SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS

COLLEGE OF ENGINEERING

BELLS UNIVERSITY OF TECHNOLOGY-NEW HORIZON

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COURSE TITLE: ROBOTICS AND EMBEDDED SYSTEMS

COURSE CODE: ICT 216

SUBMITTED TO MR. AYUBA MUHAMMAD

DECLARATION

We confirm this project is our original work, built on what we've learned and researched during our second year. Everything in this report comes from our own study of "SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS We haven't submitted this report to any other school or institution. This project is part of our bachelor's degree in Mechatronics Engineering.

Name: …..

Signature: ....

Date: ………..

APPROVAL

I’ve read and recommend this second-year project, “SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS for acceptance by Bells University of Technology. It meets the requirements for the Bachelor’s degree in Mechatronics Engineering.

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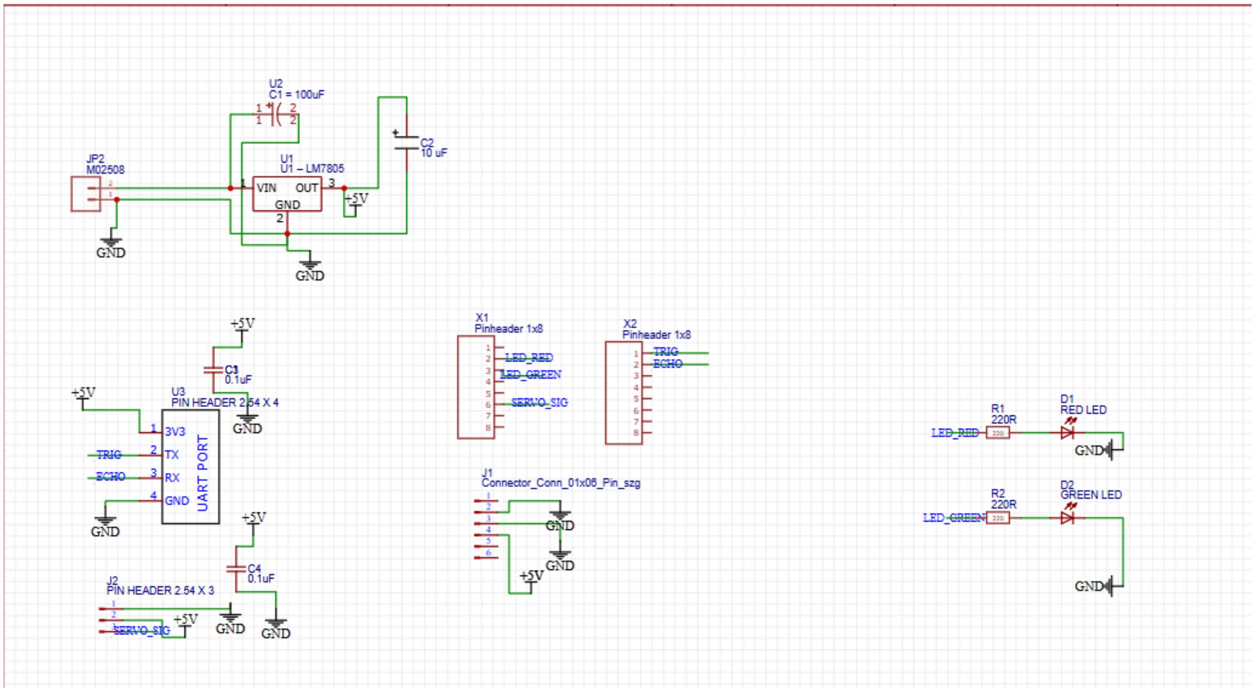
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C2
10 uF
JP2
M02508
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U1 – LM7805
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GND
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GND
U3
PIN HEADER 2.54 X 4
3V3
TX
RX
GND
UART PORT
TRIG
ECHO
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C4
0.1uF
J2
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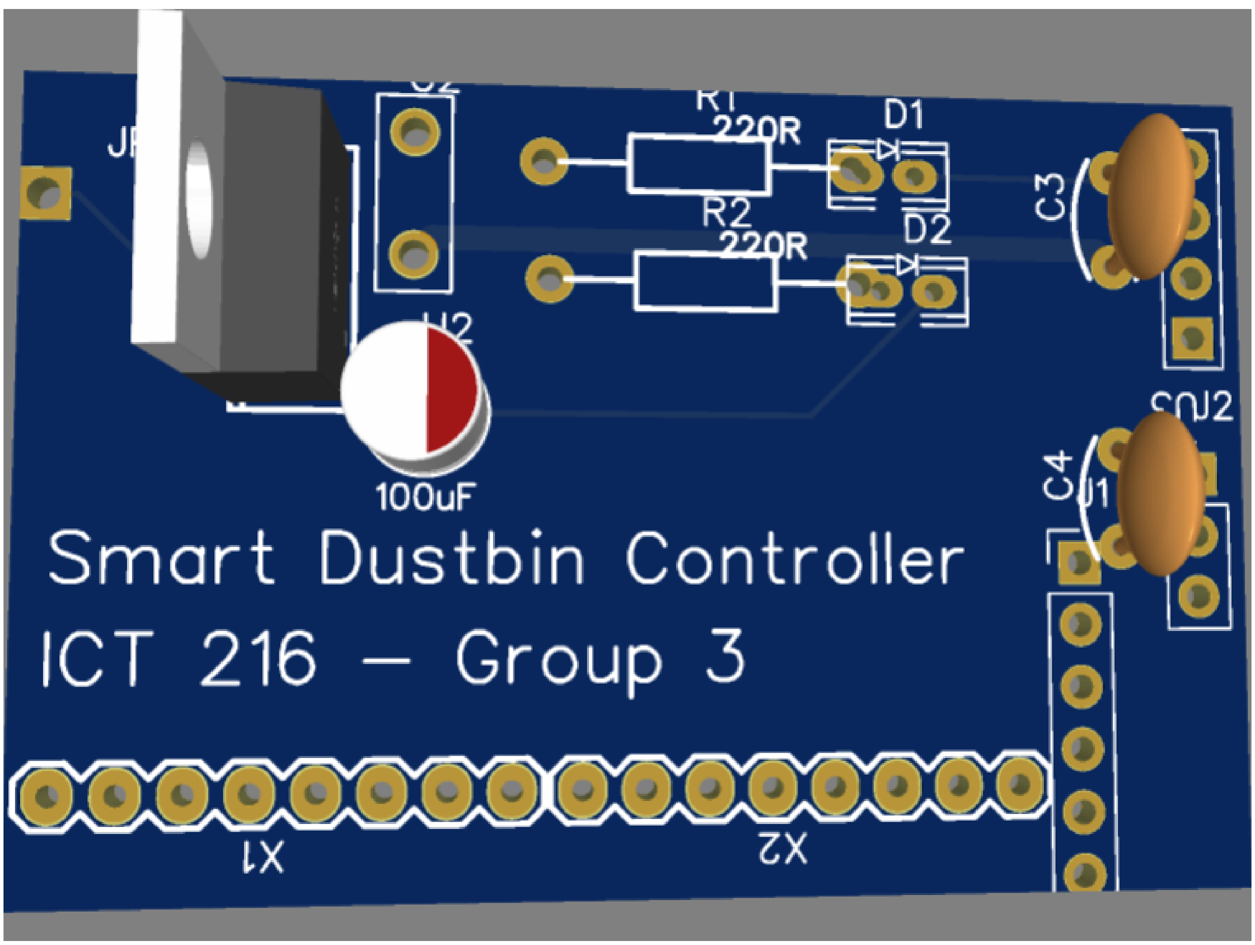
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ICT 216 – Group 3
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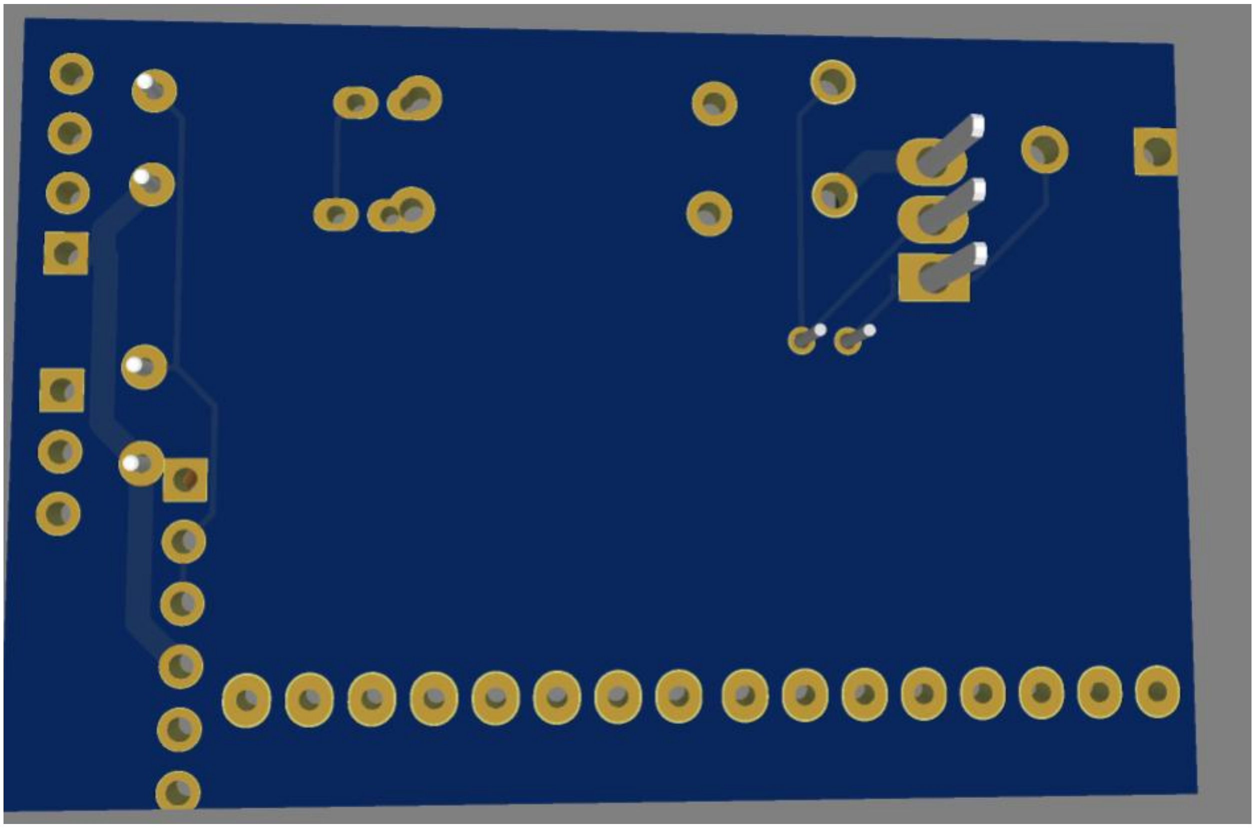

