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MODELLING AND DEVELOPMENT OF REVERSE VENDING MACHINE FOR PET BOTTLE COLLECTION WITH INTEGRATED REWARD MECHANISM

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Abstract:

Plastic pollution is a pressing environmental concern, especially in urban environments with high consumption of single-use PET bottles. Reverse Vending Machines (RVMs) offer a modern solution by combining automation, sensor technology, and user incentives to promote responsible disposal. This paper presents the design, modelling, and fabrication of an RVM that automatically detects PET bottles, verifies their suitability, shreds them for processing, and provides user rewards. A comprehensive approach including mechanical design, electronic integration, software logic, and component selection is outlined. The developed prototype demonstrates effective operation and encourages community recycling behavior.

1. Introduction

1.1Background

The proliferation of PET bottles has created a massive waste management challenge globally. Traditional recycling systems often lack user engagement and efficiency, leading to poor recycling rates. RVMs act as smart collection points, incentivizing users by offering rewards upon successful disposal. This project addresses environmental sustainability by developing an RVM tailored for Indian urban settings, capable of detecting plastic bottles, validating content, and issuing rewards.

1.2 Objectives

The objective of this work is to design and develop a smart RVM that:

- Detects PET bottles using IR and proximity sensors
- Verifies that the bottle is empty using ultrasonic sensing
- Shreds the validated bottle to ease transportation and processing
- Provides user rewards via a servo-controlled dispenser

1.3 RVM Classification

Reverse vending machines are categorized into:

- Single-Stream RVMs: Accept mixed recyclables and sort internally
- Multi-Stream RVMs: Separate compartments for each material
- Specialized RVMs: Accept only specific items (e.g., PET bottles)

Fig no 1.1 Basic design of RVM

2. Literature Review

Several studies have demonstrated the potential of Reverse Vending Machines (RVMs) in enhancing recycling behavior. Patil et al. developed a basic RVM with a reward system, while Tomari et al. achieved over 99% accuracy using CNN-based item verification. Watanyulertsakul emphasized the reliability of proximity sensors for sorting. Gaur and Priyadarshini proposed an FPGA-based multi-sensor RVM, and Siddanth et al. integrated mobile apps for user rewards. International programs in Norway and Germany show high success rates with deposit-return systems. However, cost-effective, compact RVMs for local deployment remain underexplored—a gap this work aims to fill.

3. Methodology

3.1 System Architecture

The RVM consists of:

- **Sensors (IR, Ultrasonic, Proximity):** Sensors are used to sense different actions in RVM. It is used to detect, recognize, and process containers accurately. The sensors used are ultrasonic sensor, proximity sensor, photo electric sensor, barcode sensor.
- **Arduino UNO controller**: In a Reverse Vending Machine (RVM), an Arduino controller acts as the central processing unit, orchestrating the various sensors, actuators, and displays to ensure smooth operation. The Arduino receives input signals from sensors such as ultrasonic and photoelectric sensors, which detect the presence and type of recyclable items being deposited. It processes this information to make decisions, such as activating sorting mechanisms or compaction systems via connected actuators.
- **Servo motors for door control and dispenser**: Servo motors operate based on closed-loop feedback control, where the motor’s position is constantly monitored and adjusted to match the desired angle. In the Reverse Vending Machine, a servo motor is used to provide controlled mechanical rotation of the shaft in the bottle slot. This rotational movement is responsible for turning the bottle once it is inserted into the system. By rotating the bottle, the RVM ensures that sensors such as the capacitive proximity sensor and IR sensor get an optimal view from all sides of the bottle.

- **Shredder driven by a DC motor:** DC motors convert direct current electrical energy into mechanical rotational energy using electromagnetic interaction between the stator and rotor. The DC motor in the RVM is employed to rotate the shredding mechanism once the bottle has passed all verification stages and the storage bin has reached its fill threshold.

3.2 Operation Flow:

1. Bottle insertion
2. Water detection
3. Material verification
4. Reward dispensing
5. Shredding and storage

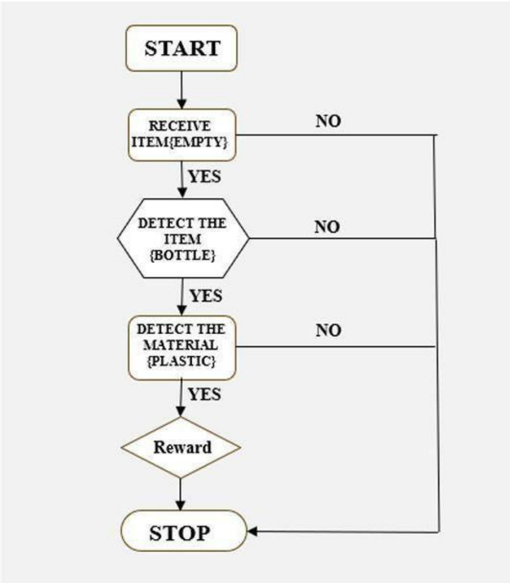

Fig no 1.2: Operation Flow

3.3 CircuitDiagrams

Detailed block diagrams define signal flow. The Arduino executes control logic based on sensor inputs. Code is written in C/C++ using Arduino IDE.

