, and control systems that are more technologically advanced.

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