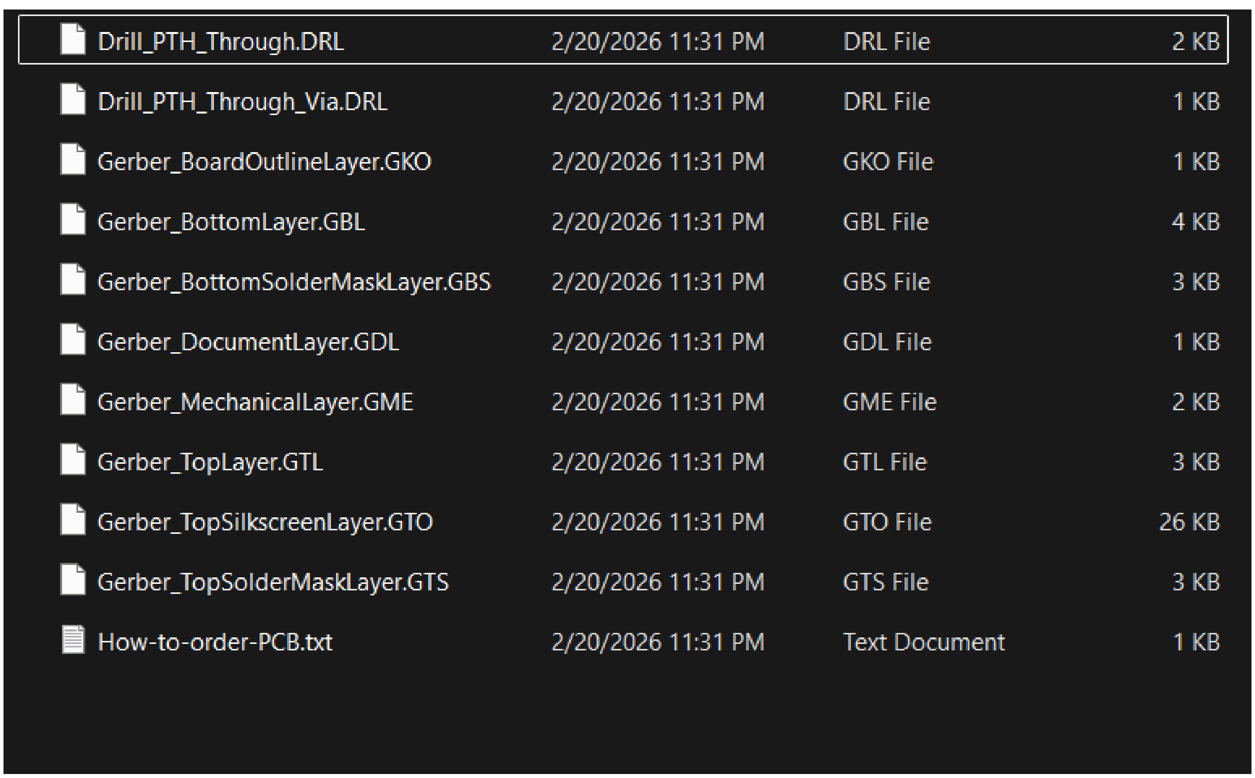

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CHAPTER 1: INTRODUCTION

1.1 Background of the Study

In the contemporary landscape of urban hygiene and sanitation, the automation of everyday appliances has become a pivotal element of the "Smart City" and "Smart Home" paradigms. Waste management, a critical component of public health, has traditionally relied on manual interactions, specifically, the physical opening of dustbin lids via hand or foot pedals. While functional, these traditional methods present significant hygiene risks, particularly in the post-pandemic era where surface-to-human transmission of pathogens is a primary concern. The integration of robotics and embedded systems offers a viable solution to this challenge. By embedding intelligence into waste receptacles, we can eliminate physical contact, thereby breaking the chain of infection. This project explores the intersection of analog electronics, digital logic, and mechanical actuation to create a "Smart Dustbin" that autonomously responds to human presence.

1.2 Problem Statement

The conventional waste disposal bin poses two primary problems: hygiene and accessibility.

1. **Hygiene:** Manual bins require physical touch, which turns the bin lid into a fomite (a surface capable of carrying infectious agents). In high-traffic areas such as hospitals, cafeterias, or restrooms, a single contaminated lid can spread bacteria to distinct users.
2. **Accessibility:** Pedal-operated bins, while touch-free for hands, require physical balance and foot coordination. This design is often exclusionary for the elderly, people with disabilities, or individuals using crutches or wheelchairs.

There is a distinct lack of low-cost, locally validatable solutions that solve these problems using robust embedded system principles. Furthermore, many existing hobbyist solutions lack rigorous analog power filtering, leading to unreliable operation and servo jitter. This project seeks to address these gaps.

1.3 Objectives

General Objective:

To design, simulate, prototype, and implement a functional robotic waste management system integrating analog circuits, sensors, actuators, and microcontroller programming, satisfying the core requirements of ICT 216.

Specific Objectives:

1. **Simulation:** To design and simulate the complete logic and wiring of the system using **Proteus** (for analog/digital verification) and **Tinkercad** (for 3D visualization and code testing).
2. **Analog Design:** To develop a robust analog power supply circuit using an **LM7805 voltage regulator** and specific capacitor filtration (100μF and 10μF) to ensure signal conditioning and noise suppression for the servo motor.
3. **Code Optimization:** To write, debug, and optimize C++ microcontroller code for the Arduino Uno to handle real-time distance calculation and servo actuation without blocking delays.
4. **PCB Design:** To design a **Professional PCB (Printed Circuit Board) layout** using **EasyEDA**, incorporating proper ground planes and track widths to replace fragile breadboard connections.
5. **Prototyping:** To build and test a physical prototype that successfully detects objects within a 20cm range and actuates the lid.
6. **Documentation:** To document the entire engineering process and publish the source code and design files to a public **GitHub repository**.

1.4 Research Questions

1. How can ultrasonic sound waves be utilized to accurately measure proximity in a waste management context?
2. What is the impact of analog signal conditioning (specifically capacitor decoupling) on the stability of a servo motor in a microcontroller circuit?
3. How does the transition from a breadboard prototype to a custom PCB affect the mechanical reliability and electrical noise performance of the robot?

1.5 Significance of the Study

This study bridges the gap between theoretical electronics and practical robotics application. It demonstrates how "noisy" electromechanical components (motors) can coexist with sensitive digital sensors through proper analog circuit design. The resulting system has immediate applications in hospitals, smart homes, and offices, reducing the transmission vectors for communicable diseases.

1.6 Scope and Limitations

- **Scope:** The project is limited to a single robotic bin unit powered by a 9V DC source, utilizing an Arduino Uno as the central processor.
- **Limitations:** The HC-SR04 ultrasonic sensor may produce erratic readings when facing sound-absorbing materials (like wool or foam). The system's power efficiency is limited by the linear regulation of the LM7805, which dissipates excess voltage as heat.

1.7 Organization of the Study

This report adheres to the strict structure mandated by the course. Chapter 2 reviews the literature. Chapter 3 details the methodology, including the critical analog design and PCB work. Chapter 4 presents the results from Proteus, Tinkercad, and the physical build. Chapter 5 concludes the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a theoretical framework for the project, analyzing the components and engineering principles used in modern robotics and automation.

2.2 Review of Existing Similar Robots

Automated bins have evolved from simple pedal mechanisms to complex sensor-based systems.

- **IR-Based Systems:** Early iterations used Infrared (IR) proximity sensors. However, research indicates IR sensors fail in direct sunlight due to ambient light interference.
- **Ultrasonic Systems:** The HC-SR04 sensor, used in this project, operates on SONAR (Sound Navigation and Ranging) principles. It is immune to light interference, making it superior for diverse lighting environments.
- **Microwave/Radar:** Industrial solutions often use radar, but these are cost-prohibitive for domestic applications. This project validates the Ultrasonic approach as the optimal balance of cost and reliability.

2.3 Analog Circuit Techniques in Robotics

A critical, often overlooked aspect of student robotics is **Power Integrity**. Motors are inductive loads; when they start or stop, they create voltage spikes (back-EMF) and drops (sags).

- **Voltage Regulation:** The **LM7805** is a linear regulator widely cited in literature for stepping down 9V/12V DC to a stable 5V logic level.
- **Decoupling Capacitors:** Standard engineering practice requires "reservoir" capacitors. A large capacitor (e.g., **100μF**) on the input acts as a buffer for low-frequency surges, while a smaller capacitor (e.g., **10μF** or 0.1μF) on the output filters high-frequency noise. Without these, the microcontroller often resets randomly, a phenomenon known as "Brown-out."

2.4 Microcontroller Selection and Justification

The **Arduino Uno (ATmega328P)** was selected for this project.

