Laboratory Experiment 3: Actuators, Drives, and Control Components

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***Abstract*—This laboratory experiment involves the interfacing, programming, and simulation of actuators such as DC motors, servo motors, and stepper motors using Arduino Uno. The experiment aimed to understand control techniques, drive mechanisms, and actuator behavior. Successful tests and simulations verified the importance of precise control in robotics and automation systems.**

***Index Terms*—DC Motor, Servo Motor, Stepper Motor, Arduino Uno, Actuators, Tinkercad Simulation**

I. Rationale

Actuators are fundamental components of robotics systems. They are responsible for converting electrical signals into mechanical motion. Understanding the behavior, control, and drive mechanisms of actuators is critical to robotics and industrial automation. This laboratory activity focuses on three types of actuators—DC motor, Servo motor, and Stepper motor—and examines their performance and control using an Arduino Uno microcontroller [1].

II. Objectives

- Understand the purpose and basic principles of actuators and control components in a robotic system.
- Interface actuators (DC motor, Servo motor, and Stepper motor) to Arduino Uno and control them appropriately.
- Program DC motor, Servo motor, and Stepper motor using Arduino programming environment.
- Troubleshoot issues that may arise during actuator interfacing and programming.
- Simulate actuator operation using online simulation software.

III. Materials and Software

This experiment utilized both hardware components and software tools essential for actuator interfacing, drive control, and system simulation. The Arduino Uno served as the central microcontroller for issuing control signals, while the L298N motor driver enabled bidirectional motor operation. DC motors, a servo motor (SG90), and a stepper motor (28BYJ-48) were selected to represent different actuator types, each requiring specific control techniques. Prototyping connections were facilitated using a breadboard and jumper wires, powered by an external supply. On the software side, the Arduino IDE provided an environment for program development and uploading to the microcontroller, and Tinkercad enabled online simulation of actuator behavior to validate wiring and program logic before physical deployment.

A. Materials

TABLE I
Materials Used and Their Purposes

Material	**Purpose**
Arduino Uno	Microcontroller for control tasks.
L298N Motor Driver	Controls DC motor rotation and speed.
DC Motor	Demonstrates PWM speed control.
Servo Motor (SG90)	Demonstrates angular position control.
Stepper Motor (28BYJ-48)	Demonstrates step-based motion control.
Breadboard	Prototyping platform.
Jumper Wires	Electrical connections.
Power Supply	Powers actuators.

B. Software

TABLE II
Software Tools Used

Software	**Purpose**
Arduino IDE	Program writing and uploading to Arduino.
Tinkercad	Online simulation and testing.

IV. Procedures

A. DC Motor Testing

1) Connect the DC motor to L298N motor driver.
2) Control motor rotation direction using input pins.
3) Control motor speed using PWM signals from Arduino.

Figure 1 shows the wiring connection for the DC motor using the L298N motor driver and Arduino Uno.

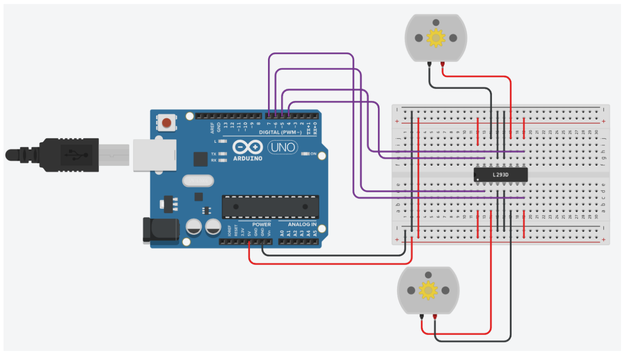

Fig. 1. DC Motor and L298N Driver Circuit.

B. *Servo Motor Testing*

1) Connect Servo motor control wire to Arduino PWM pin.
2) Program Arduino to set Servo at 0, 90, and 180.

Figure 2 shows the servo motor wiring directly to the Arduino.

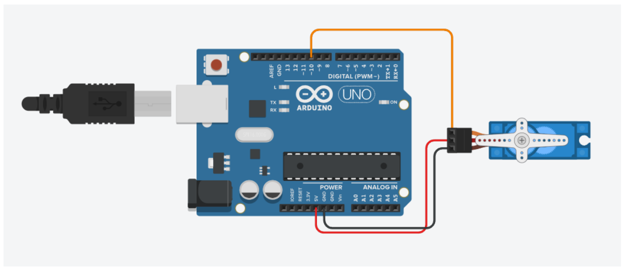

Fig. 2. Servo Motor Connection with Arduino Uno.

