CASA0016 Coursework Report

Title: Smart Bin – An Automated Sensor-Based Waste Monitoring System

Word Count: 1685 (excludes table)

GitHub URL: https://github.com/minJerrymin/Smart-Bin.git

Declaration of Authorship

I, ***Tianrui Min***, confirm that the work presented in this assessment is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Sign: Tianrui min

ASSESSMENT DATE : 10/01/2026

Introduction

1.1 Background

As urbanisation levels continue to rise across regions, an increasing number of people live within cities, leading to a surge in waste volumes. Consequently, the proper collection and disposal of waste has become an issue that cannot be overlooked.

Under the traditional urban waste clearance model, the schedule for emptying bins is fixed, and all bins must be cleared within the allocated timeframe. However, real-world uncertainties affect bin usage patterns: some bins may fill rapidly, while others remain empty for days. Therefore, manually inspecting every bin is an highly inefficient approach. Meanwhile, from a hygiene perspective, failure to promptly clear waste risks spreading germs and viruses (Poddar et al., 2017). With the availability of low-cost sensors and microcontrollers, it has become feasible to transform conventional bins into responsive, sensor-driven waste management systems.

1.2 Previous Research and Motivation

Previous research has addressed capacity detection challenges. For instance, Ramson and Moni (2017) developed a wireless sensor network solution using ultrasonic sensors to measure waste height within bins. However, ultrasonic sensors are significantly affected by noise signals in confined spaces of small scale, resulting in unstable measurements and substantial errors.

Murugaanandam et al (2018) employed rain sensors to regulate bin lid operation, thereby preventing the spread of contaminants and viruses. This bin could sense environmental changes, automatically closing its lid during rainfall while simultaneously measuring remaining capacity via ultrasonic sensors. Nevertheless, this approach has a significant drawback: people still need to dispose of rubbish during bad weather, and keeping bin lids closed on rainy days is clearly an unreasonable practice.

Both optimisation approaches exhibit shortcomings. Consequently, I have drawn upon their designs whilst implementing enhancements to resolve these issues.

1.3 Design Aim and Objectives

Having reviewed the above case studies, I plan to develop an automated waste monitoring system based on sensor networks and existing design solutions, capable of both external interaction and internal state monitoring. The specific objectives are as follows:

- “Smart Bin” can automatically open lid when the user approaches and closes when the user moves away.
- Automatically detects bin usage levels and issues an alert when usage reaches a preset threshold.

This smart bin prototype addresses two major pain points. Firstly, at the societal level, it significantly enhances the efficiency of managing bins across large areas. Secondly, by improving the timeliness of waste collection and reducing physical contact between users and bins, the design offers increased hygiene standards compared to traditional bins, thereby lowering the risk of pathogen transmission and disease spread.

Project Overview

The Smart Bin project integrates sensors, microprocessors and actuators to construct an interactive system that responds to environmental changes and monitors internal capacity utilisation.

The system performs two functions: automatic lid operation and capacity monitoring with alerts. The system supports multiple power supply options, capable of operating either directly from mains electricity or via rechargeable batteries.

The smart bin is a functional prototype that demonstrates how interconnected sensor systems can enhance the convenience and adaptability of everyday objects.

Materials and Methods

3.1 Main Components

Based on the functional requirements of this smart waste bin, the system employs two types of distance sensors, a servo motor, and a buzzer to collect data and execute commands. The Arduino R3 serves as the central processing unit, coordinating all components. Specific data and functions are detailed in Table 1.

Component Name	Figure	Functional Description
HC-SR04 ultrasonic distance sensor		The ultrasonic distance sensor calculates the distance between a person and a waste bin by measuring the time difference between the emission and return of ultrasonic waves. This sensor fully meets the accuracy requirements and, being more cost-effective than laser sensors, is therefore employed for the proximity sensing function in the project.