- **Justification:** It operates at 5V (compatible with the servo and sensor), provides 6 PWM (Pulse Width Modulation) pins necessary for servo control, and allows for easy In-System Programming (ISP) via USB.
- **Comparison:** Unlike the ESP32 (3.3V logic), the Arduino Uno does not require logic level shifters for the 5V HC-SR04 sensor, simplifying the analog circuit design.

2.5 Use of Proteus and Tinkercad in Industry/Education

Simulation is a non-negotiable step in professional engineering.

- **Tinkercad:** Provides a "Digital Twin" visualization, allowing for the verification of pin mapping and physical wiring logic before hardware purchase.
- **Proteus VSM:** Offers SPICE-level simulation. It allows the verification of the analog power stage and the execution of the actual HEX machine code, bridging the gap between coding and hardware behavior.

2.6 PCB Design Trends in Robotics

The transition from breadboard (prototyping) to PCB (Printed Circuit Board) is the mark of a finished product. PCBs reduce **parasitic capacitance** and resistance found in jumper wires. Modern tools like **EasyEDA** have democratized this process, allowing for cloud-based design and integration with fabrication houses like JLCPCB.

2.7 Research Gap Identification

While many tutorials exist for connecting an Arduino to a servo, few academic reports rigorously document the **Analog Power Supply** stage or the **PCB design** workflow. Most rely on the Arduino's onboard regulator, which is insufficient for driving motors. This project fills that gap by engineering a dedicated power stage.

CHAPTER 3: METHODOLOGY

3.1 System Block Diagram

The system architecture is linear and consists of four main blocks:

1. **Power Block:** 9V Battery to LM7805 Regulator (+ Capacitors) to 5V Bus.
2. **Input Block:** HC-SR04 Ultrasonic Sensor to Arduino (Pins 9/10).
3. **Control Block:** Arduino Uno (PID Algorithm/Logic).
4. **Output Block:** SG90 Servo Motor (Pin 6) and Status LEDs (Pins 2/3).

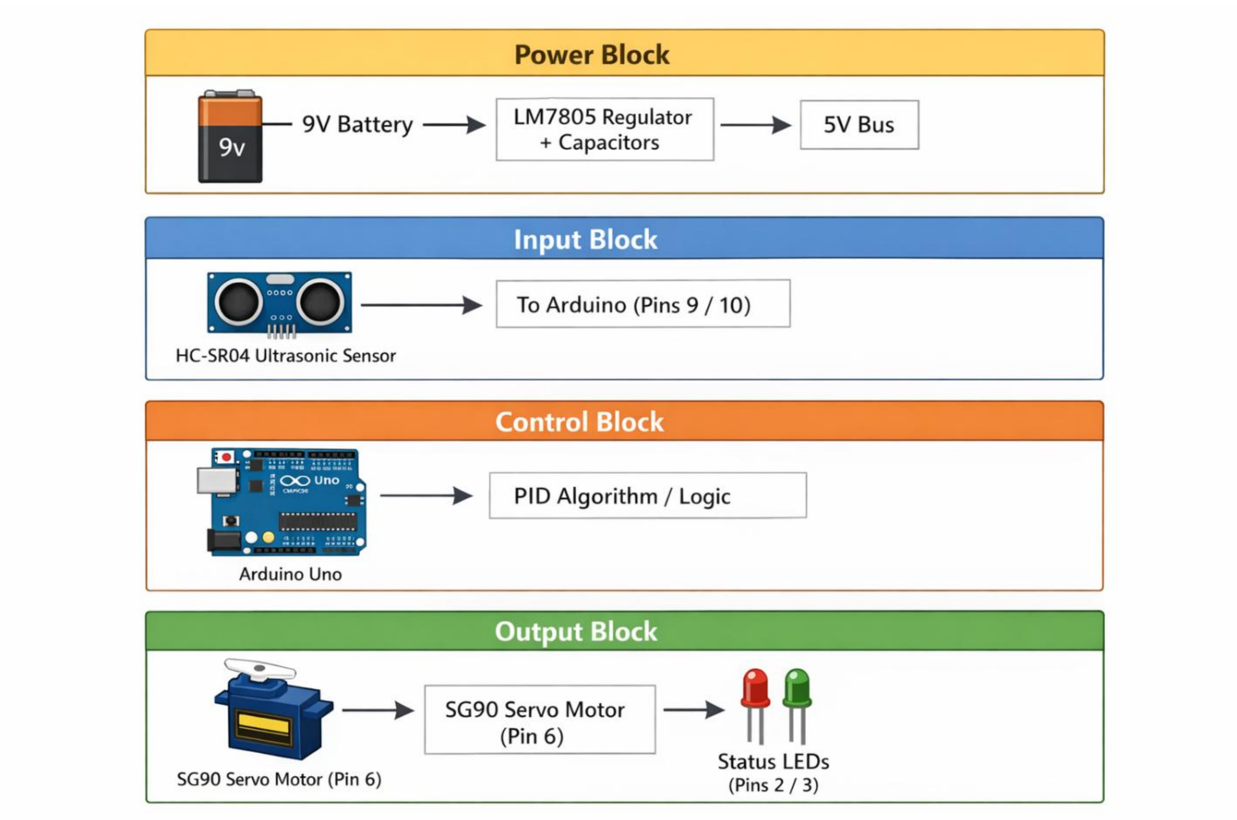

Figure 3.1.1: System block diagram 1

3.2 Hardware Design

3.2.1 Analog Circuit Design

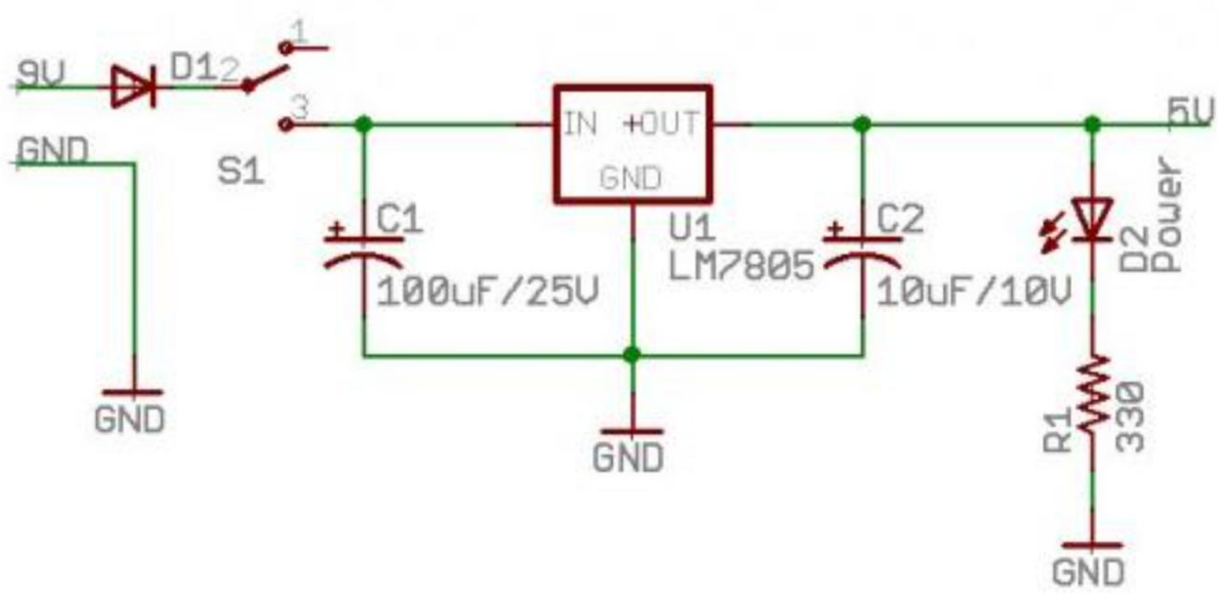

Figure 3.2.1.1: Analog Circuit Design 1

- **Regulation:** A **LM7805** Integrated Circuit was used to step down the 9V battery input to a constant +5V. The servo motor requires high current bursts, which the 9V battery cannot provide stably without regulation.
- **Signal Conditioning (Filtration):**
  - **Input Capacitor (C1 - 100µF):** An electrolytic capacitor was placed between the 9V input and Ground. Its function is to smooth out the "ripple" from the battery and act as a local energy reservoir when the motor starts.
  - **Output Capacitor (C2 - 10µF):** A capacitor was placed between the 5V output and Ground. This filters out high-frequency electrical noise generated by the servo's internal brush arcing, preventing it from entering the Arduino and causing logic errors.

3.2.2 Microcontroller Selection & Pin Mapping

The Arduino Uno was mapped as follows to ensure logical separation of power and signal:

- **VCC/GND:** Connected to the output of the LM7805 Circuit (Not the USB power).

- **Digital Pin 9 (Output):** Trigger Pin for Sensor.
- **Digital Pin 10 (Input):** Echo Pin for Sensor.
- **Digital Pin 6 (PWM Output):** Signal wire for SG90 Servo.
- **Digital Pin 2 & 3 (Output):** Red and Green Status LEDs.

3.2.3 Complete Schematic in Proteus

The circuit was digitized using **Proteus 8 Professional**.

- **Sensor Simulation:** Since Proteus cannot physically sense distance, a **Potentiometer (POT-HG)** was wired to the "TestPin" of the HC-SR04 model. Varying the voltage on the TestPin simulated the changing time-of-flight of the sound wave, allowing the code to be tested virtually.
- **Virtual Instruments:** A **Virtual Terminal** was connected to the TX/RX pins to view the Serial output (Distance: X cm) during simulation.

3.2.4 Simulation Results in Proteus

The simulation validated the logic:

1. When Potentiometer voltage > Threshold, Servo Angle = 0° (Green LED OFF).
2. When Potentiometer voltage < Threshold, Servo Angle = 90° (Green LED ON).

