Smart Disposal Machine

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Final Submission Report

Contents:

1 Abstract

This project introduces a **Smart Disposal Machine (SDM)**, an advanced waste management system designed for real-time waste monitoring and efficient disposal operations. The SDM utilizes sensor-based detection to continuously track waste levels, allowing for optimized collection schedules. This helps prevent bin overflow, which can lead to unsanitary conditions, unpleasant odours, and increased maintenance efforts. By ensuring timely waste collection, the system significantly enhances hygienic operations, particularly in high-traffic environments such as public spaces, offices, and commercial facilities.

The SDM is equipped with automated mechanical systems that reduce the need for frequent manual intervention. These mechanisms allow for longer operational uptime, decreasing labour requirements and improving overall efficiency. For advanced functionality, **IoT integration** enables remote monitoring and automation, allowing waste management personnel to receive real-time data on waste levels and system status. This feature enhances efficiency by facilitating predictive maintenance and timely waste disposal, reducing operational costs and response times.

Additionally, the system can incorporate automated waste segregation, streamlining the recycling process by categorizing waste into different types, such as biodegradable and non-biodegradable materials. By addressing key inefficiencies found in traditional waste disposal methods—such as irregular waste collection, inefficient bin usage, and lack of real-time monitoring—the SDM offers a cleaner, more sustainable approach to waste management. This makes it an ideal solution for high-footfall environments where effective waste disposal is crucial for maintaining cleanliness and public health.

2 Problem Understanding

- **Smart Waste Monitoring System:**

  The system is designed to **continuously track and monitor waste levels in real-time**, ensuring that waste collection schedules are optimized based on actual bin capacity. This prevents **waste overflow**, which can lead to hygiene issues, operational inefficiencies, and unnecessary collection efforts. By prioritizing waste disposal in high-traffic areas, this system enhances **public sanitation and resource allocation**, reducing costs associated with inefficient waste collection.

- **Hygienic and Efficient Waste Disposal:**

  The solution aims to **minimize human exposure** to unsanitary conditions by automating waste collection and disposal processes. By integrating touch-free mechanisms and reducing direct interaction with waste, the system ensures **safer disposal operations**, particularly in areas prone to contamination, such as hospitals, food courts, and public spaces. Additionally, the system's efficiency reduces the frequency of required maintenance, making it more **cost-effective and sustainable** over time.

- **IoT-Enabled Automation:**

  The incorporation of **Internet of Things (IoT) technology** allows for **remote monitoring, automated alerts, and predictive maintenance**, reducing reliance on manual checks. By providing real-time waste level updates, the system ensures timely intervention before bins reach capacity. Automated notifications improve operational efficiency by alerting waste management personnel about full bins enabling proactive waste collection and maintenance scheduling.

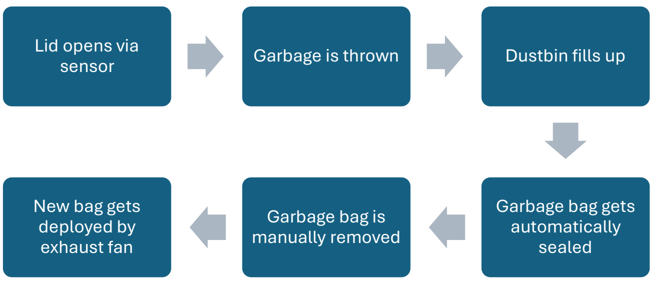
- **Automated Waste Segregation:**

  The system is designed to intelligently **classify waste into biodegradable, recyclable, and non-recyclable categories**, reducing the burden of manual sorting. This feature enhances **recycling efficiency**, ensures proper disposal of different waste types, and supports environmental sustainability initiatives. By automating segregation, the system promotes a more **streamlined and eco-friendly waste management approach**, minimizing landfill waste and optimizing resource recovery.

Each of these components contributes to a **robust, scalable, and intelligent waste management system**, aiming to improve **sanitation, efficiency, and sustainability** in high-footfall environments. The integration of **smart monitoring, automation, and waste segregation** ensures that waste disposal is not only more efficient but also more environmentally responsible.