MG90S servo		The MG90S is use to control the opening and closing of the lid.
VL53L0X time-of-flight laser distance sensor		The VL53L0X sensor serves to measure the internal capacity of the bin within this project. Its operating principle involves emitting infrared laser pulses and calculating distance by measuring the time required for the pulses to return after emission. Compared to ultrasonic ranging technology, this sensor offers superior accuracy, rendering it more suitable for high-precision measurement scenarios within confined spaces.
Electromagnetic buzzer SD160709		When the waste bin requires emptying, the microprocessor transmits a signal to activate the buzzer, emitting an audible alert to serve as a reminder.
Arduino Uno R3		The Arduino Uno R3 development board serves as the information processing unit, responsible for integrating data and making decisions based on programmed settings, acting as the system's brain. Simultaneously, it functions as a voltage conversion device, providing certain components with voltage inputs distinct from the main power supply.

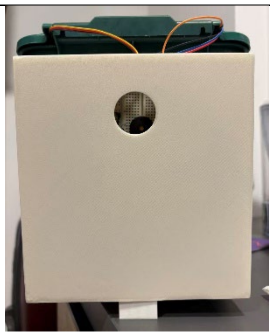
Rechargeable 5V battery module		The system is powered by a rechargeable 18650 lithium-ion battery combined with a DC–DC boost converter that supplies a regulated 5V output. This configuration enables portable operation while providing sufficient current for both the microcontroller and the servo motor.
3D printing box		Protect the circuit and control module, enhancing the prototype's aesthetic appeal.

