Analysis of Lifting Load Current on Trainable Robot Arm Based on Arduino Mega 2560

Muhammad Erpandi Dalimunthe, Marshal Warisman Hutapea

Abstract

The rapid advancement of robotics has significantly influenced industrial automation, education, and research. Among the most studied systems is the robotic arm, which mimics human arm movements and can be programmed for repetitive and precision tasks. This study focuses on the analysis of lifting load current in a trainable robotic arm controlled by an Arduino Mega 2560 microcontroller. The main objective is to investigate the current consumption of servo motors under various load conditions, ranging from 50 g to 500 g, and to identify the optimal operating range. The methodology employed includes system design, hardware implementation, current measurement using sensors, and experimental validation under incremental load variations. Results indicate a linear correlation between the lifted load and current consumption, with 400 g identified as the maximum safe load at 0.72 A. Beyond this threshold, motor overheating and vibrations were observed. The findings contribute to the design of energy-efficient robotic arms, optimal actuator selection, and safe operational guidelines for educational and industrial applications.

***Keywords**:* Arduino Mega 2560, Trainable Robot, Load Current, Robotic Arm.

Muhammad Erpandi Dalimunthe
Department Teknik Elektro, Universitas Pembangunan Panca Budi, Indonesia
e-mail: erpandi@dosen.pancabudi.ac.id

Marshal Warisman Hutapea
e-mail: marshal.warisman31@gmail.com

Introduction

In general, robot technology consists of mechanical devices controlled by microcontrollers with embedded programs tailored to the desired functions of the robot application. On the other hand, smartphone technology is currently developing rapidly, incorporating computer-based technology and the ability to connect wirelessly to various other devices, enabling communication without the use of cables [12]. Robotics has emerged as a key enabling technology in the era of Industry 4.0 and beyond, playing a transformative role in manufacturing, logistics, healthcare, and education [1]. Robotic arms, in particular, have gained popularity due to their ability to replicate human arm movements with high precision and repeatability. These systems are extensively employed in assembly lines, pick-and-place operations, and training platforms for engineering students [2]. In low-cost and educational robotic applications, the Arduino platform is widely adopted due to its simplicity, affordability, and flexibility [3]. Arduino is an open-source physical computing platform, primarily known for its simple input-output board. The platform enables the development of interactive physical systems that can detect and respond to real-world situations and conditions using software and hardware [13]. The Arduino Mega 2560 microcontroller, with its 54 digital I/O pins, 16 analog inputs, and higher memory capacity, offers an efficient solution for controlling multiple servo motors in a robotic arm system. However, the performance of such robotic systems depends heavily on the actuators, specifically servo motors, which consume electrical current proportionally to the load they handle [4].

Excessive current draw in servo motors may result in increased heat, reduced efficiency, and premature component failure [5]. Therefore, analyzing the current consumption under various load conditions is critical to ensuring operational safety and energy efficiency. This study aims to evaluate the current drawn by servo motors in a trainable robotic arm when lifting different loads, thereby determining the optimal load capacity for reliable operation. The rest of this paper is structured as follows. Section II presents the literature review, highlighting prior work on robotic arm systems and motor load analysis. Section III describes the research methodology, including system design, hardware setup, and experimental procedures. Section IV discusses the experimental results and analysis. Section V concludes the study with key findings and suggestions for future research.

Literature Review

Numerous studies have investigated the design and implementation of robotic arms for both industrial and educational purposes. Smith and Brown [6] designed an Arduino-based robotic arm that demonstrated effectiveness as a low-cost platform for teaching automation and control concepts. Similarly, Kumar and Gupta [7] developed a trainable robotic arm capable of recording and replicating human movements, though the study did not provide a detailed analysis of motor current consumption. Current analysis of servo motors has been addressed in several works. Chen et al. [8] examined servo motor performance in industrial robotic systems and confirmed that current draw increases linearly with load torque. Hassan [9] highlighted the importance of selecting servo motors with sufficient torque ratings to prevent overheating and stall conditions in robotic applications. Recent advancements in robotic arm development also emphasize energy efficiency and sustainability. Yadav and Sharma [10] investigated the relationship between load variations and power consumption in robotic actuators, suggesting that efficient load-current modeling can reduce overall energy costs. However, limited studies specifically address low-cost trainable robotic arms for educational purposes with detailed current analysis. This research aims to fill this gap by providing empirical data and analysis on the relationship between load mass and servo motor current in an Arduino-based robotic arm system.

