An Embedded System for Hands-Free Waste Disposal and Waste Level Monitoring

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***Abstract*—This report presents the design and implementation of a Smart Dustbin using dual ultrasonic sensors, a servo motor, and a 16×2 LCD. The system opens its lid automatically when a hand is detected and calculates the bin's fill level using distance measurements. The fill percentage is displayed in real-time, offering a hygienic and efficient waste management solution for indoor environments.**

Keywords — Autonomous Waste Management, Ultrasonic Sensing, IoT Automation.

I. INTRODUCTION

With growing urban populations and increasing waste generation, efficient and hygienic waste management has become a pressing need. The Smart Dustbin addresses this by combining automation with real-time monitoring. Using an Arduino Uno, ultrasonic sensors, and a servo motor, the system detects user presence to open the lid automatically and continuously measures the bin's fill level. This data is displayed on a 16×2 LCD, supporting timely collection and improved sanitation in public and residential settings.

II. MEASUREMENT TECHNIQUES

In the Smart Dustbin project, accurate measurement of distances is pivotal for both automated lid operation and fill-level estimation. The system employs two HC-SR04 ultrasonic sensors, each dedicated to a specific function. The first sensor, mounted at the top of the dustbin, is used to detect the presence of a hand or object, which in turn triggers the servo-driven lid to open. The second sensor is positioned at the bottom of the dustbin to continuously monitor the level of accumulated waste, enabling the computation of a fill percentage. The ultrasonic sensor operates by emitting a high-frequency sound pulse (typically 40 kHz) through its trigger pin. Once the pulse is transmitted, it travels through the air until it encounters an object. The pulse is then reflected back and detected at the sensor's echo pin. This measurement technique is applied for both sensors.

III. INSTRUMENTS REQUIRED

- Arduino Uno
- 2 Ultrasonic Sensors (HC-SR04)
- SG-90 Servo Motor
- 16 x 2 LCD Display (JHD162A)
- 10k Ω Potentiometer
- Breadboard and Jumper Cables
- 9V Battery Module

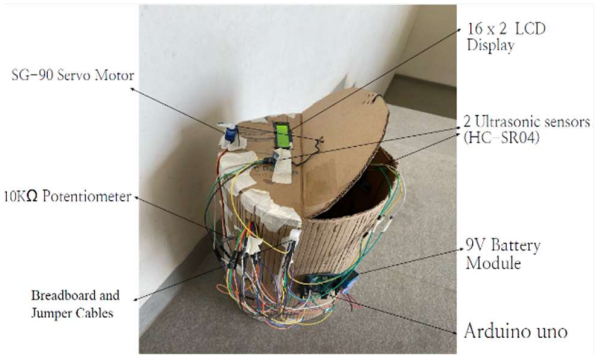

Fig. 1: Photograph showing all the required materials and the working prototype

IV. THEORY

The Smart Dustbin system is founded on three core technologies: ultrasonic distance measurement, servo-based actuation, and character display via a liquid-crystal interface. Together, these elements enable hands-free operation and real-time monitoring of waste accumulation

A. Ultrasonic Distance Sensing

Ultrasonic sensors (HC-SR04) determine object distance by emitting a brief high-frequency acoustic pulse and timing the echo's return. The trig pin emits 10^{-5} pulses per second [1] and elapsed round-trip time t (in seconds) correlates with distance d according to

$$d = \frac{v \times t}{2}$$

where v is the speed of sound in air (≈343 m/s). In our design:

- The top sensor continuously measures the distance to any object placed above the lid. When d<20 cm, the controller interprets that as a user's hand, triggering the servo to open the lid without physical contact.
- The bottom sensor sits at the bin's ceiling and measures the distance to the waste surface. By comparing this distance to the known internal bin height H, the system computes the fill percentage η:

$$\eta = \frac{H-d}{H} \times 100\%$$

B. Servo Driven Lid Actuation

A standard SG90 hobby servo receives pulsewidthmodulated (PWM) commands from the Arduino Uno. The pulse width sets the shaft angle, with approximately 1 ms corresponding to 0˚ (lid fully open) and 2ms 180˚ (lid fully closed). By intermittently attaching the servo and issuing the appropriate PWM pulse, the system ensures precise lid movement while minimizing power draw.