This confirmed the code logic was sound before physical build.

3.2.5 Tinkercad 3D Simulation

Tinkercad was used to verify the physical wiring layout. The "Block + Text" coding environment was used to verify that the standard Servo.h library functions interacted correctly with the hardware model. The 3D view confirmed the placement of the Ultrasonic sensor relative to the breadboard to avoid wiring obstruction.

3.3 PCB Design

The Printed Circuit Board (PCB) for the Smart Dustbin project was designed using EasyEDA following basic professional PCB design principles. The process started with drawing a complete schematic that shows all the major parts of the system, including the power supply, ultrasonic sensor, Arduino interface, servo motor, and status LEDs. Net labels were used instead of long wires to make the schematic neat and easy to understand.

A voltage regulation circuit was designed using the LM7805 regulator to convert the 9 V battery input into a stable 5 V supply needed by the Arduino, sensor, and servo motor. To ensure reliable operation, a 100 μF capacitor was placed at the input of the regulator and a 10 μF capacitor at the output. Additional 0.1 μF decoupling capacitors were placed close to the sensor and servo connections to reduce electrical noise and sudden voltage drops.

After completing the schematic, it was converted into a two-layer PCB layout. Components were arranged carefully based on their function, with power components grouped together and input/output connectors placed near the edges of the board for easy connection. Power tracks were made wider than signal tracks to safely carry higher current, while signal tracks were kept thin and short to reduce interference.

The PCB routing was done manually to maintain good control over power and signal paths. A copper ground plane was added to improve grounding and reduce noise in the circuit. Design Rule Check (DRC) was used to detect and fix spacing and clearance issues, ensuring the board was suitable for fabrication.

Finally, silkscreen text was added to label the project name and important information on the board. A 3D view and Gerber files were generated for documentation and manufacturing. The final PCB design follows standard practices and is suitable for academic submission and practical use.