3 Approach

In this section, we outline the approach adopted for developing the Smart Disposal Machine (SDM) to enhance waste management efficiency and hygiene. We begin by describing the **ultrasonic sensor-based waste level monitoring system, which categorizes fill levels at 33%, 66%, and 100% indicated by LEDs and provides real-time notifications through a web application**. This is followed by an overview of the automatic lid mechanism, which utilizes ultrasonic sensors to minimize human exposure and maintain hygiene. Additionally, an automatic sealing mechanism is implemented to prevent waste exposure. To enhance waste classification, methane and alcohol sensors are incorporated to differentiate between biodegradable and non-biodegradable waste before disposal. Furthermore, an automated bag deployment system is integrated, where a vacuum exhaust fan deploys the new cut bag once the sealing is executed and filled bag is removed. This integrated approach ensures efficient waste management, improved sanitation, and enhanced automation. Following is the workflow.



3.1 Electronics

This system incorporates a total of three microcontroller boards to manage various functions. An **Arduino Uno** is responsible for hand detection, lid operation, and new bag deployment via the exhaust mechanism. An **Arduino Mega 2560** controls the sealing mechanism and level detection, while a **NodeMCU** is integrated for IoT connectivity.

3.1.1 Lid opening:

The lid opens in response to an **ultrasonic sensor** that detects **hand proximity** and is actuated by a **TowerPro MG90S micro servo motor**. Once triggered, the lid remains open for a predetermined duration, allowing sufficient time for trash disposal before automatically closing. Safety measures ensure that the lid does not close abruptly, preventing accidental obstructions or injuries.

3.1.2 New bag deployment:

A new bag is deployed using a **vacuum mechanism** that relies on an **exhaust fan** powered by an **EMAX 1400KV BLDC motor**, which is switch-operated. The exhaust is strategically positioned at the bottom corner inside a housing, ensuring efficient suction. The fan generates a controlled vacuum force, which is strong enough to pull the plastic bag just enough to prepare it for the next filling cycle without causing excessive stretching or misalignment.

The system uses a **single large garbage bag** (refer [1]) as a continuous material source for multiple refills. Instead of using pre-cut individual bags, the large bag remains folded or loosely arranged within the housing. As each sealing and cutting cycle is completed, the vacuum mechanism pulls the next section of the bag forward, ensuring that a fresh portion is available for the next filling operation. This process allows the bottom of the newly deployed bag to be sealed simultaneously while the top of the filled bag is cut off. The vacuum ensures that the plastic bag is smoothly positioned before filling, preventing wrinkles or improper alignment. Once the new section of the bag is in place, the vacuum mechanism disengages, allowing the system to proceed with the next cycle seamlessly.

3.1.3 Sealing mechanism:

The sealing process is achieved using a **single-axis mechanism** designed for precise linear motion. A **nichrome sealing element**, fixed on one side, is responsible for simultaneously sealing and cutting plastic bags, like a plastic bag sealing machine. The system employs a **lead screw mechanism**, driven by an **RMCS 1023 stepper motor**, to control movement along a single axis. A **prismatic joint** guides this motion, ensuring accuracy and repeatability. (refer [2])

A rod, rigidly attached to the nut of the lead screw, serves as the actuator that pulls the plastic bag toward the sealing element. As the bag reaches the sealing position, the heated nichrome wire seals the top of the filled bag while simultaneously cutting and sealing the bottom of the next bag, ensuring a continuous and efficient sealing process(refer [1],[3]). Once sealing is complete, the actuator retracts to its home position, ready for the next cycle. A **relay** controls the activation of the sealing element, and the entire system operates using a **LiPo battery** for power.

3.1.4 Waste classification:

Alcohol and methane sensors will be integrated into the system and positioned near the waste disposal opening to classify waste as either **biodegradable or non-biodegradable** before disposal. As waste is introduced, the sensors detect the presence of specific gases, such as methane and alcohol vapours, which indicate organic decomposition. If the detected gases exceed a predefined threshold, the waste is classified as biodegradable; otherwise, it is categorized as non-biodegradable.