Research Methodology

The research methodology was structured systematically, as illustrated in Figure 1.

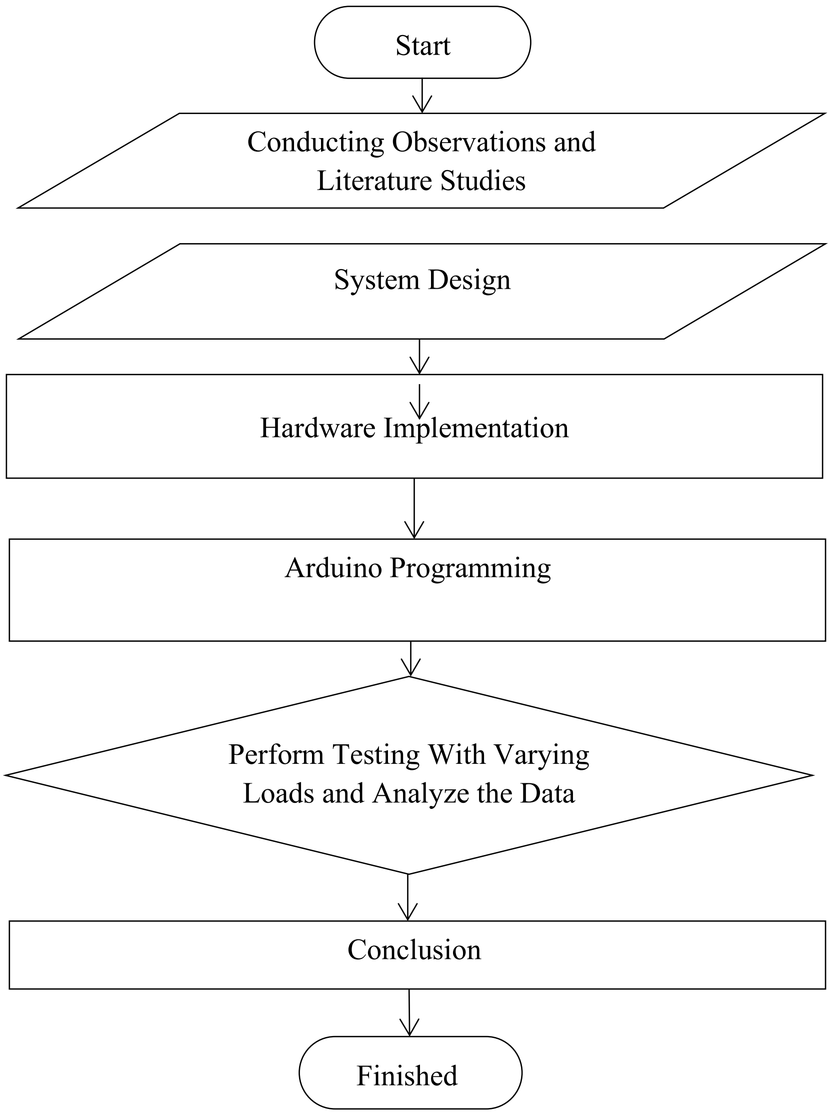

Figure 1. Flowchart Methodology

The methodology consists of the following stages:

1. **System Design**
   The robotic arm was designed with four degrees of freedom (DOF), each actuated by a servo motor. The control unit was based on the Arduino Mega 2560, chosen for its multiple I/O pins and memory capacity.
2. **Hardware Implementation**
   The robotic arm was constructed using lightweight materials, and servo motors were integrated into the joints. A current sensor (ACS712) and a digital multimeter were employed to measure current consumption during load lifting.

3. **Software Development**
   The Arduino IDE was used to program the robotic arm in a trainable mode. The system recorded manual movements and replicated them automatically during testing.
4. **Experimental Setup**
   Loads ranging from 50 g to 500 g were applied incrementally to the robotic arm gripper. For each load, current consumption was measured three times, and average values were recorded to minimize errors.
5. **Data Analysis**
   Measured current values were analyzed to determine the relationship between load mass and motor current consumption.

