IoT-Enabled CVM Design & Architecture for E-Waste Management: A Solution towards Environmental Sustainability

Singh, Kuldeep
Kabadi Techno Pvt. Ltd

Singh, Pushpa
GL Bajaj Institute of Technology and Management

Kumar, Anuj
Kendriya Vidyalaya No.1

Walde, Vishwajit
Kabadi Techno Pvt. Ltd

https://doi.org/10.5109/7172291

出版情報：Evergreen. 11 (1), pp.343-353, 2024-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

IoT-Enabled CVM Design & Architecture for E-Waste Management: A Solution towards Environmental Sustainability

Kuldeep Singh[1], Pushpa Singh[2,*]Anuj Kumar[3], Vishwajit Walde[4]
[1,4]Kabadi Techno Pvt. Ltd. Uttar Pradesh, India
[2]GL Bajaj Institute of Technology and Management, Greater Noida, India
[3]Kendriya Vidyalaya No.1, IIT Kharagpur, India

*Author to whom correspondence should be addressed:
E-mail:pushpa.gla@gmail.com

(Received August 31, 2023: Revised January 2, 2024: Accepted January 19, 2024)

Abstract: There is exponential growth in electronic devices, and people frequently change or replace these devices, leading to a significant increase in electronic waste (E-waste). Consequently, proper electronic waste management techniques are essential to preserve and sustain the environment and natural resources. The proposed Collector Vending Machine (CVM) model is an IoT-based smart device that enables customers to dispose of their E-waste and receive a token amount in return. To participate in this system, customers need to register with the proposed model to obtain a Quick Response (QR) code. This QR code is then attached to the e-waste item, which can be deposited in the CVM. Once a threshold level of 80% is reached, the CVM alerts the nearest Collector to gather the E-waste. Collectors then deposit the collected E-waste in the warehouse, where an efficient recycling mechanism is applied to extract the precious metals. The ESP32 microcontroller is utilized to mount sensors and collect data from them. The overall goal of this work is to provide an effective and sustainable solution to electronic waste management, contributing to environmental sustainability.

Keywords: E-waste; Recycling; E-waste management; IoT; CVM; ESP32; Sensors; Environment

1. Introduction

Electronic equipment is an integral part of our lives. People are surrounded by multiple electronic devices such as mobile phones, computers, laptops, home appliances, wearable devices and entertainment devices. These devices are frequently exchanged and inclined[1)]. People dispose of old and non-functional electronic equipment because it has become useless or cconsidered waste with resulting in electronic waste or E-waste. E-waste encompasses any electronic item or hardware part that reaches the end of its useful life. This includes microwaves, phones, televisions, DVD players, and more. Home entertainment devices, home appliances, handheld or information and communication devices, user-oriented electronic utilities, and medical equipment can all become E-waste over time. E-waste poses a significant problem due to the presence of harmful elements in electronic equipment. It comprises various toxic materials and valuable metals such as gold, mercury, platinum, cadmium, gallium, lead, silver, beryllium and indium. Several studies indicate that the disposal of E-waste often occurs without proper awareness and procedural protocols. Unattended E-waste can lead to both environmental and health problems[2)].

E-waste management outlines a method that includes recycling, disposing of, reusing, and reselling discarded electronic and electrical waste to transform them into valuable products. While waste is typically considered non-valuable, this notion does not hold true for E-waste, which consists of valuable constituents such as palladium, copper, platinum, silver, iron, and aluminum. However, it may also contain hazardous materials like cadmium, lead, mercury, barium, beryllium, arsenic, hexavalent chromium, etc. urban mining aims to extract precious and semi-precious materials from E-waste to benefit the cities. However, if done unscientifically, it may lead to environmental degradation and pose risks to human health[3)]. Figure 1 illustrates the country-wise generation of E-waste, revealing that India is the third-largest country in E-waste generation.