To provide immediate feedback to users, an **LED indicator** will blink according to the classification of the waste. Different blinking patterns or colours can be used to distinguish between biodegradable and non-biodegradable waste, ensuring clear and intuitive identification. This visual indication helps guide users in placing waste correctly, reducing misclassification. The sensor placement near the opening ensures that classification occurs before disposal, minimizing errors and improving accuracy. The entire process is automated, eliminating the need for manual sorting at the point of disposal.

3.2 Arduino Code

Following are the code snippets of every mechanism:

3.2.1 Lid opening:

```
#include<Servo.h>

Servo servo;
const int _USOutsideTrig = 10;
const int _USOutsideEcho = 9;
float time = 0;
const int maxTime = 15;

float _USOutsideDur, _USOutsideDist;

void setup() {
  servo.attach(3);
  servo.write(0);
  pinMode(_USOutsideTrig, OUTPUT);
  pinMode(_USOutsideEcho, INPUT);
  Serial.begin(9600);
}

void servoOpen() {
  time = 0.001;
  servo.write(90);
}
```

```
void servoClose() {
  time = 0;
  servo.write(0);
}

void loop() {
  digitalWrite(_USOutsideTrig, LOW);
  delayMicroseconds(2);
  digitalWrite(_USOutsideTrig, HIGH);
  delayMicroseconds(10);
  digitalWrite(_USOutsideTrig, LOW);

  _USOutsideDur = pulseIn(_USOutsideEcho, HIGH);
  _USOutsideDist = (_USOutsideDur*.0345)/2;
  delay(100);
  if (_USOutsideDist < 100)
  {
    Serial.print("Opening Lid");
    servoOpen();
  }
  else if (time !=0 ){
    time += 0.5;
  }
  if (time >= maxTime){
    servoClose();
  }
}
```

3.2.2 New bag deployment:

```
#include<Servo.h>

Servo ESC;
int speed;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  ESC.attach(9);
  delay(1);
  ESC.write(10);
  delay(5000);
}

void loop() {
//   put your main code here, to run repeatedly:
  while(Serial.available() > 0)
  {
    speed = Serial.parseInt();
    Serial.println(speed);
    ESC.write(speed);//45 limit
  }
}
```

3.2.3 Sealing element:

```
// Ultrasonic sensor pins
const int trigPin = 2;
const int echoPin = 3;

// Relay pin
const int relayPin = 4;

// Detection distance threshold (in cm)
const int detectionDistance = 20;

void setup() {
  // Initialize ultrasonic sensor pins
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  // Initialize relay pin
  pinMode(relayPin, OUTPUT);
  digitalWrite(relayPin, HIGH); // Turn off relay initially

  // Start serial communication for debugging
  Serial.begin(9600);
}
```