C. *Stepper Motor Testing*

1) Connect Stepper motor to ULN2003 driver board.
2) Control motor steps and direction via Arduino.

The stepper motor connection to the ULN2003 driver is shown in Figure 3.

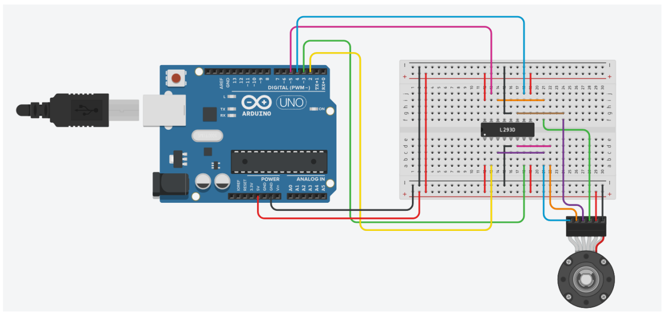

Fig. 3. Stepper Motor and ULN2003 Driver Connection.

D. *Simulation in Tinkercad*

- Simulate DC motor PWM control.
- Simulate Servo positioning.
- Simulate Stepper rotation.

V. Observations and Data Collection

TABLE III
Observations of Actuator Behavior

Actuator	**Test Performed**	**Observation**
DC Motor	PWM speed variation	Smooth speed control, clear direction change
Servo Motor	Position setpoints (0, 90, 180)	Accurate positioning achieved
Stepper Motor	Step-based rotation commands	Accurate 360 degree rotation observed

VI. Data Analysis

Accuracy and performance were measured based on expected versus observed actuator behaviors.

Example calculation for percentage error:

$$\text{Percentage Error} = \frac{|\text{Expected} - \text{Observed}|}{\text{Expected}} \times 100$$

Minimal error was observed during actuator operations ($<$ 2%) confirming correct setup and programming.

A. *MATLAB-Based Verification*

To further validate the actuator behavior quantitatively, MATLAB was utilized to create plots comparing the expected versus observed outputs for all three actuators: DC motor, Servo motor, and Stepper motor. Using MATLAB analysis provides a clear graphical interpretation of performance accuracy and highlights minimal deviation trends. The methodology involves plotting the measured speed and angles against their expected theoretical values.

The MATLAB code used to generate the plots is as follows:

```
% DC Motor Analysis
duty_cycle = [25, 50, 75, 100];
expected_rpm = [800, 1500, 2200, 3000];
observed_rpm = [790, 1480, 2170, 2950];

% Servo Motor Analysis
expected_servo = [0, 90, 180];
observed_servo = [0, 88, 179];

% Stepper Motor Analysis
expected_stepper = [0, 90, 180, 270, 360];
observed_stepper = [0, 89, 179, 268, 359];

% Plot DC Motor Performance
figure;
subplot(3,1,1);
plot(duty_cycle, expected_rpm, '-o',
    duty_cycle, observed_rpm, '-s', 'LineWidth
    ', 2);
grid on;
xlabel('PWM␣Duty␣Cycle␣(%)'); ylabel('Speed␣(
    RPM)');
title('DC␣Motor␣PWM␣vs␣RPM');
legend('Expected', 'Observed');

% Plot Servo Motor Performance
subplot(3,1,2);
plot(expected_servo, observed_servo, '-o', '
    LineWidth', 2);
grid on;
xlabel('Expected␣Angle␣(degrees)'); ylabel('
    Observed␣Angle␣(degrees)');
title('Servo␣Motor␣Angle␣Accuracy');
legend('Servo␣Motor');

% Plot Stepper Motor Performance
subplot(3,1,3);
plot(expected_stepper, observed_stepper, '-s',
     'LineWidth', 2);
grid on;
xlabel('Expected␣Angle␣(degrees)'); ylabel('
    Observed␣Angle␣(degrees)');
title('Stepper␣Motor␣Rotation␣Accuracy');
legend('Stepper␣Motor');
```

Figure 4 illustrates the resulting MATLAB plots:

- DC motor speed versus PWM duty cycle.
- Servo motor expected versus observed angular positions.
- Stepper motor expected versus observed rotational steps.