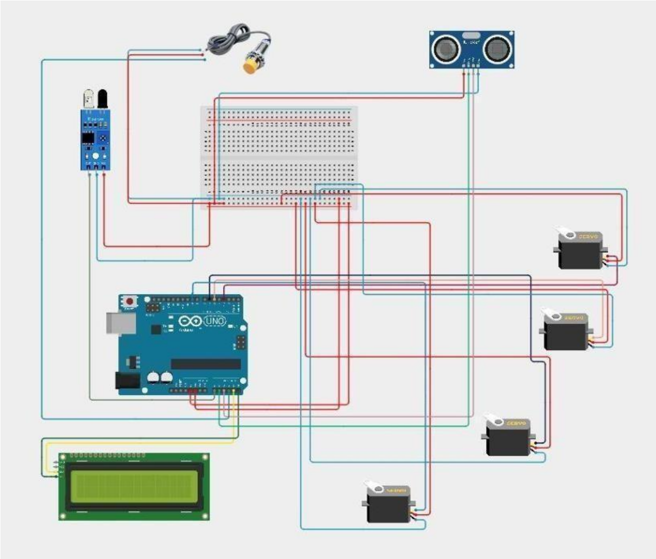

Fig no 1.3: Circuit Diagram

4. Design and Fabrication

4.1 CAD Design

All components were designed using SolidWorks. Major units include:

- **Bottle receiver with mounts**

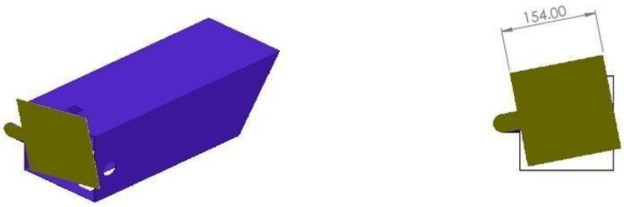

Fig no 1.4: Bottle receiver

- **Servo-actuated reward dispenser**

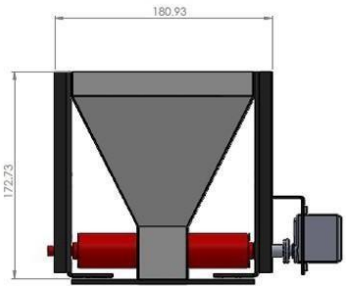

Fig no 1.5: Reward dispenser

- **Blade-based shredder mechanism**

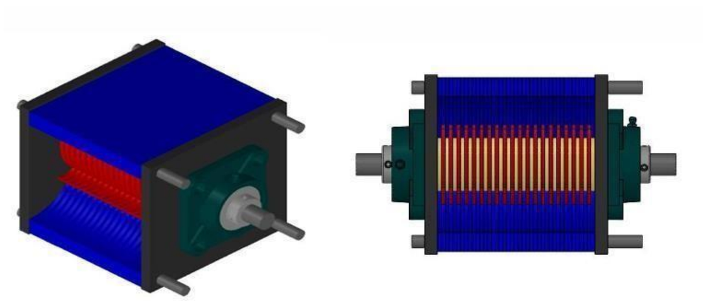

Fig no 1.6: Shredder

- **Welded MS frame for housing**

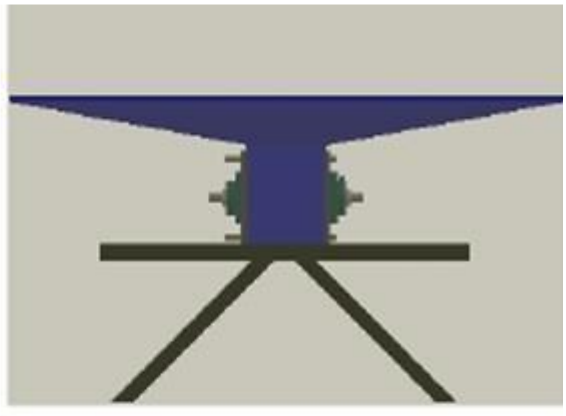

Fig no 1.6: Welded Frame

4.2 Material Selection

- GI Sheets for outer structure
- Mild Steel for shredder shafts
- Plastic and aluminum for moving parts

4.3 Arduino Code Highlights

- **Infrared sensor detects**

  presence SensorValue =

  analogRead(analogPin);

```
Serial.print(sensorValue);
if (sensorValue < 600) {
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Bottle detected!");
Serial.println("Bottle
detected!");
```