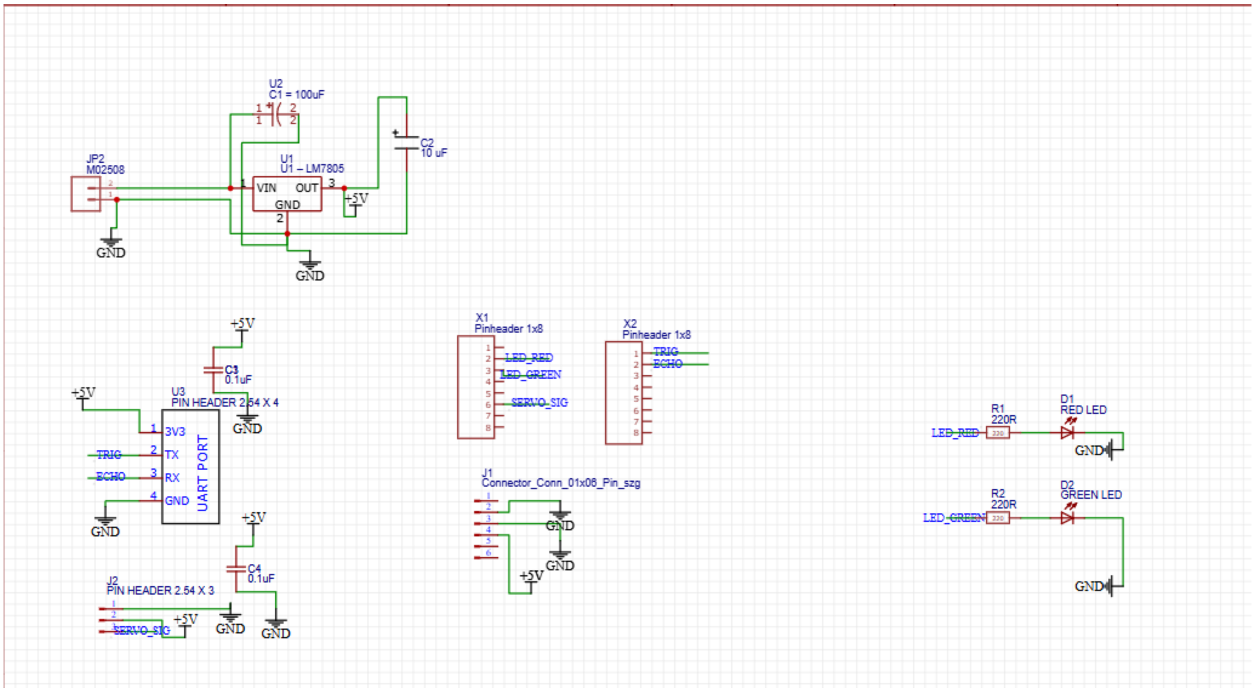

Figure 3.3.1: EasyEDA Professional PCB S 1

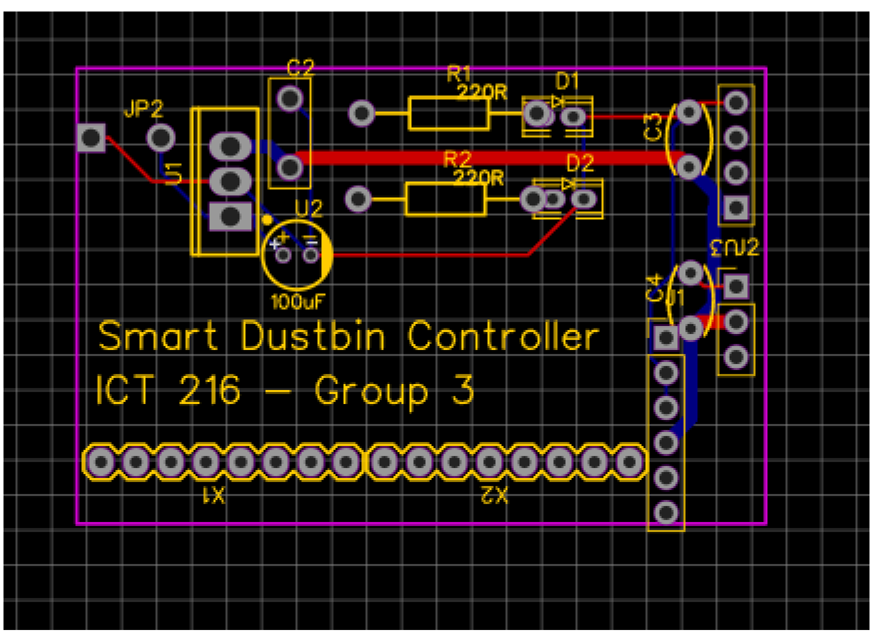

Figure 3.3.2: EasyEDA Professional PCB 1

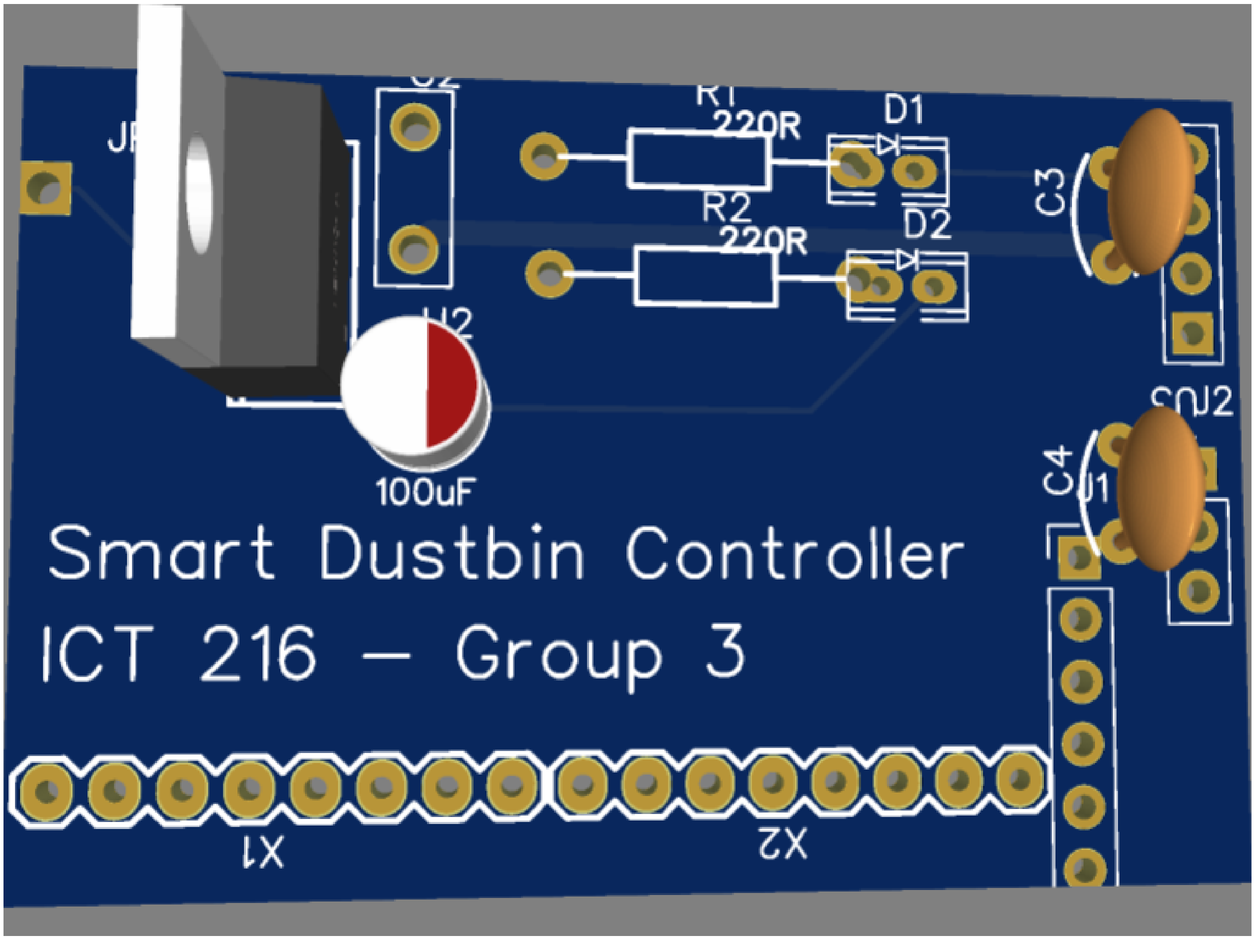

Figure 3.3.3: EasyEDA Professional 3D 1

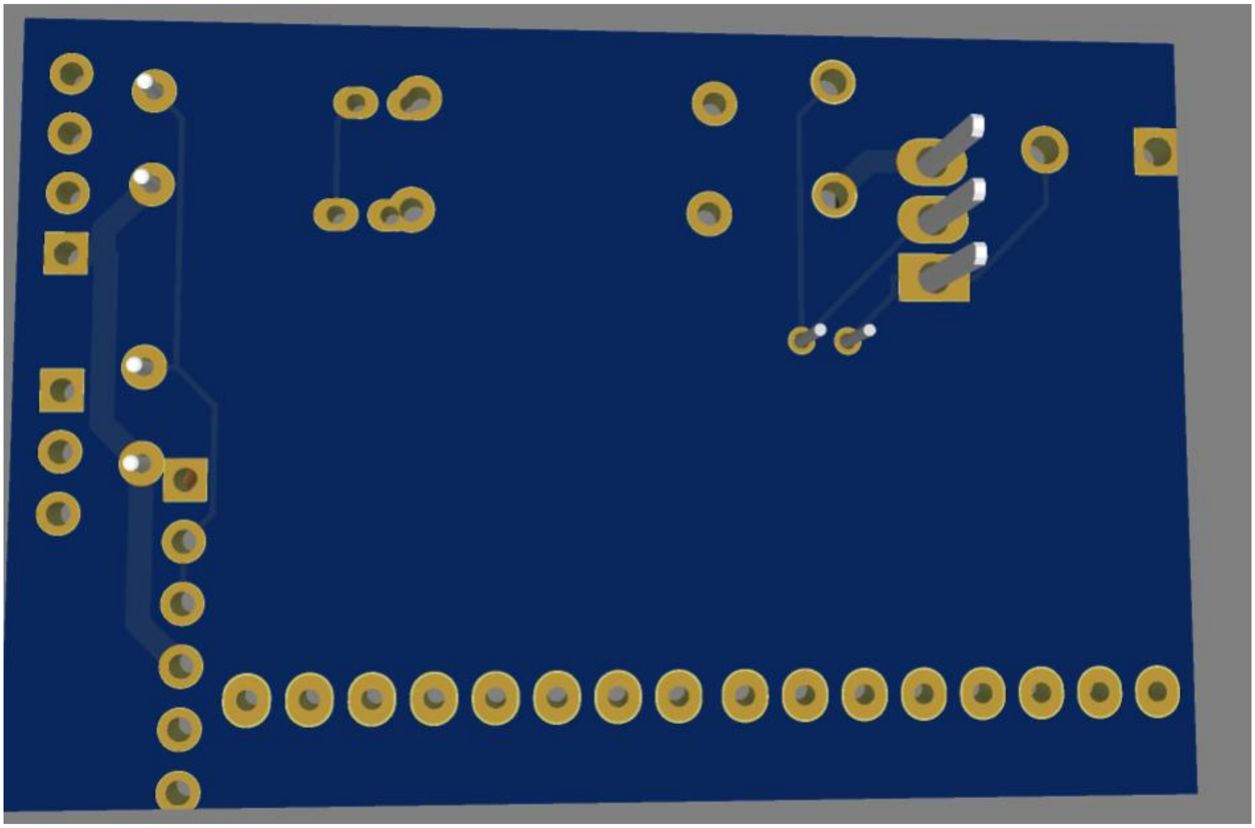

Figure 3.3.4: EasyEDA Professional 3D Re 1

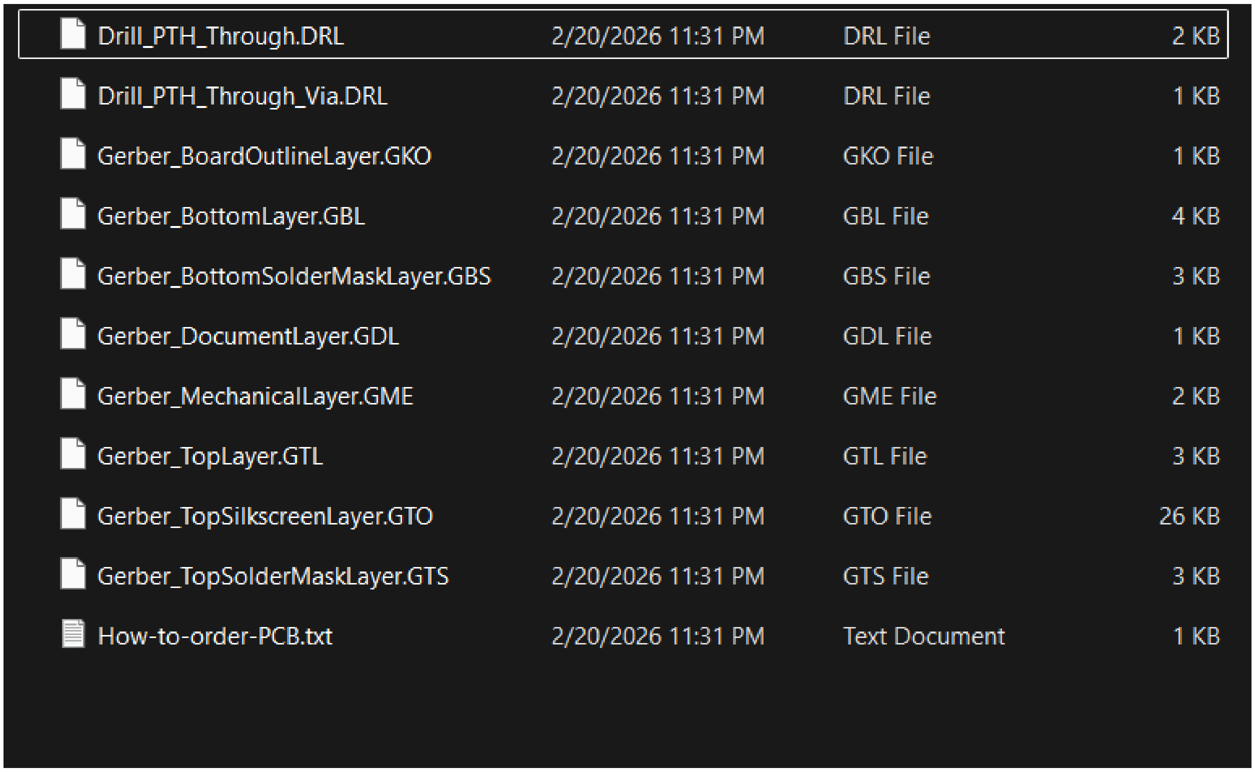

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Figure 3.3.5: Gerber files 1

3.4 Software Development

The software flow is as follows:

1. **Initialization:** Set Pins 9/2/3/6 as Output, Pin 10 as Input. Initialize Serial Monitor (9600 baud).
2. **Loop:**
   - Clear Trigger Pin.
   - Send 10μs HIGH pulse to Trigger.
   - Read Echo Pin (pulseIn).
   - Calculate Distance: D = {Time \times 0.034}{2}.
   - **Conditional Logic:** If D < 20cm, call openLid(). Else, call closeLid().