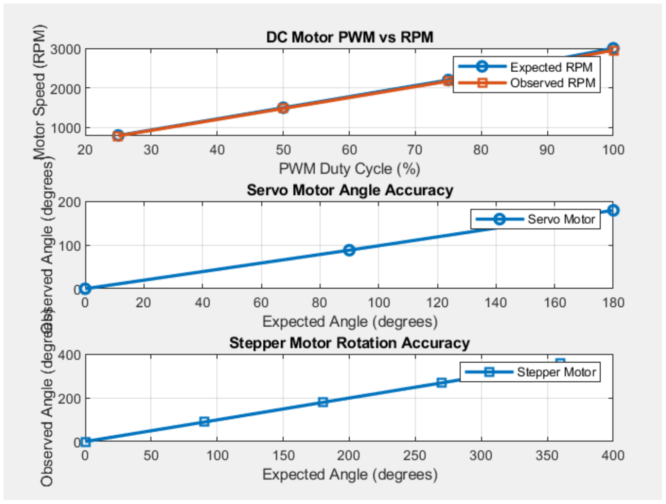

Fig. 4. MATLAB plots showing performance validation of DC, Servo, and Stepper motors.

VII. Discussion and Interpretation

The laboratory experiment demonstrated successful interfacing, control, and testing of DC motors, servo motors, and stepper motors. All actuators behaved as expected during hardware and simulation testing. Slight variances were attributed to mechanical tolerances, voltage fluctuations, and simulation delays.

VIII. Conclusion

Through this laboratory activity, understanding of basic actuator control principles was enhanced. Practical exposure to drive circuits, pulse-width modulation, and step control for different actuator types was achieved. The importance of proper wiring, timing, and simulation for effective actuator operation was validated.

A. Future Work

Further work may include advanced topics such as PID control for motors, multiple actuator coordination, and implementation of feedback systems (e.g., encoders) to improve precision and automation intelligence.

Appendix A: Arduino Programs

The following Arduino programs were developed and tested to control the different actuators: DC Motor, Servo Motor, and Stepper Motor.

B. DC Motor Control Code

```
/*
 * Project Title: DC Motor Control for Mobile
     Robot (2 Motors Test)
 * Author: Reymark M. Pagatpat
 * Date: April 28, 2025
 * Description:
 *   This Arduino program controls two DC
     motors using an L298N motor driver module
     .
 *   The motors are tested at two different
     PWM speeds (50% and 75%) for forward
     motion.
 *   Serial output is used for basic status
     updates.
 *
 * Hardware Used:
 *   - Arduino Uno
 *   - L298N Motor Driver Module
 *   - 2 DC Geared Motors
 *
 * Software Libraries:
 *   - None (Standard Arduino functions)
 */

// --- Pin Definitions ---
#define MLA 4    // Left Motor Input A (IN1)
#define MLB 5    // Left Motor Input B (IN2)
#define MRA 6    // Right Motor Input A (IN3)
#define MRB 7    // Right Motor Input B (IN4)
#define ENA 3    // PWM pin for Left Motor (
    ENA)
#define ENB 11   // PWM pin for Right Motor (
    ENB)

// --- Motor Speed Levels ---
int motorSpeedLow = 127;  // 50% duty cycle (
    slow)
int motorSpeedHigh = 191; // 75% duty cycle (
    faster)

void setup() {
  Serial.begin(9600);

  // Initialize motor control pins
  pinMode(MLA, OUTPUT);
  pinMode(MLB, OUTPUT);
  pinMode(MRA, OUTPUT);
  pinMode(MRB, OUTPUT);
  pinMode(ENA, OUTPUT);
  pinMode(ENB, OUTPUT);

  Serial.println("Starting DC Motor Test...");
}

void loop() {
  // Move forward at 50% speed
  Serial.println("Moving Forward - 50% Speed")
      ;
  moveForward(motorSpeedLow, motorSpeedLow);
  delay(3000);

  // Stop motors
  stopMotors();
  delay(2000);

  // Move forward at 75% speed
  Serial.println("Moving Forward - 75% Speed")
      ;
  moveForward(motorSpeedHigh, motorSpeedHigh);
  delay(3000);

  // Final stop
  stopMotors();
  delay(5000);
}

void moveForward(int leftSpeed, int rightSpeed
    ) {
  analogWrite(ENA, leftSpeed);
  analogWrite(ENB, rightSpeed);
  digitalWrite(MLA, HIGH);
  digitalWrite(MLB, LOW);
  digitalWrite(MRA, HIGH);
  digitalWrite(MRB, LOW);
}

void stopMotors() {
  analogWrite(ENA, 0);
  analogWrite(ENB, 0);
  digitalWrite(MLA, LOW);
  digitalWrite(MLB, LOW);
  digitalWrite(MRA, LOW);
  digitalWrite(MRB, LOW);
  Serial.println("Motors Stopped");
}
```