C. Liquid Crystal Display (LCD)

A 16×2 HD44780compatible LCD is driven in 4bit mode to present the fill percentage. Six microcontroller pins (RS, EN, D4–D7) transmit commands and data; a 10 kΩ potentiometer adjusts contrast at V_0. Only the numeric percentage is displayed to maintain clarity. Updates occur each loop iteration, reflecting the most recent fill calculation.

V. PROCEDURE

The following subsections outline the procedure followed in both hardware setup and software development. reliable.

A. Electrical Connections

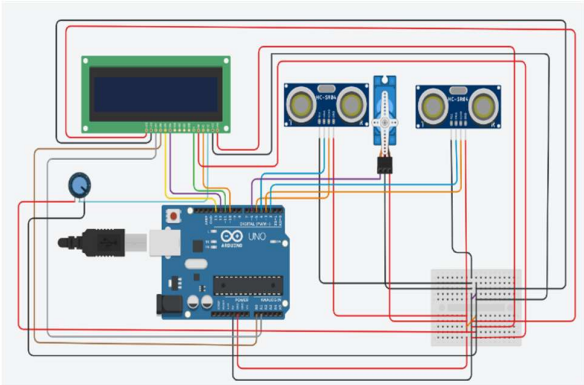

Fig. 2: Complete circuit diagram of the Smart Dustbin prototype designed using Tinkercad [2]

All components in the Smart Dustbin prototype were connected to the Arduino Uno using a shared 5 V and GND rail on a breadboard. The bottom ultrasonic sensor (for fill level) was connected to pins D2 and D3, while the top sensor (for hand detection) used pins D4 and D5. The SG90 servo motor's signal wire was connected to D6, with power drawn from the 5 V rail. The 16×2 LCD was interfaced in 4-bit mode using pins D10, D11, D12, D13, A0, and A1, with its RW pin grounded. A 10 kΩ potentiometer was used for contrast adjustment, and a 220 Ω resistor was added to the LCD backlight. This configuration ensured stable voltage levels and reliable operation of all components

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B. Software Implementation

The Arduino Uno was programmed using the Arduino IDE in C++. The code continuously reads distances from both ultrasonic sensors using the PulseIn() function and converts them into centimeters. The fill level is computed by comparing the measured distance from the bottom sensor to the known bin height and mapping it linearly to a percentage. If the top sensor detects a hand within 20 cm, the servo motor is triggered to open and close the lid using the Servo library. The fill percentage is displayed on a 16×2 LCD via the LiquidCrystal library and also printed to the Serial Monitor every 3 seconds using millis() for timed output. The code avoids unnecessary delays and power consumption by detaching the servo when idle.

```
distanceBottom = getDistance(trigPin1, echoPin1);
if (distanceBottom > 0 && distanceBottom < binHeight) {
  fillPercent = map(binHeight - distanceBottom, 0, binHeight, 0, 100);
} else {
  fillPercent = 0;
}

lcd.clear();
lcd.setCursor(0, 0);
lcd.print(fillPercent);
lcd.print("%");

if (distanceTop > 0 && distanceTop < 20) {
  servo.attach(servoPin);
  servo.write(0);
  delay(3000);
  servo.write(150);
  delay(1000);
  servo.detach();
}
```

Fig. 3: Arduino Code for Fill Detection and Lid Control.

VI. RESULTS

The Smart Dustbin was tested under various conditions, and the system responded accurately to hand detection and fill-level monitoring. When a hand was placed within 20 cm of the top sensor, the lid opened automatically and closed after a short delay, confirming proper servo operation. The bottom ultrasonic sensor consistently measured waste levels, and the fill percentage was displayed in real-time on the LCD. The reading was stable and responded appropriately to changes in trash volume.

VII. CONCLUSION

The Smart Dustbin prototype met its design goals by enabling fully automated lid operation and accurate fill-level monitoring using two HC-SR04 ultrasonic sensors and an SG90 servo motor. The Arduino-based system successfully detected hand proximity to open the lid and calculated fill percentage based on real-time distance readings, which were displayed on a 16×2 LCD. The system functioned reliably under various test conditions, demonstrating its potential for improving hygiene and reducing manual intervention in small-scale indoor waste management applications. Future enhancements such as IoT connectivity and multi-bin sorting can further extend its usability in smart infrastructure.

REFERENCES

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[2] Autodesk, "Tinkercad," [Online]. Available: https://www.tinkercad.com [Accessed: 22-Apr-2025].