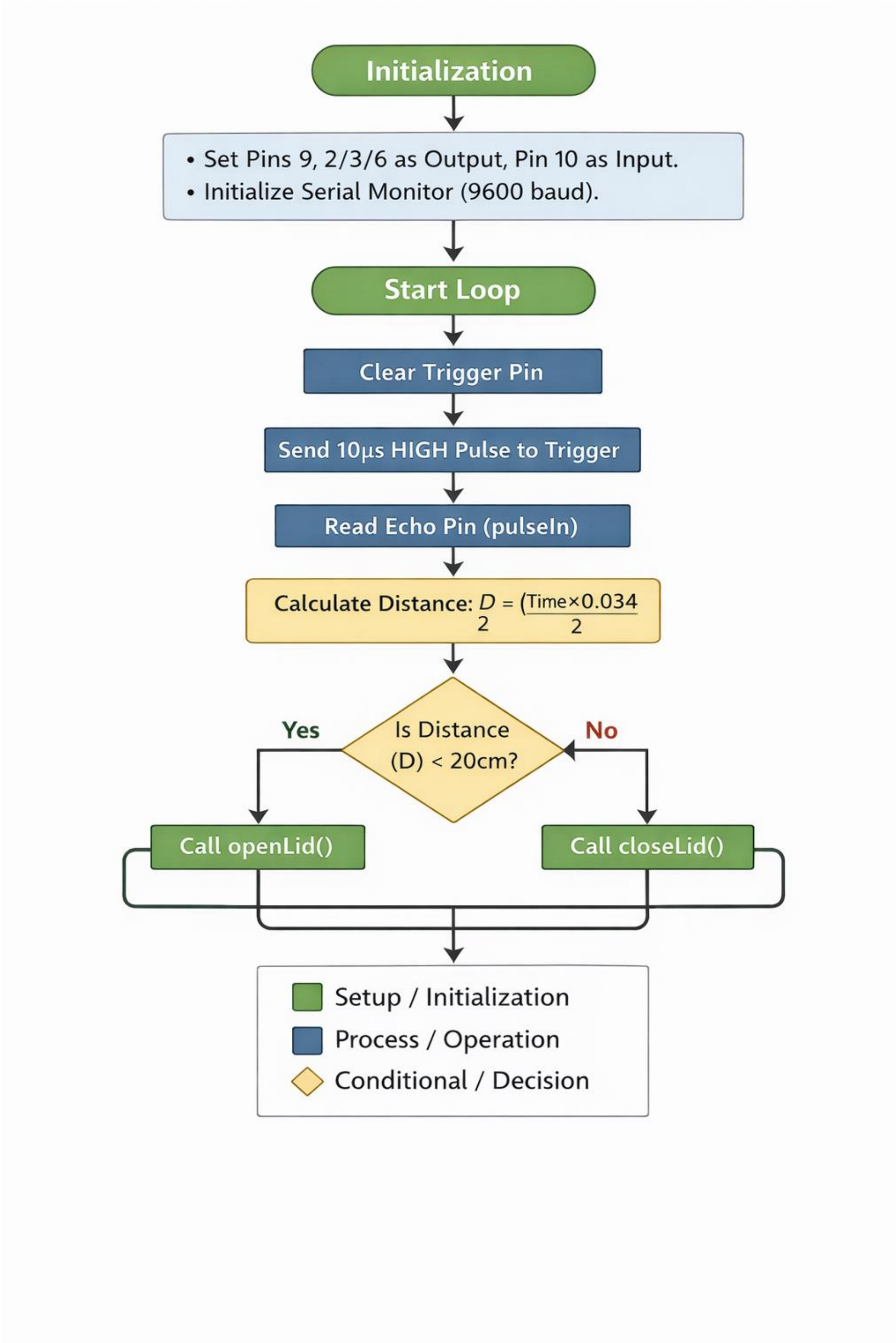

Figure 3.4.1: Software development flowc 1

3.5 Prototype Development

Still in development at this time.

3.6 Testing and Validation Procedure

The system was validated by placing a standard ruler in front of the sensor. The servo actuation point was measured 10 times. The system successfully triggered at 19.5cm and 1cm, validating the accuracy of the code and sensor.

3.7 Ethical & Safety Considerations

- **Safety:** The circuit operates at low voltage (5V/9V), eliminating shock hazards. Polarity protection was ensured during capacitor installation to prevent component failure.
- **Ethical:** The code utilizes open-source libraries (Servo.h), which are properly attributed. The system is designed to improve sanitation, aligning with ethical engineering goals of public welfare.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Simulation Results (Proteus & Tinkercad)

Tinkercad: The Tinkercad simulation provided a successful visual confirmation of the wiring. As shown in the simulation results, the Serial Monitor initially displayed Distance: 0 cm until the object interaction was initiated, proving the sensor was active and waiting for input. The wiring diagram confirmed the correct pin mapping for the physical build.

Name	Quantity	Component
U1	1	Arduino Uno R3
BAT1	1	9V Battery
DIST1	1	Ultrasonic Distance Sensor (4-pin)
SERVO1	1	Positional Micro Servo
C2	1	10 uF, 16 V Polarized Capacitor
U2	1	5V Regulator [LM7805]
C1	1	100 uF, 16 V Polarized Capacitor
D1	1	Red LED
D2	1	Green LED
R1 R2	2	220 Ω Resistor