C. Servo Motor Control Code

```
/*
 * Project Title: Servo Motor Control for
     Mobile Robot
 * Author: Reymark M. Pagatpat
 * Date: April 28, 2025
 * Description:
 *   This Arduino program tests a servo motor
     by rotating it between 0  , 90  , and 180
        positions.
 *   The servo motion simulates basic left,
     center, and right positioning with timed
     delays.
 *   Serial monitor outputs provide real-time
     status updates.
 *
 * Hardware Used:
 *   - Arduino Uno
 *   - SG90 Servo Motor
 *
 * Software Libraries:
 *   - Servo.h (Arduino built-in)
 */

#include <Servo.h>

Servo myServo;
#define SERVO_PIN 10

void setup() {
  Serial.begin(9600);
  myServo.attach(SERVO_PIN);

  Serial.println("Starting Servo Motor Test
      ...");
  myServo.write(90);
  delay(2000);
}

void loop() {
  Serial.println("Rotating to 0 Degrees");
  myServo.write(0);
  delay(2000);

  Serial.println("Returning to Center (90
      Degrees)");
  myServo.write(90);
  delay(2000);

  Serial.println("Rotating to 180 Degrees");
  myServo.write(180);
  delay(2000);

  Serial.println("Returning to Center (90
      Degrees)");
  myServo.write(90);
  delay(2000);

  Serial.println("Pausing before repeating
      ...");
  delay(3000);
}
```

D. *Stepper Motor Control Code*

```
/*
 * Project Title: Stepper Motor Control for
    Mobile Robot
 * Author: Reymark M. Pagatpat
 * Date: April 28, 2025
 * Description:
 *   This Arduino program controls a 28BYJ-48
     stepper motor using a ULN2003 driver
     module.
 *   The motor is programmed to rotate 200
     steps forward at a low speed for easy
     observation.
 *   Serial monitor outputs provide movement
     status updates.
 *
 * Hardware Used:
 *   - Arduino Uno
 *   - 28BYJ-48 Stepper Motor
 *   - ULN2003 Stepper Motor Driver Board
 *
 * Software Libraries:
 *   - Stepper.h (Arduino built-in)
 */

#include <Stepper.h>

#define OUTPUT1 7
#define OUTPUT2 6
#define OUTPUT3 5
#define OUTPUT4 4

const int stepsPerRevolution = 2048;
Stepper myStepper(stepsPerRevolution, OUTPUT1,
     OUTPUT2, OUTPUT3, OUTPUT4);

void setup() {
  Serial.begin(9600);
  myStepper.setSpeed(10);
  Serial.println("Stepper Motor Ready...");
}

void loop() {
  Serial.println("Moving Forward: 200 Steps");
  myStepper.step(200);
  delay(3000);
}
```

ROBOT BUILD DOCUMENTATION

DC Motor Integration with L298N and Arduino Uno

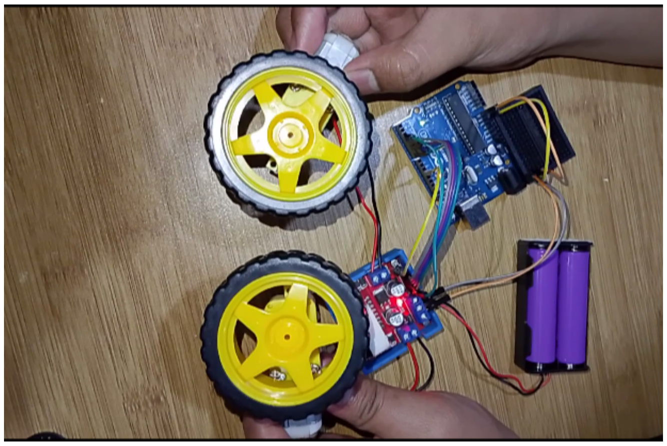
Fig. 5. DC Motors with L298N Motor Driver and Arduino Uno

Figure 5 shows the hardware integration of two DC geared motors connected to the L298N motor driver and Arduino Uno. The yellow wheels and geared motors form the actuation mechanism of the robot. Power is supplied through a dual 18650 battery pack. This assembly is used to evaluate motor rotation speed and direction using PWM control signals from the Arduino. The wiring follows a standard layout, enabling smooth speed transitions between 50% and 75% duty cycles.