- **Ultrasonic sensor checks water level** digitalWrite(TRIG_PIN, LOW); delayMicroseconds(2); digitalWrite(TRIG_PIN, HIGH); delayMicroseconds(10); digitalWrite(TRIG_PIN, LOW); duration = pulseIn(ECHO_PIN, HIGH); distance = (duration * 0.0343) / 2;

```
...
if (distance < 10) { lcd.print(" Water Present ");
  ...
} else { lcd.print("Water
NOT Found");
  ...
}
```

- **Servo motor controls bottle intake door** for (pos = 0; pos <= 180; pos += 1) { myservo.write(pos); delay(15); } for (pos = 180; pos >= 0; pos -= 1) { myservo.write(pos); delay(15);

```
}
```

- **LCD display communicates system status**

```
lcd.setCursor(0, 0);
lcd.print(" System ");
...
lcd.print("Bottle detected!");
```

```
...
lcd.print("Water Present");
...
lcd.print("Collect Reward");
...
lcd.print("Tray Empty");
```

5. Components and Assembly

- **IR, Proximity, and Ultrasonic sensors:** In the Reverse Vending Machine (RVM), three key sensors ensure accurate and efficient operation. The ultrasonic sensor monitors the storage bin level by measuring the distance to accumulated bottles, triggering a full-bin alert when the threshold is crossed. The capacitive proximity sensor detects the presence of water inside bottles by identifying changes in capacitance, allowing the system to reject filled bottles and maintain hygiene. Meanwhile, the infrared (IR) sensor analyzes reflected IR light to verify the plastic type, ensuring that only recyclable materials like PET are accepted, thereby improving the quality and efficiency of the recycling process.

- **Servo motors (MG995) for door and dispenser:** In the Reverse Vending Machine (RVM), a servo motor provides precise, controlled rotation of the bottle slot. This rotation ensures sensors like the capacitive proximity and IR sensors can scan the bottle from all angles, enhancing the accuracy of water detection and material identification. Its closed-loop feedback system allows for accurate and responsive movement, making it ideal for this application.

- **DC motor with gearbox for shredding:** DC motors convert direct current electrical energy into mechanical rotational energy using electromagnetic interaction between the stator and rotor. The DC motor in the RVM is employed to rotate the shredding mechanism once the bottle has passed all verification stages and the storage bin has reached its fill threshold. This motor is selected for its ability to deliver high torque, which is essential for crushing 49 plastic bottles efficiently. When activated, the DC motor powers the shredder shaft, enabling it to break the bottle into smaller pieces for easy disposal or further recycling. Its simplicity, reliability, and torque-handling capability make it suitable for this high-power task in the system.

- **LCD (16x2) for feedback:** In a Reverse Vending Machine (RVM), the LCD display serves as the main user interface, showing instructions, accepted item types, rewards, and machine status. It enhances user interaction by providing real-time feedback and encouraging engagement with the recycling process.

- **Arduino UNO for processing:** The Arduino controller functions as the RVM's central processor, managing inputs from sensors and controlling outputs like actuators and displays. It ensures coordinated operation by processing data, making decisions, and delivering user feedback through the LCD.

- **Shredder blades fabricated from hardened steel:** The shredding mechanism in the Reverse Vending Machine (RVM) uses high-speed, motor-driven blades mounted on a durable, high-strength shaft to cut validated PET bottles into small, recyclable flakes. The blades, typically made of hardened steel, ensure precise shredding, while the shaft—secured with keyways and supported by bearings—efficiently transmits torque from the motor. This setup ensures smooth, reliable, and maintenance-friendly operation, with protective housing and sensors ensuring safe and efficient processing.