Results and Discussion

Figure 2. Condition of the Robot Arm after Assembly

Figure 2 shows the condition of the robot after assembly [11]. The results of this study focus on the analysis of the correlation between lifting load and current consumption in the trainable robot arm powered by DC motors and controlled via Arduino Mega 2560. The data presented in Table 1 summarizes the average current consumption for load variations from 50 g to 500 g, while Figure 3 illustrates the trend of this relationship graphically.

Table 1. Average Current Consumption vs. Load

Load (g)	Current (A)	Observation
50	0.22	Stable operation
100	0.30	Smooth lifting
200	0.45	Minor delay observed
300	0.58	Slight vibration
400	0.72	Noticeable heating
500	0.85	Overload tendency

As shown in Table 1, the average current consumption increases proportionally with the applied load. At a minimum load of 50 g, the motor current is 0.22 A, which represents the base operating condition required to overcome frictional and inertial forces of the mechanical structure. As the load gradually increases to 200 g, the current consumption rises moderately (0.45 A). This stage indicates that the motor is still operating within its linear response region, where torque demand and current draw are nearly proportional. However, from 300 g upwards, the current shows a sharper increase, reaching 0.58 A at 400 g and peaking at 0,85 A at 500 g. This nonlinear escalation reflects the motor approaching its saturation region. At this stage, the torque-to-current efficiency decreases, and additional load requires disproportionately higher current. The increase also indicates elevated stress on the motor winding and driver circuits, potentially causing heat buildup and reducing long-term reliability. Thus, the data suggests a clear operational threshold. For sustained operation, maintaining loads below 400 g would be advisable to avoid excessive current demand and ensure stable performance.

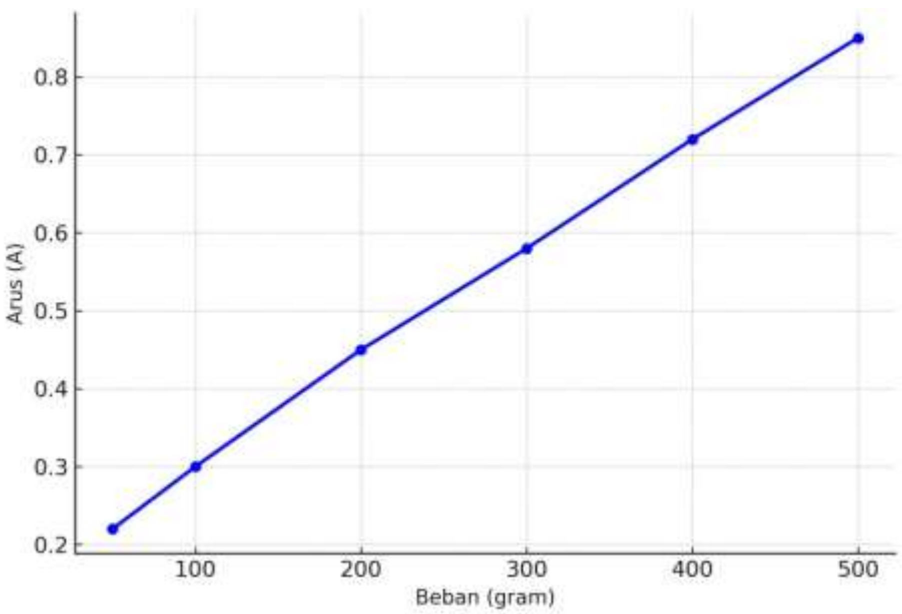

Figure 3. Relationship Between Load and Motor Current

The results indicate a clear linear trend between the lifted load and current consumption. Each additional 100 g increased the current draw by approximately 0.13 A. At 400 g, the servo motors exhibited heating but remained within acceptable limits. At 500 g, signs of overload, including excessive vibration and temperature rise, were evident. These findings validate previous works [8], [9] that established the proportional relationship between load torque and current. However, this study extends the analysis to low-cost educational robotic arms, highlighting the importance of defining operational limits to prevent damage.

Conclusion

This study successfully analyzed the lifting load current of a trainable robotic arm controlled by an Arduino Mega 2560. The results demonstrated a linear correlation between load mass and current consumption, with 400 g identified as the safe maximum load corresponding to a current of 0.72 A. Beyond this threshold, the system exhibited overload symptoms. The study contributes to the optimization of robotic arm design for educational and low-cost applications by providing practical guidelines for load limits and current management. Future research should investigate advanced control strategies, such as adaptive current control and predictive algorithms, to enhance efficiency and extend the operational range.

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