3.2.4 Level detection and stepper motor (sealing):

```
#define TRIG_PIN 30
#define ECHO_PIN 28
#define LED_33 26
#define LED_66 24
#define LED_FULL 22
#define NICHROME 32
#define X_STEP_PIN 2  // Pin for step signal (X-axis)
#define X_DIR_PIN 5   // Pin for direction signal (X-axis)
#define X_ENABLE_PIN 8 // Pin to enable/disable the motor
int dist = 5;
bool run = false;


void setup() {
  pinMode(X_STEP_PIN, OUTPUT);
  pinMode(X_DIR_PIN, OUTPUT);
  pinMode(X_ENABLE_PIN, OUTPUT); // Enable the motor (LOW to enable)
  digitalWrite(X_ENABLE_PIN, LOW); // Set direction of rotation
  digitalWrite(X_DIR_PIN, HIGH); // HIGH for one direction, LOW for the
other
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);
  pinMode(LED_33, OUTPUT);
  pinMode(LED_66, OUTPUT);
  pinMode(LED_FULL, OUTPUT);
  pinMode(NICHROME, OUTPUT);
  Serial.begin(9600);
}
long getDistance() {
    digitalWrite(TRIG_PIN, LOW);
    delayMicroseconds(2);
    digitalWrite(TRIG_PIN, HIGH);
    delayMicroseconds(10);
    digitalWrite(TRIG_PIN, LOW);
    long duration = pulseIn(ECHO_PIN, HIGH);
    long distance = duration * 0.034 / 2;  // Convert to cm
    return distance;
}
void runStepper(int distance)
{
  for (int i = 0; i < distance * 200; i++) { // Assuming 200 steps per
revolution
          digitalWrite(X_STEP_PIN, HIGH);
          delayMicroseconds(1000); // Adjust speed by changing the delay
          digitalWrite(X_STEP_PIN, LOW);
          delayMicroseconds(1000);
      }
}
void loop() {
    long distance = getDistance();

    Serial.print("Distance: ");
    Serial.print(distance);
    Serial.println(" cm");

    // Turn on LEDs based on distance thresholds
    if(distance !=0){
      digitalWrite(LED_33, (distance <= 37) ? HIGH : LOW);
      digitalWrite(LED_66, (distance <= 29) ? HIGH : LOW);
      digitalWrite(LED_FULL, (distance <= 20) ? HIGH : LOW);
    }

    if ((distance < 20)&& (distance !=0)) {
        run = true;
        runStepper(dist);
        digitalWrite(NICHROME, HIGH);
        delay(10000);
        digitalWrite(X_DIR_PIN, !digitalRead(X_DIR_PIN));
        digitalWrite(NICHROME, LOW);
        runStepper(dist);
        digitalWrite(X_DIR_PIN, !digitalRead(X_DIR_PIN));
    }
}
```

3.3 Chassis and dimensions

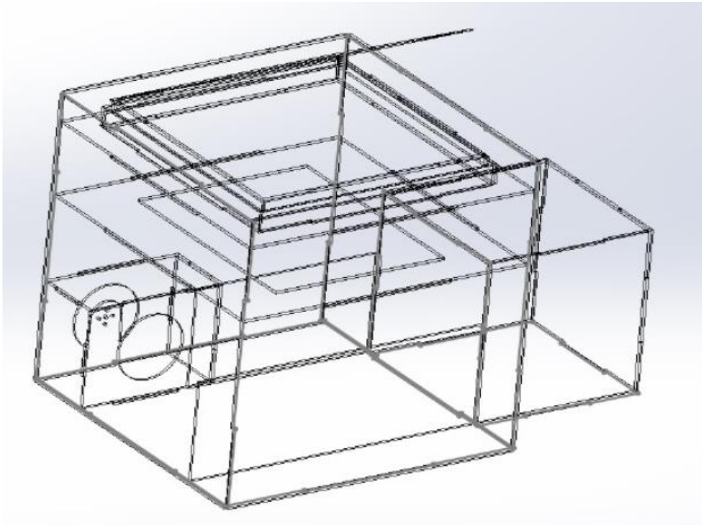
The **chassis** of the bin has been meticulously designed using **4mm thick acrylic sheet cutouts**, ensuring a lightweight yet robust structure. The entire assembly is precisely engineered to fit within a compact **45 × 45 × 45 mm volume**, optimizing space efficiency while maintaining structural integrity. Within this framework, the **storage compartment** is allocated a dedicated volume of **25 × 25 × 25 mm**, allowing for efficient containment and management of waste.

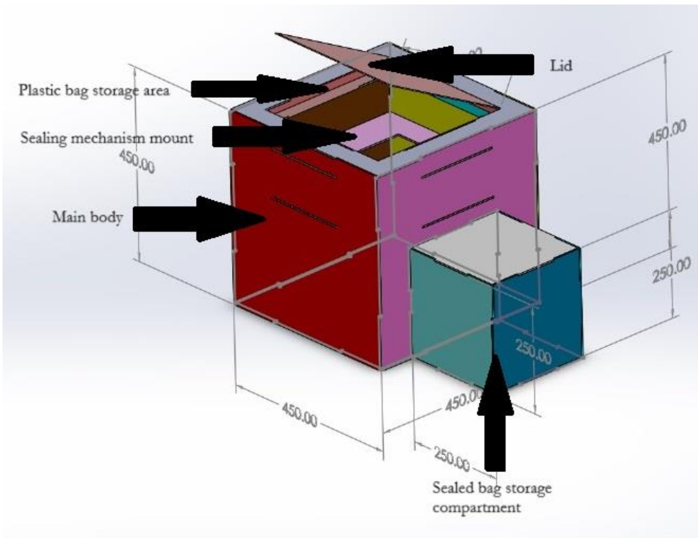
The system's component arrangement follows a hierarchical order from **top to bottom**, ensuring smooth operation and accessibility. The sequence of placements is as follows:

1. **Lid Opening Mechanism**: Positioned at the topmost layer, this mechanism facilitates automated or manual opening of the bin lid, ensuring ease of waste disposal.
2. **Bag Refill System**: Directly beneath the lid opening mechanism, the bag refill system allows for seamless waste bag replacement, ensuring continuous usability without manual intervention.
3. **Sealing Mechanism**: This module is responsible for securely sealing the waste bag after disposal, preventing leakage and maintaining hygiene within the storage compartment.
4. **Vacuum Exhaust Fan**: To optimize space utilization and maintain internal air pressure, a vacuum exhaust fan is incorporated below the sealing mechanism. This component aids in the removal of excess air, facilitating a compact and efficient waste management process.
5. **Storage Compartment**: The final section houses the storage area where sealed waste is accumulated. The storage design ensures **optimal space utilization** while maintaining stability and accessibility.

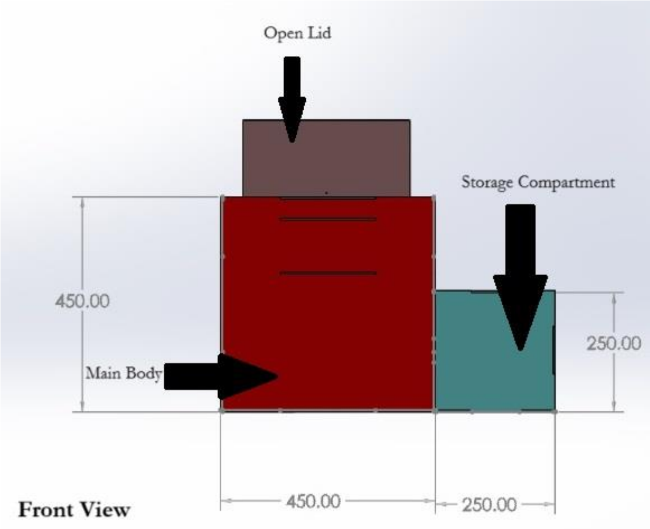
The **entire design process** was executed using **SolidWorks 2024**, leveraging its advanced **parametric** modelling to refine the structural and functional aspects of the bin. The software facilitated precise geometric modelling, component alignment, and stress analysis, ensuring that the final design adheres to durability and manufacturability constraints.

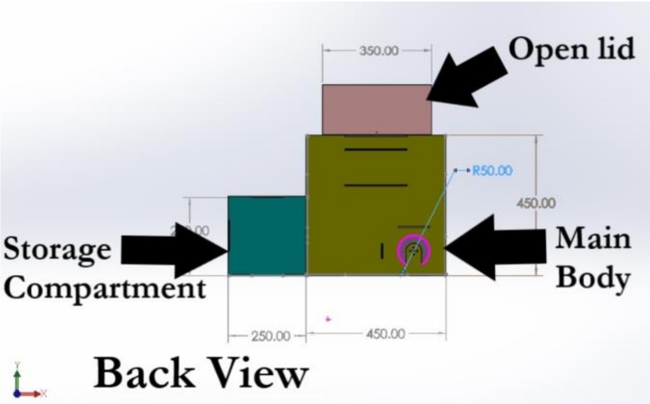
To further illustrate the spatial configuration and component integration, the following technical diagrams provide multi-view representations of the geometry and internal structure of the bin. These diagrams serve to highlight key design considerations, including component fitment, structural stability, and operational workflow.