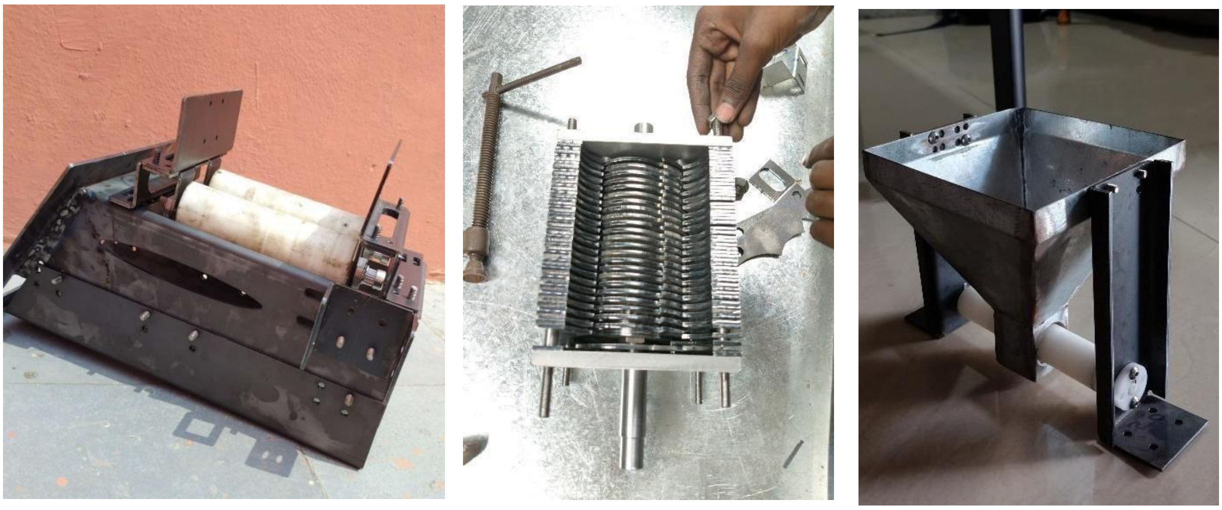

Fig no 1.7 Fabricated Components

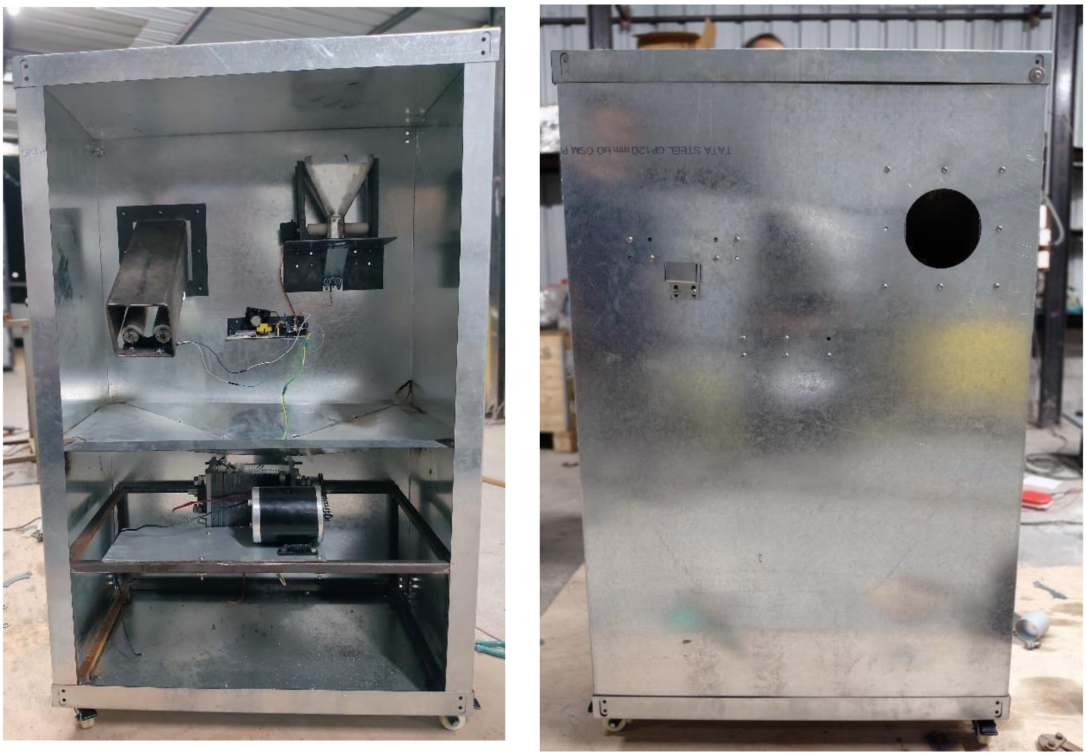

Fig no 1.8 Final Assembly of the Machine

6. Results and Testing

The system was successfully tested for:

- Bottle detection and rejection of non-plastic items
- Accurate reward dispensing upon validation
- Efficient shredding with minimal jamming
- Compact storage for shredded plastic

7. Conclusion

The developed Reverse Vending Machine (RVM) integrates detection, validation, shredding, and incentivization into a compact, user-friendly system that promotes recycling and reduces plastic waste in urban environments. By automating the process and offering rewards, it encourages sustainable behavior and improves waste management efficiency. Its scalable design makes it suitable for public deployment in areas like malls and transit hubs. Future enhancements, such as IoT integration for real-time monitoring and mobile payment systems for seamless reward distribution, can further increase its functionality, making it a smart solution for modern, sustainable cities.

7.1 Authorship Contributions

D. Pavan Kumar: System design, CAD modeling

K. Aksharaakruthi: Arduino programming, circuit design

T. Sumith Singh: Fabrication, material procurement

B. Sukesh Kumar: Literature review, documentation, final assembly

Mr. P. Shashidar: Supervision, mentoring, final validation

7.2 Declaration of competing interest

We declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7.3 Acknowledgements

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