Table 1. Main Components list

3.2 Hardware Architecture

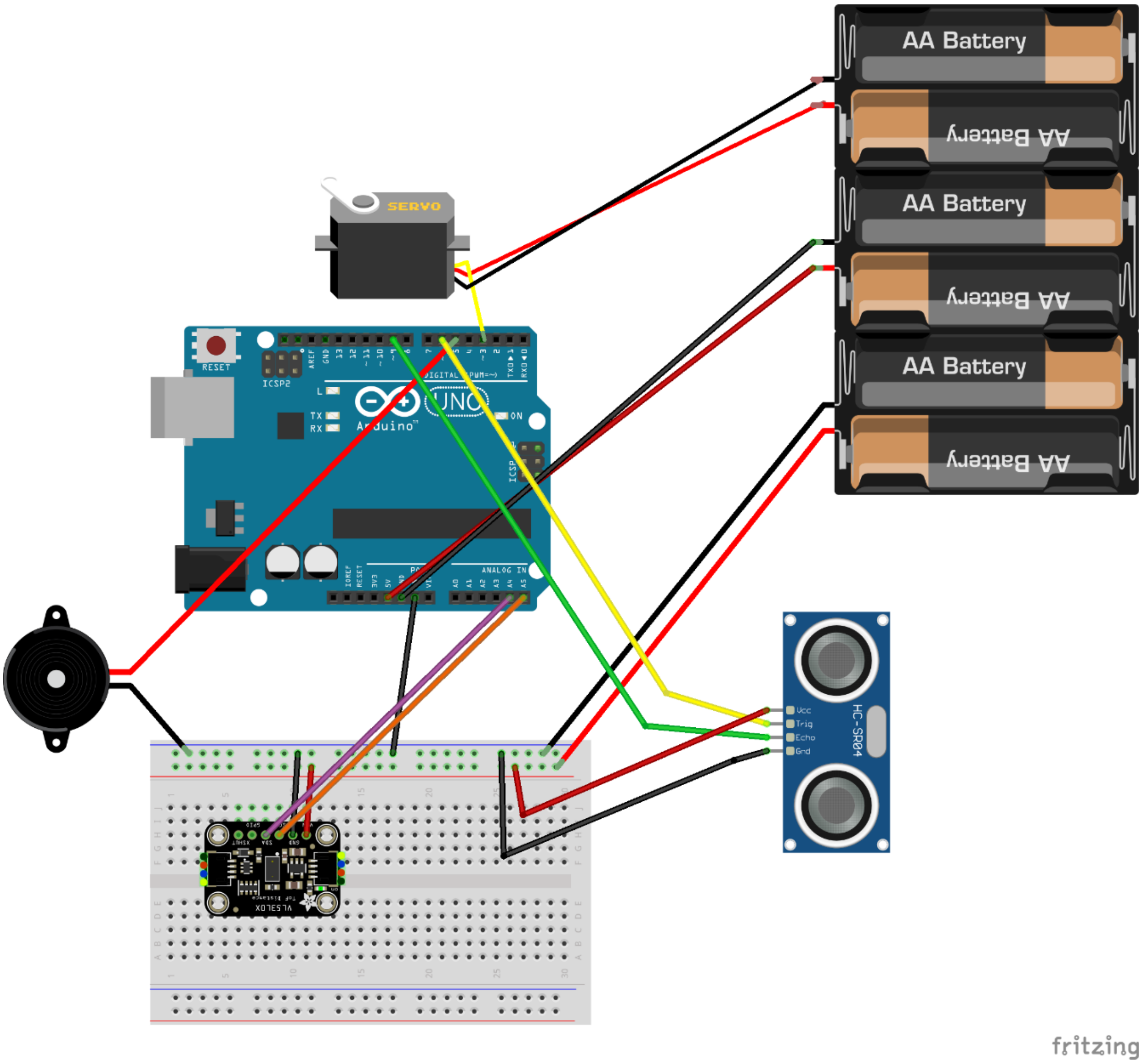


Figure 1: Circuit Diagram

The circuit connection diagram of the Smart Bin is shown in Figure 1. The entire system is powered by the battery module. It is worth noting that the servo motor requires a stable 5V voltage supply to ensure proper operation, and is therefore connected directly to the battery module.

3.3 Software Design and Control Logic

3.3.1 Overall Program Structure

The logic algorithm for the smart bin was developed using the Arduino IDE, adhering to a straightforward loop structure. The programme runs continuously within the main loop function, enabling the system to repeatedly read sensor data and update outputs in real time. Key tasks such as distance measurement, bin usage calculation, and alarm control are implemented as separate functions, making the code easier to test and modify.

3.3.2 Automatic Lid Control

The automatic lid-opening function is realised based on data from ultrasonic distance sensors. The echo duration represents the round-trip travel time of the ultrasonic pulse. Dividing the duration by 58 converts time in microseconds into distance in centimetres, based on the approximate speed of sound in air and accounting for the round-trip path. During system operation, the microprocessor continuously evaluates the distance value. Two distance thresholds are set within the programme to control servo movement: when the measured distance falls below the opening threshold, the servo motor rotates to a preset angle to open the bin lid; When the distance exceeds the second threshold, the lid will close. The closing threshold is slightly higher than the opening threshold. This dual-threshold design takes advantage of the hysteresis effect to prevent rapid lid oscillation when the user approaches the boundary distance.

```
// Function: Ultrasonic distance measurement (from Arduino library)
float getDistanceCm() {
  digitalWrite(TRIG_PIN, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);

  long duration = pulseIn(ECHO_PIN, HIGH, 30000); // timeout 30 ms

  if (duration == 0) {
    // If no reading is obtained, return a large value
    return 999.0;
  }

  // Speed of sound is approximately 340 m/s.
  //Distance (m) = time × speed.
  //Converted: distance (cm) = time (µs) / 58.
  float distanceCm = duration / 58.0;
  return distanceCm;
}
```

Figure 2: distance measurement function

```
if (!lidIsOpen && distance <= OPEN_DISTANCE_CM) {
  // Person approaches, open the lid
  lidServo.write(LID_OPEN_ANGLE);
  lidIsOpen = true;
  Serial.println("Lid OPEN");
  delay(300); // Buffer to prevent repeated triggering
}
else if (lidIsOpen && distance >= CLOSE_DISTANCE_CM) {
  // Person leaves, close the lid
  lidServo.write(LID_CLOSED_ANGLE);
  lidIsOpen = false;
  Serial.println("Lid CLOSE");
  delay(300);
}
```

Figure 3 :Dual-threshold logic

3.3.3 Capacity Monitoring and Alarm

Capacity monitoring is achieved via time-of-flight laser distance sensor. The sensor is mounted on the bin lid, and it continuously measures the vertical distance to the surface of waste within the container. Subsequently, using the measured distance and the bin's total depth as equation variables, a percentage utilisation value is calculated, reflecting the bin's fill level. This programming logic transforms raw sensor data into information required for system operation.