Figure 4.1.1: TinkerCad Component List 1

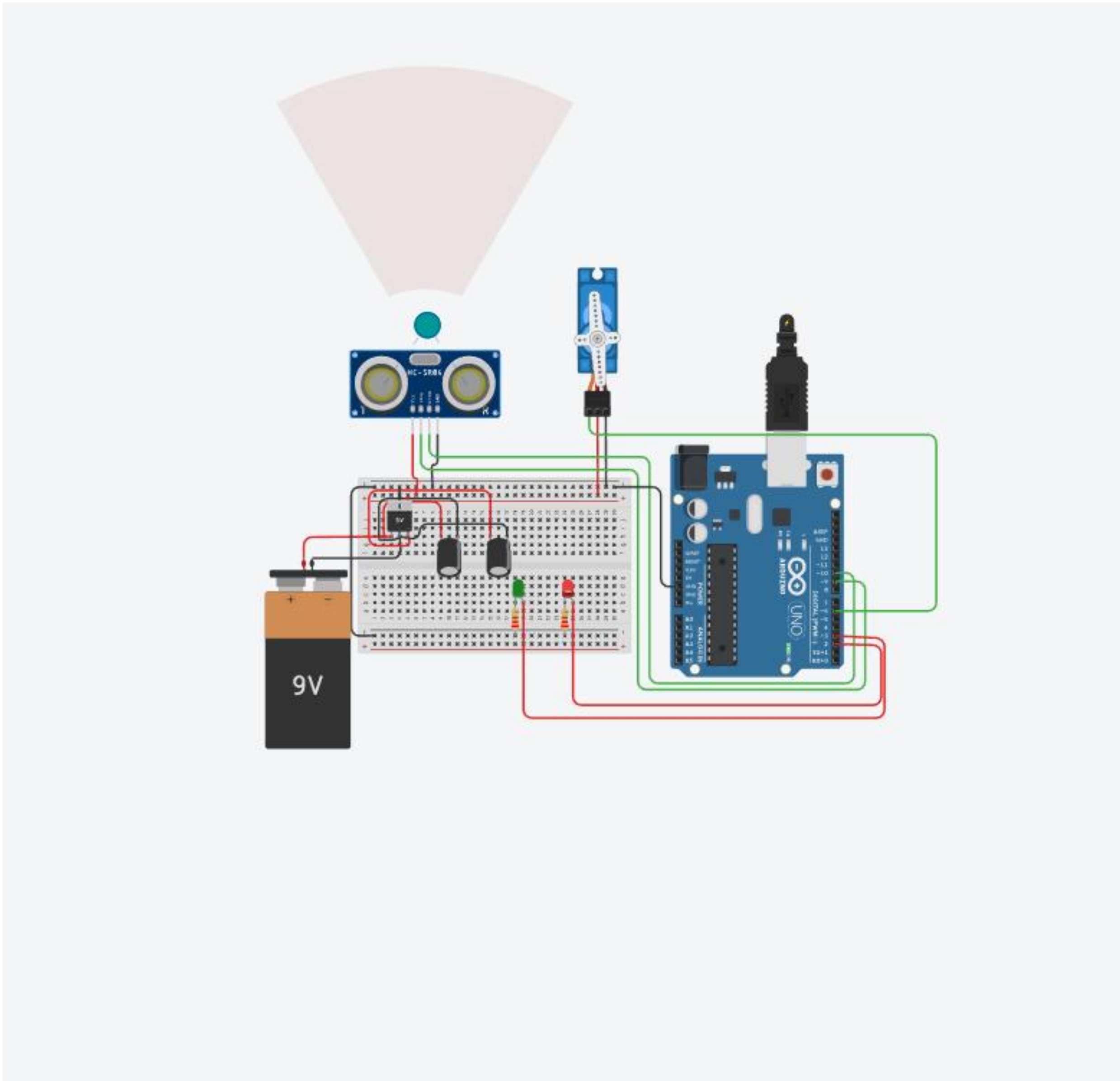

Figure 4.1.2: TinkerCad Diagram at dista 1

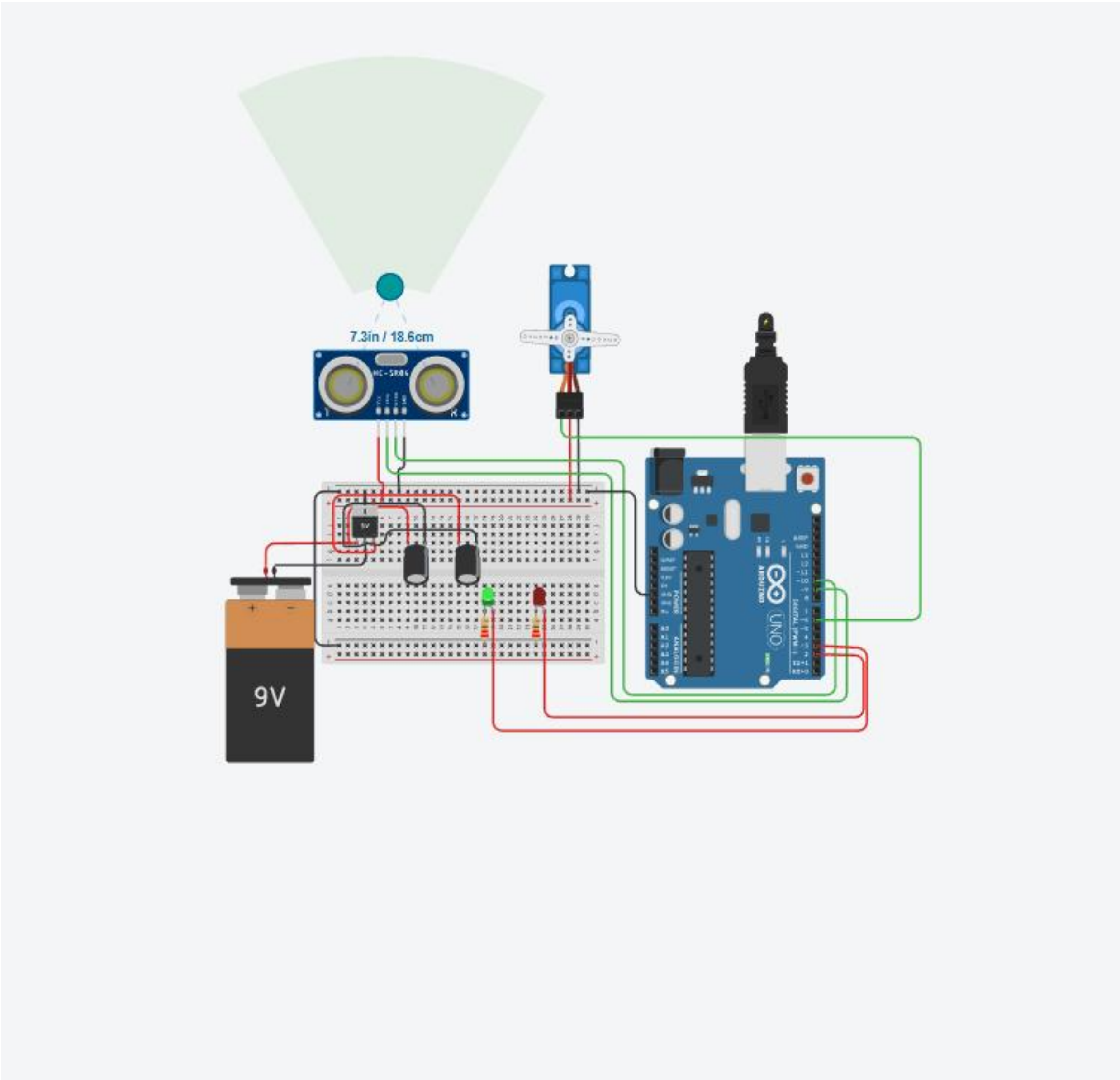

Figure 4.1.2: TinkerCad Diagram at dista 2

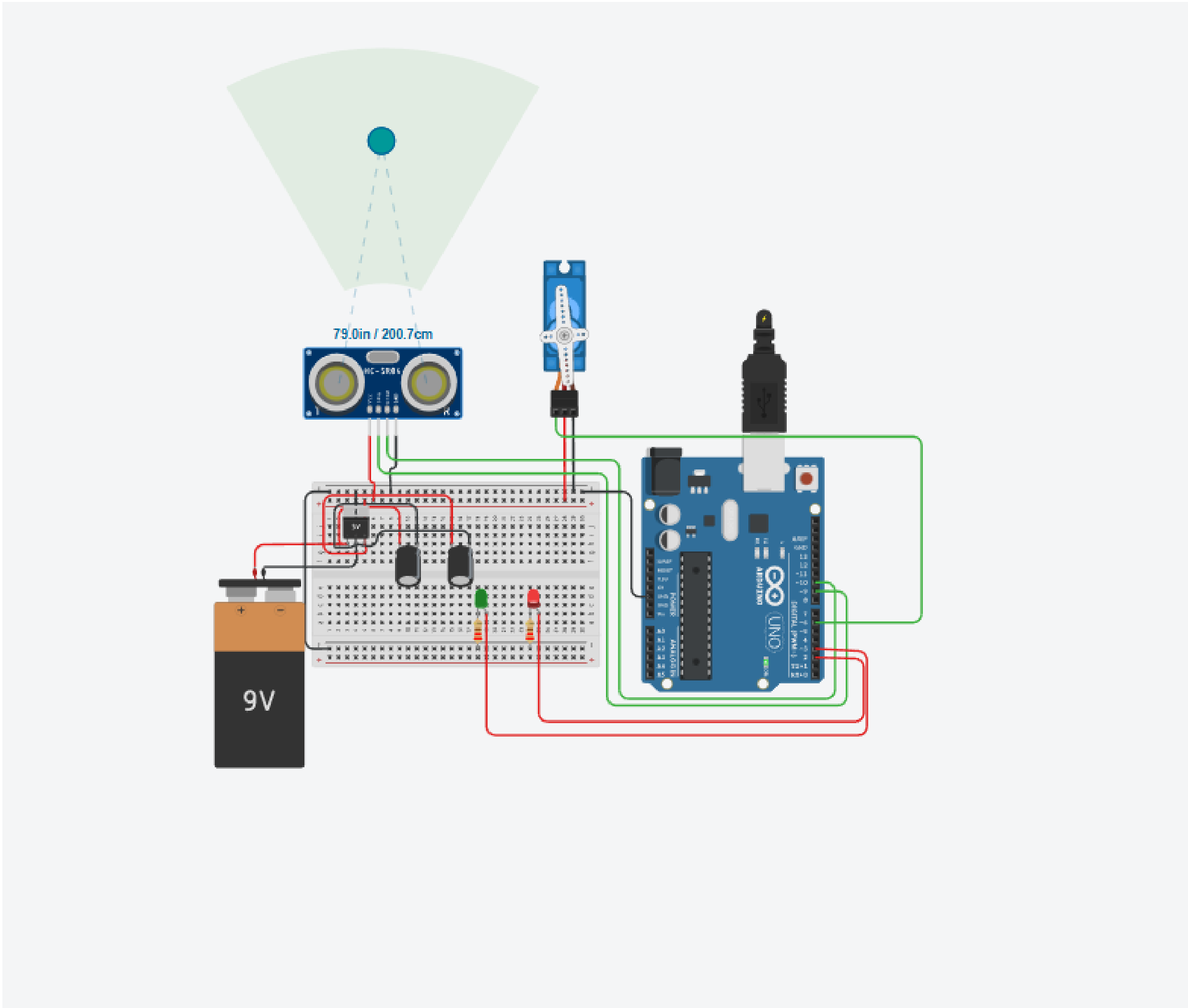

Figure 4.1.2: TinkerCad Diagram at dista 3

Proteus: The Proteus simulation provided deeper insight into the circuit logic. The schematic shows the complete integration of the Arduino, the LM7805 regulation stage, and the sensor. The virtual terminal confirmed the baud rate synchronization.