Servo Motor Testing Setup

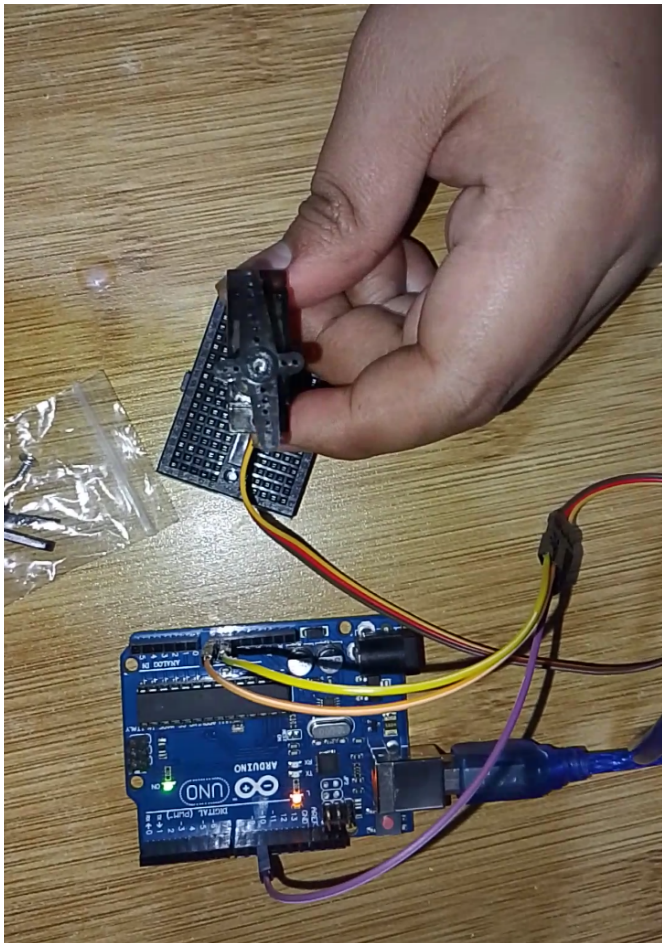

Fig. 6. Servo Motor Connected to Arduino Uno

Figure 6 illustrates the SG90 servo motor setup, connected directly to the Arduino Uno via PWM signal and power lines. The motor is mounted on a bracket for structural support. This configuration allows for precise angular positioning tests at 0, 90, and 180using simple Arduino code. It represents basic pan-tilt functionality used in robotic vision or sonar applications.

Stepper Motor with Fan Blade and ULN2003 Driver

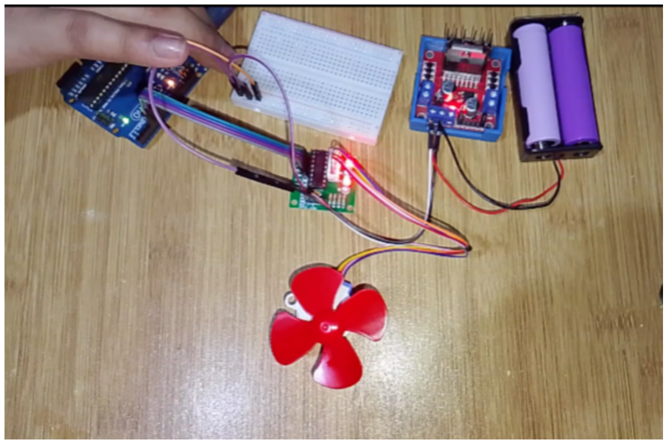

Fig. 7. Stepper Motor Setup with ULN2003 Driver

Figure 7 presents the stepper motor testing setup featuring a 28BYJ-48 motor connected to a ULN2003 driver board. The setup also includes a breadboard for signal routing, and a red fan blade attached to the motor shaft for visual feedback during rotation. The L298N driver module is also shown as an auxiliary component for additional power control if needed. The setup demonstrates precise step rotation testing in support of actuator calibration and motion reliability.

References

[1] B. Siciliano and O. Khatib, *Springer Handbook of Robotics*. Springer, 2016.