It not only facilitates subsequent threshold comparisons but also enables the system to present meaningful capacity information to users.

The alarm logic is implemented through threshold comparison and status tracking: when the calculated utilisation rate exceeds the upper threshold, the buzzer will sound an alarm. To prevent repeated alarms, a reset lower threshold is configured—the system will only trigger the alarm again once the usage rate falls below this reset level. This design, based on hysteresis, enhances the accuracy of the operational feedback mechanism.

```
    // Remaining depth inside the bin
    float depthCm = measure.RangeMilliMeter / 10.0;

    float garbageHeightCm = BIN_DEPTH_CM - depthCm;

    if (garbageHeightCm < 0)            garbageHeightCm = 0;
    if (garbageHeightCm > BIN_DEPTH_CM) garbageHeightCm = BIN_DEPTH_CM;

    float usagePercent = garbageHeightCm * 100.0 / BIN_DEPTH_CM;
    return usagePercent;
}
```

Figure 4: Waste bin utilisation rate calculation

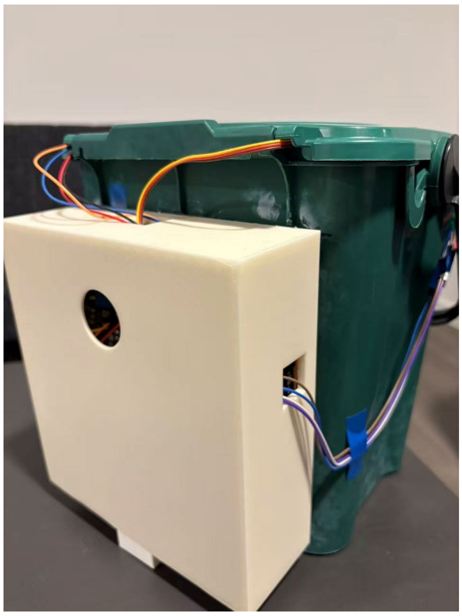
```
    // Alarm logic
    if (!hasAlarmed && usagePercent >= FULL_THRESHOLD_PERCENT) {
      Serial.println("Bin >= 80%, ALARM 5s!");
      beepFor5Seconds();
      hasAlarmed = true;  // Mark that the alarm has been triggered
    }
    else if (hasAlarmed && usagePercent <= RESET_THRESHOLD_PERCENT) {
      Serial.println("Bin usage back below reset threshold, alarm reset.");
      hasAlarmed = false;
    }
  }
```

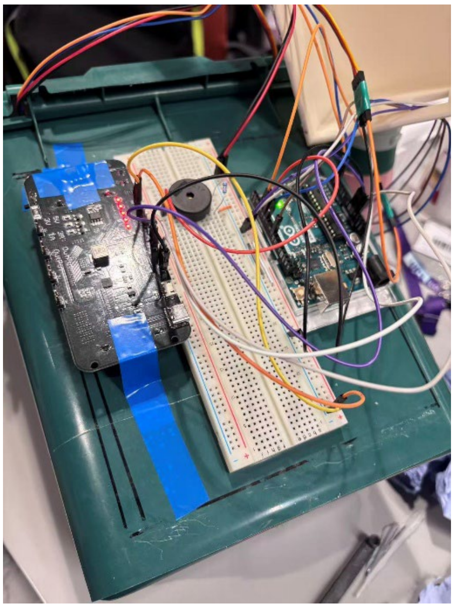
Figure 5: Alarm trigger and Reset logic

Implementation and Result

4.1 Physical Construction

The physical structure design of the smart bin focuses on integrating electronic components within the compact shell area while ensuring reliable sensor operation. A custom 3D-printed casing accommodates the Arduino, battery module, and wiring assembly, providing protection for components while enhancing the overall system aesthetics. The ultrasonic sensor is fixed to the front of the bin, while the time-of-flight sensor is mounted at the centre of the lid. A servo motor operates in conjunction with the lid via a lever linkage to control opening and closing. The final assembled prototype is robust and portable, capable of sustained operation across diverse environments.