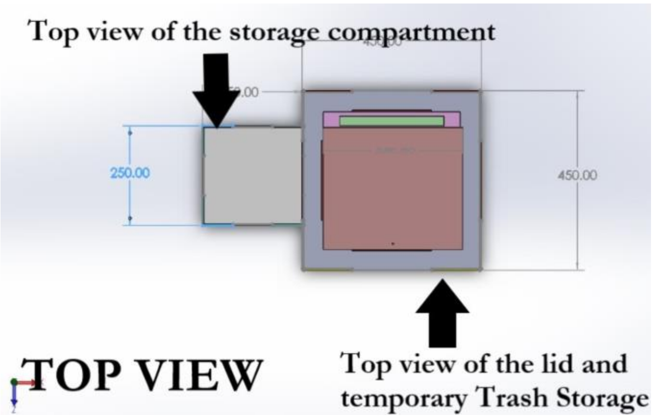


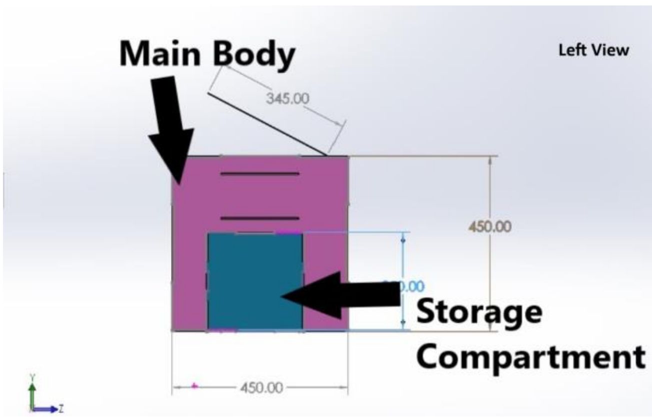


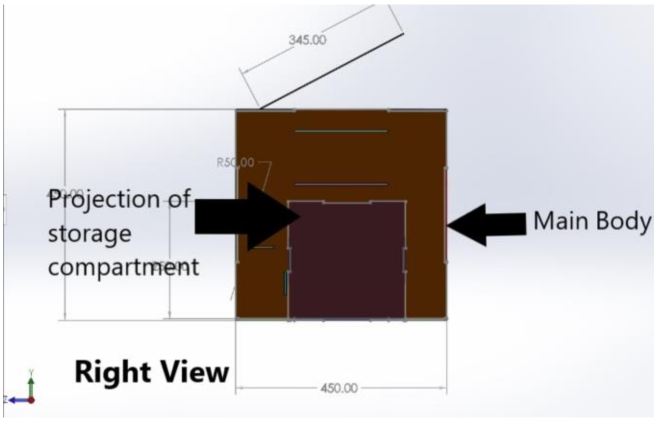
Smart Disposal Machine

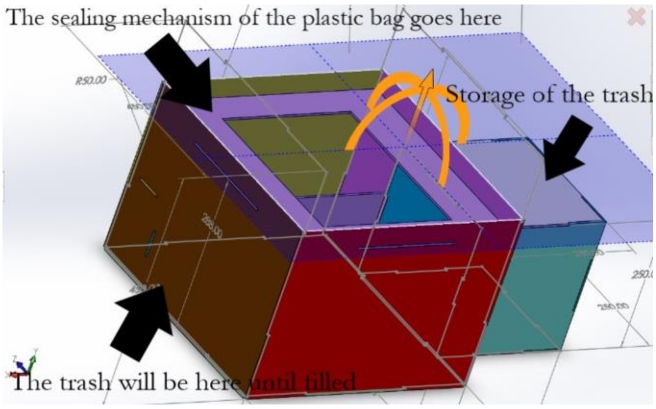


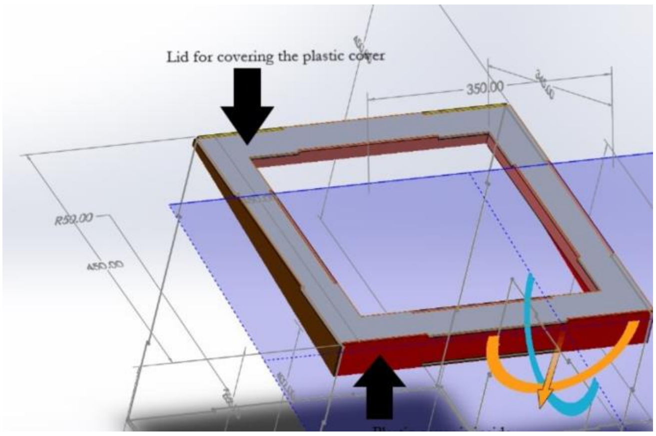


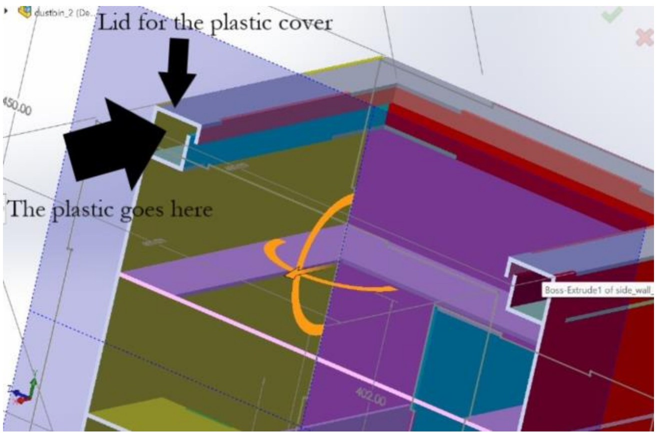












4 Future Scopes and Applications

The Smart Disposal Machine (SDM) has the potential for significant advancements and widespread applications in various sectors. Future enhancements and potential applications include:

4.1 Integration with AI for Smart Waste Sorting: By incorporating artificial intelligence and machine learning, the SDM could autonomously classify waste with greater accuracy. Using computer vision and advanced sensor fusion, the system could distinguish between different categories of biodegradable and non-biodegradable materials. This would enhance **automated sorting**, ensuring that recyclable, organic, and general waste are processed more efficiently. AI-driven classification could also adapt over time, improving sorting accuracy based on collected data and reducing errors in waste segregation.

4.2 IoT-Enabled Data Analytics and Smart City Integration: The SDM can be integrated with **cloud-based IoT platforms**, enabling real-time monitoring of waste levels and predictive analytics for better resource management. This would allow municipalities and waste collection agencies to optimize **garbage collection routes**, minimizing fuel consumption and operational costs. Real-time data can be used to predict peak waste disposal time and adjust collection schedules accordingly, preventing bin overflow. Additionally, SDMs across a city could be networked into a **smart city infrastructure**, where centralized monitoring helps enhance urban waste management strategies.

4.3 Solar-Powered Operation for Sustainability: To reduce dependence on external power sources, future SDM models could be equipped with **solar panels** for self-sustained operation. This would be particularly beneficial in **remote areas, public parks, and off-grid locations**, where conventional power sources may not be readily available. Solar integration would enhance energy efficiency, allowing the SDM to operate with minimal environmental impact while ensuring uninterrupted functionality even during power outages.

4.4 Industrial and Commercial Applications: The SDM could be deployed in **high-footfall locations** such as hospitals, malls, airports, and office buildings, where efficient waste management is crucial. By automating waste disposal, it can help **reduce labour requirements and improve hygiene** in areas where large amounts of waste are generated daily. Additionally, in **industrial settings**, the SDM could be programmed to **segregate hazardous and non-hazardous waste**, ensuring compliance with safety and environmental regulations. This would streamline waste processing in factories, laboratories, and medical facilities, where improper disposal can pose risks.