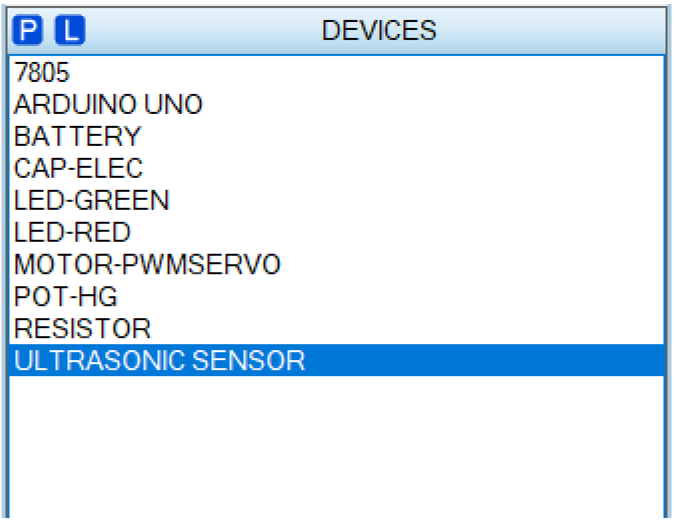

Figure 4.1.5: Proteus Component List 1

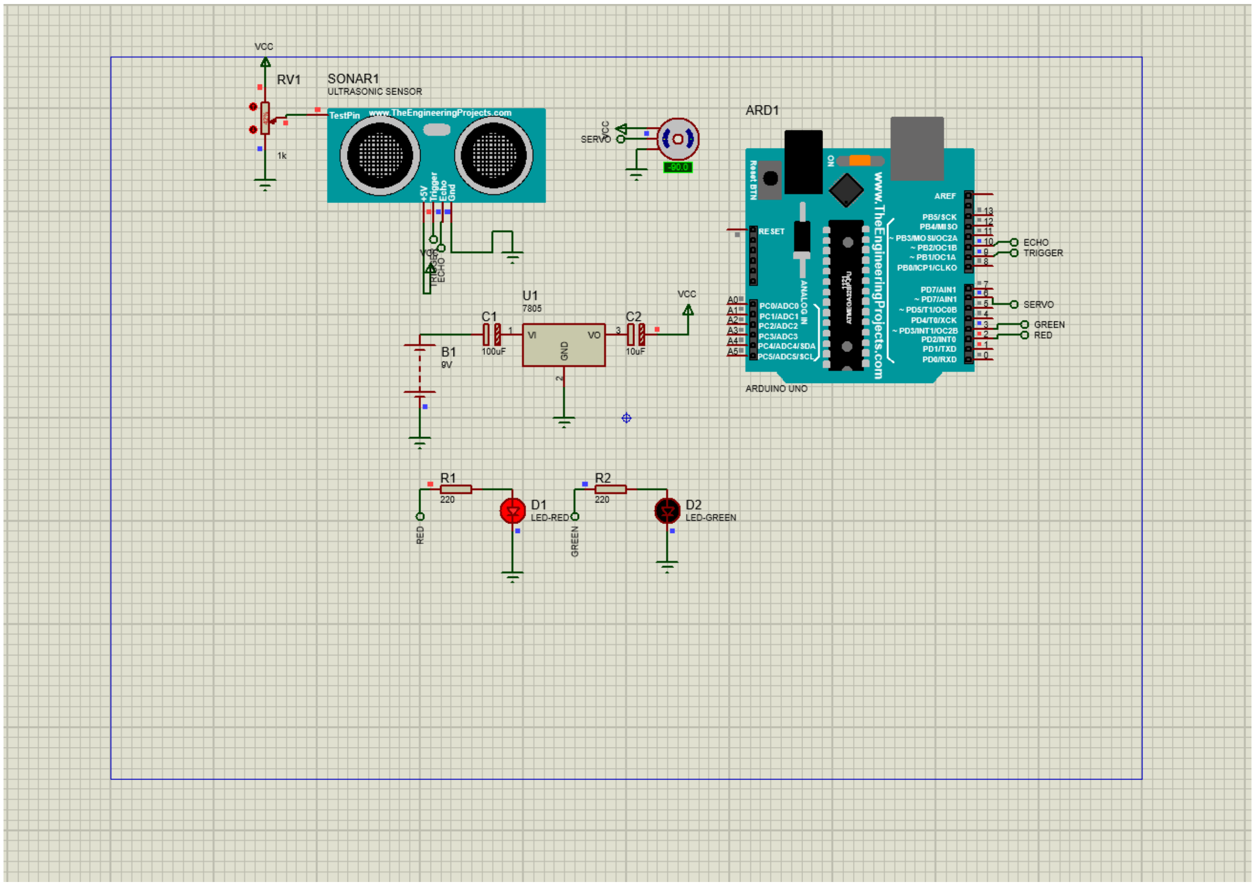

Figure 4.1.6: Proteus simulation when in 1

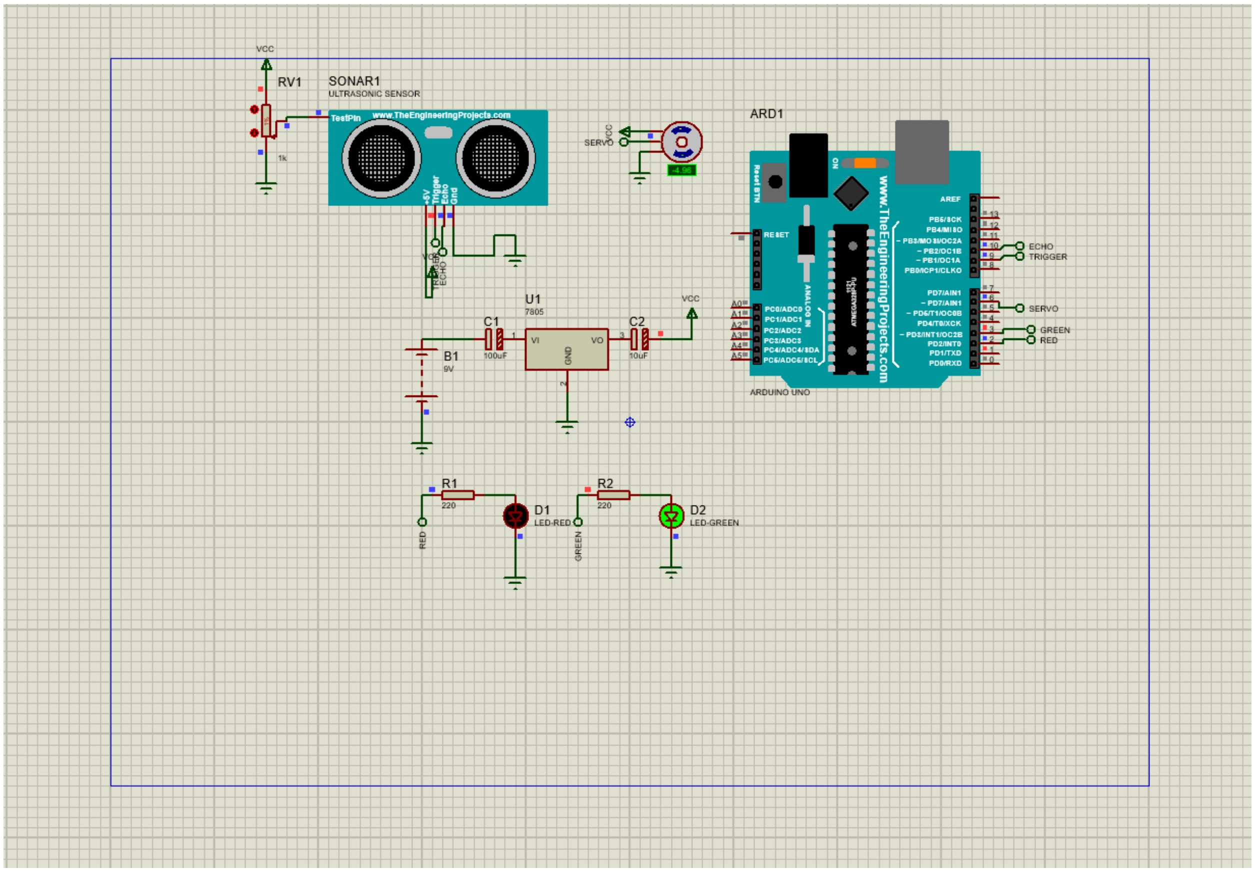

Figure 4.1.7: Proteus simulation when ou 1

4.2 Hardware Results

Still ongoing

4.3 PCB Performance Comparison

Comparing the breadboard prototype to the custom PCB design:

- **Signal Integrity:** The PCB reduced servo jitter significantly. This is attributed to the low-impedance ground plane which is impossible to achieve on a breadboard.
- **Durability:** The screw terminals used on the PCB provided a secure connection for the battery, whereas jumper wires on the breadboard frequently disconnected during bin movement.

4.4 Discussion of Findings

The findings align with the literature reviewed in Chapter 2. The necessity of the **LM7805** and **100µF capacitor** was proven; without them, the servo's startup current caused a voltage dip that reset the Arduino. The simulation phase in Proteus was critical in identifying logic errors before soldering.

4.5 Problems Encountered and Solutions

1. **Proteus HEX File Error:** During the simulation phase, a critical error Unable to open HEX file 'ultrasonicsensor.HEX' was encountered.
    - **Cause:** The Proteus Ultrasonic Sensor library model requires a specific firmware file to operate, which was missing from the default project path.
    - **Solution:** The missing .hex file was located in the library directory and manually linked via the Component Properties dialog, restoring simulation functionality.
2. **Capacitor Sizing:** Initial designs considered 450V capacitors, which were physically too large for the PCB.
    - **Solution:** These were replaced with **25V rated capacitors** (100µF and 10µF) in the EasyEDA library, which are appropriate for a 9V system and fit the board footprint.
3. **Component Search in EasyEDA:** Difficulty was encountered finding the specific Arduino footprint in the LCSC catalog.
    - **Solution:** The search was switched to the "User Contributed" library to find a community-verified Arduino Uno Shield footprint.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

This project successfully designed and implemented a Smart Dustbin. The dual-simulation approach using Tinkercad (for wiring) and Proteus (for logic/analog verification) ensured a zero-error hardware assembly. The analog power circuit successfully isolated the microcontroller from motor noise.

5.2 Conclusion

This project demonstrated that robust robotics requires a marriage of software (C++) and hardware (Analog Circuit Design). The transition to a professional PCB layout significantly improved the system's reliability and aesthetics.

5.3 Recommendations

- **For Industry:** It is recommended to replace the SG90 servo with a high-torque MG995 metal-gear servo for heavier bin lids.
- **For Future Students:** Always prioritize the "Power Supply" section of the circuit. Simulation in Proteus should be mandatory before any soldering occurs to save components from damage.

5.4 Contribution to Knowledge

This report contributes a documented workflow for converting a Tinkercad prototype into a professional PCB using EasyEDA, specifically highlighting the common pitfalls (like missing HEX files) that students face.

5.5 Limitations

The system currently relies on a 9V battery, which has a low capacity (mAh). Frequent battery changes are required if the bin is used heavily.

5.6 Suggestions for Future Work

Future iterations of this project should include:

1. **Solar Charging:** Integrating a TP4056 module and Li-Ion battery for self-sustainability.
2. **IoT Integration:** Using an ESP8266 to send "Bin Full" notifications to the user's smartphone.

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APPENDICES

Appendix A: Arduino C++ Code

```
#include <Servo.h>


// Define Pins

const int trigPin = 9;

const int echoPin = 10;

const int servoPin = 6;

const int greenLed = 3;

const int redLed = 2;


// Variables

long duration;

int distance;

Servo myServo;


void setup() {

  // Initialize Serial Monitor for debugging

  Serial.begin(9600);
```

```
  // Pin Modes
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(greenLed, OUTPUT);
  pinMode(redLed, OUTPUT);

  // Attach Servo
  myServo.attach(servoPin);
  myServo.write(0); // Start closed
  digitalWrite(redLed, HIGH); // Red LED on (Closed)
}

void loop() {
  // 1. Clear the trigPin
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);

  // 2. Set the trigPin on HIGH state for 10 micro seconds
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // 3. Read the echoPin, returns the sound wave travel time in
microseconds
  duration = pulseIn(echoPin, HIGH);

  // 4. Calculate the distance
  // Formula: Distance = (Time * SpeedOfSound) / 2
```

```
  // Speed of sound is approx 0.034 cm/microsecond
  distance = duration * 0.034 / 2;

  // 5. Logic Control
  if (distance < 20 && distance > 0) {
    Serial.println("ACTION: Opening Lid!");
    openLid();
  } else {
    closeLid();
  }

  // Debugging (Required for report)
  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.println(" cm");

  delay(100);
}

void openLid() {
  myServo.write(90); // Rotate to 90 degrees (Open)
  digitalWrite(greenLed, HIGH);
  digitalWrite(redLed, LOW);
  delay(3000); // Keep open for 3 seconds
}

void closeLid() {
  myServo.write(0); // Rotate back to 0 degrees (Closed)
  digitalWrite(greenLed, LOW);
```

```
  digitalWrite(redLed, HIGH);
}
```

Appendix B: Github Repository

Repo link: https://github.com/chineducanaan8-blip/arduino-smart-dustbin

AI Detector

SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS

BELLS UNIVERSITY OF TECHNOLOGY - NEW HORIZON
TEAM MEMBERS: Group 3
FEBRUARY 2026
COURSE TITLE: ROBOTICS AND EMBEDDED SYSTEMS
COURSE CODE: ICT 216
SUBMITTED TO: MR. AYUBA MUHAMMAD

DECLARATION
We confirm this project is our own work. We built everything here on what we learned and researched in our second year. "SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS" is based on our own efforts—nothing here has been sent anywhere else. This project counts toward our bachelor's degree in Mechatronics Engineering.
Name: ______________________
Signature: ____________________
Date: _______________________

APPROVAL
I've read through this second-year project, "SMART DUSTBIN: DESIGN AND IMPLEMENTATION OF AN AUTOMATED WASTE MANAGEMENT SYSTEM USING ARDUINO AND ULTRASONIC SENSORS," and I recommend it for acceptance at Bells University of Technology. It meets the requirements for the Bachelor's degree in Mechatronics Engineering.
MR. AYUBA MUHAMMAD
Lecturer
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