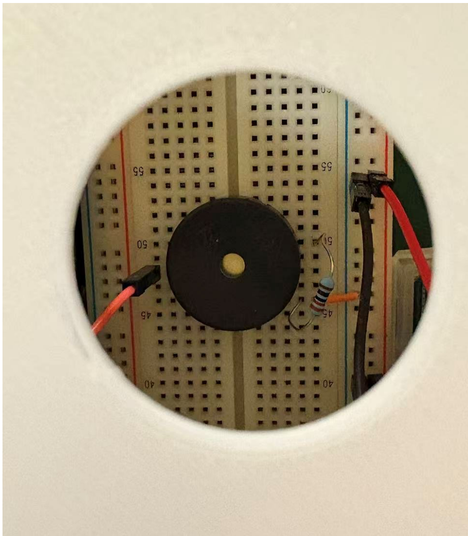


Figure 6,7,8,9: appearance of Smart Bin

4.2 Test and Result

After the prototype was completed, it underwent a period of trial use. The results indicated that the system performed as expected under normal operating conditions.

The system accurately detected human proximity, executing lid opening and closing operations at the designated positions, with the lid opening angle also matching expectations. Concurrently, the dual-threshold design successfully prevented false activations when users stayed near the proximity threshold.

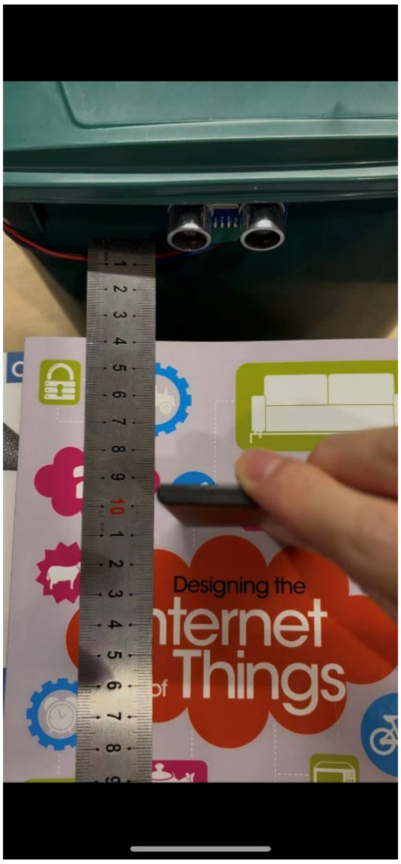


Figure 10: Distance > 6cm

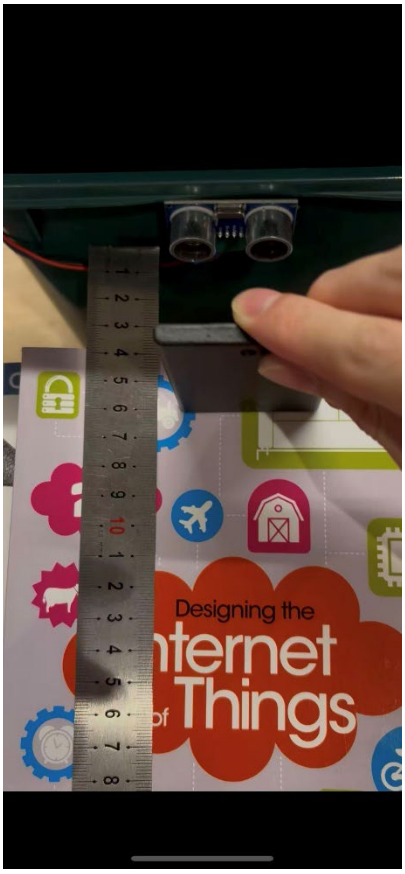


Figure 11 : Distance ≤ 6cm

When testing the capacity monitoring function, I placed waste of varying volumes into the bin and subsequently recorded the percentage of usage. Testing demonstrated that the VL53L0X sensor provided stable distance readings, enabling the system to accurately estimate the bin's utilised capacity. As expected, the system triggered a five-second buzzer alarm when usage exceeded 80%. After emptying the bin to reduce usage below 70%, the system correctly reset and subsequently triggered the alarm again.

```
Bin usage: 0.00 %
Distance: 53.31 cm
Bin usage: 58.10 %
Distance: 53.38 cm
Bin usage: 78.57 %
Distance: 53.40 cm
Bin usage: 80.95 %
Bin >= 80%, ALARM 5s!
Distance: 52.98 cm
Bin usage: 0.00 %
Bin usage back below reset threshold, alarm reset.
Distance: 53.81 cm
Bin usage: 0.00 %
Distance: 53.83 cm
```

Figure 12: Capacity and alarm

Given the project's outcomes are not suitable for quantification, I have included only a few comparison photographs here. Detailed demonstration videos can be viewed in my GitHub repository.

Reflection and Improvement

5.1 Strengths and Limitations

Overall, the smart waste bin project has successfully achieved its objectives, functioning effectively throughout testing and demonstrations. Notably, this prototype addresses certain shortcomings in existing work. Compared to the ultrasonic sensors employed by Ramson and Moni (2017) for capacity detection—which yielded unstable readings—the VL53L0X time-of-flight sensor selected for smart bin demonstrated superior reliability in practice. Furthermore, unlike designs triggering control actions based on environmental conditions (Murugaanandam et al., 2018), this project links lid control logic to human behaviour. This ensures usability remains unaffected in practical scenarios, enhancing the project's feasibility.