4.5 Public Awareness and Incentive-Based Recycling: A future version of the SDM could incorporate an **incentive system** to encourage responsible waste disposal. Users could be rewarded with **credits, coupons, or discounts** for properly sorting their waste into the correct disposal sections. This feature could be particularly effective in commercial areas, schools, and public spaces, promoting better **waste segregation habits** and increasing recycling rates. By providing immediate feedback on correct disposal behaviour, the system could also serve as an **educational tool** for communities.

4.6 Robotic Waste Handling and Automation: Integrating **robotic arms or conveyor-based mechanisms** could further enhance automation in waste handling. These features would enable **precise waste placement, compression, and movement** within the disposal unit, minimizing human intervention. For large-scale waste management, robotic sorting could improve efficiency by handling bulky or irregularly shaped waste items that conventional sorting mechanisms struggle with. Additionally, automation could enhance the **processing of recyclable materials**, separating them more effectively for reuse.

4.7 Accessibility for People with Disabilities: To ensure **inclusive and user-friendly waste disposal**, the SDM could be designed with accessibility features such as **voice command activation, motion sensors, and automated waste dispensing**. These features would assist individuals with disabilities, making it easier for them to dispose of waste **without requiring physical effort**. Additional improvements, such as adjustable height settings and **Braille-based instructions**, could further enhance usability for a wider range of users, ensuring that the system is adaptable to diverse accessibility needs.

By implementing these advancements, the **Smart Disposal Machine (SDM) can become a more efficient, technologically advanced, and scalable waste management solution**, addressing key challenges in waste disposal while adapting to various urban and industrial needs.

5 Results and Conclusions

The development of the **Smart Disposal Machine (SDM)** resulted in a **functional prototype**, demonstrating the feasibility of automated waste management. The system successfully integrates **ultrasonic sensor-based waste level monitoring**, categorizing fill levels at **33%, 66%, and 100%**, with real-time notifications sent through a **web application**. This feature allows users or waste management personnel to track bin capacity remotely, reducing the need for **manual inspections**.

The prototype includes an **automatic lid mechanism**, which operates via an **ultrasonic sensor and a TowerPro MG90S micro servo motor**. This minimizes direct human contact with waste, improving hygiene and reducing the risk of contamination. Additionally, **methane and alcohol sensors** classify waste into **biodegradable and non-biodegradable** categories before disposal. An **LED indicator** provides real-time feedback to users, ensuring proper segregation at the point of disposal.

A key feature of the SDM prototype is its **automated waste sealing and bag deployment mechanism**. Once the bin reaches full capacity, the system initiates a sealing process using a **nichrome sealing element and a lead screw-driven actuator**. The filled bag is sealed and separated, while a vacuum-based mechanism ensures that a new section of the garbage bag is deployed for the next cycle. This automation reduces **manual intervention**, enhancing efficiency and making waste disposal more streamlined.

However, as a **prototype**, the SDM is still in its early development stages and **may not function flawlessly in all scenarios**. Certain mechanical, electronic, or environmental factors could lead to **occasional inconsistencies** in waste detection, sealing, or sorting. Factors such as sensor calibration, bag alignment, and power fluctuations could affect performance, highlighting areas for further refinement.

While this version serves as a proof of concept, there is significant potential for improvement. Future advancements could include AI-driven waste sorting, IoT-based data analytics, and expanded automation features to enhance accuracy, efficiency, and scalability. With continued development, the SDM has the potential to evolve into a reliable, fully automated waste management solution, capable of addressing inefficiencies in modern waste disposal systems.

References

[1] Research paper/Patent: https://ppubs.uspto.gov/dirsearch-public/print/downloadBasicPdf/20240327111?requestToken=eyJzdWIiOiIzNTQ0N2E2Mi1jYzI3LTQ4MGEtYjdiYi0xODE3NDBmODBhYzEiLCJ2ZXIiOiIyYzc0N2U3ZC0wY2UzLTRiZDItOTFkYi01NDA2NDY5MTk2MWUiLCJleHAiOjB9

[2] Video 1: https://youtu.be/5tFnOZyDE_Q?si=TQ6Yb1H6t06FDDJ1

[3] Video 2: https://youtu.be/1gI3jva89lk?si=dEMHP1La-I92vb21