It must be acknowledged that the project retains several notable limitations. Feedback from demonstrations highlighted a rather rough physical construction, with components merely secured using tape. Furthermore, the large breadboard used for wiring ineffectively occupied a significant amount of space. A practical solution to these issues would be adopting an embedded installation approach, integrating all components directly into the bin body and replacing the large breadboard with smaller alternatives, strip boards, or custom PCBs. These modifications would significantly enhance compactness and durability. Furthermore, although no failures occurred during testing, the current design carries a potential risk of waste obstructing the servo mechanism, which requires resolution through more refined mechanical engineering.

5.2 Future Development

The future development of this project may focus on model optimisation, development of additional functionalities and deep integration with IoT.

- Adding features such as WiFi enables the system to remotely transmit bin status data, allowing users to monitor bin capacity via mobile applications and overcome spatial usage constraints.
- Developing more precise capacity calculation algorithms can better address uneven waste surfaces, thereby enhancing the accuracy of usage estimates.
- Monitoring changes in chemicals produced by waste can improve the bin's contribution to hygiene. For instance, odour sensors can detect whether waste is decomposing, enabling timely clearance.

Conclusion

This report presented the design and implementation of an automated sensor-based waste monitoring system. The system successfully combined automatic lid control with capacity monitoring and alarm feedback, improving both hygiene and usability. Through testing and evaluation, the prototype demonstrated reliable sensing and actuation in real time. While the Smart Bin remains at prototype stage, the project clearly illustrates the potential of connected sensor systems to enhance everyday objects and provides a solid foundation for future development.

References

- Poddar, H. *et al.* (2017) ‘Design of smart bin for smarter cities’, *2017 Innovations in Power and Advanced Computing Technologies (i-PACT)*, pp. 1–6. doi:10.1109/ipact.2017.8245162.
- Ramson, S.R.J. and Moni, D.J. (2017) ‘Wireless Sensor Networks based smart bin’, Computers & Electrical Engineering, 64, pp. 337–353. doi:10.1016/j.compeleceng.2016.11.030.
- Murugaanandam, S., Ganapathy, V. and Balaji, R. (2018) ‘Efficient IOT based Smart Bin for Clean Environment’, 2018 International Conference on Communication and Signal Processing (ICCSP), pp. 0715–0720. doi:10.1109/iccsp.2018.8524230.