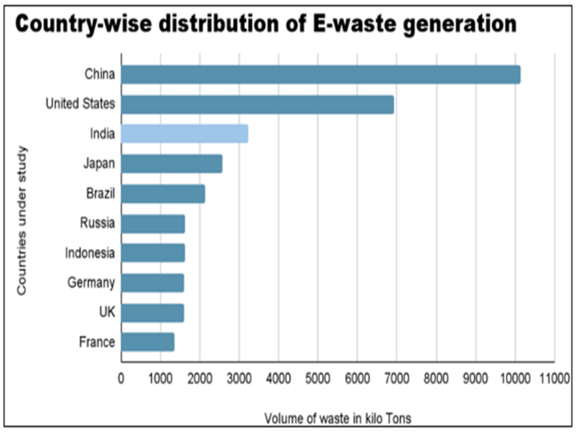

Fig.1: E-waste Statistics

Figure 2 suggests that India faces challenges in achieving equilibrium between E-waste generation and recycling. With only 20% of E-waste being recycled and reused correctly in India, this is a matter of alarming concern. A mechanism must be required to efficiently handle E-waste management, dismantling, collection, and disposal.

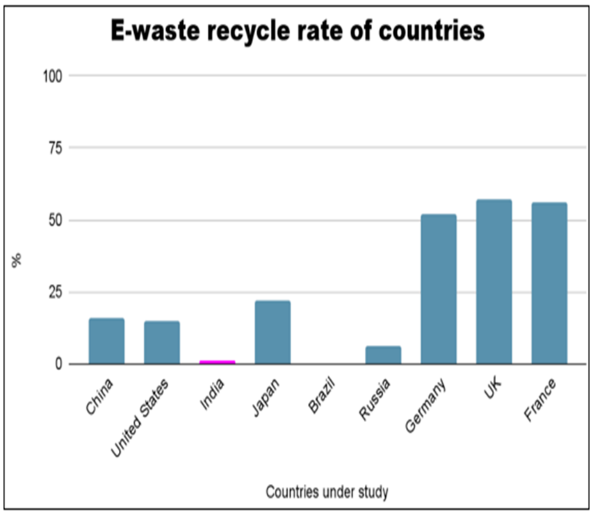

Fig.2: E-waste recycling rate of countries

India is the second largest importer of E-waste after China. Therefore, appropriate E-waste management practices are crucial to conserve natural resources and ensure environmental sustainability[3,4]. Emerging technology such as AI, IoT, and cloud computing have the potential to address the issue of E-waste management [5]. IoT is a physical object network with embedded technology that enables interaction and communication with the internal or external environment. It connects machines, tools, and devices to the Internet through wireless technologies. The current advancements in IoT witness the unification of technologies such as big data, cloud computing, machine learning, networking, and low-powered embedded systems.

E-waste management can be revolutionized with the help of IoT, providing sustainable solutions for the environment. The primary objective of the proposed model is to design an IoT-based Collection Vendor Machine (CVM) for E-waste management to address the E-waste problem. The Proposed model introduces a method to dispose of E-waste smartly, efficiently, and cost-effectively. The proposed system utilizes a laser sensor to calculate the volume of E-waste in containers. Simultaneously, it transmits the CVM data over the Internet and notifies the Collector when the container volume exceeds a specified threshold.

The remaining sections of the paper cover the motivation and background, discussed in Section 2, followed by the design and implementation of the proposed model in Section 3. Section 4 includes the results and discussion, while Section 5 presents the conclusion.

2. Motivation and Background

Recently due to COVID-19 extensive usage of electronic devices and proficient disposal of the E-waste produced by the Information and Communication Technology (ICT) sector has become a severe concern [6, 7] which need quick attention. The recycling and acquisition rate of E-waste for its management and control continues to stay low in India. Authors in[8,9] presented the status of E-waste in India along with several methods used for recycling and their limitations. Improving this situation is the need of the hour, given that the generation of e-junk is increasing at a growth rate of approximately 31%. Figure 3 illustrates the types of E-waste at the consumer level and the influx of potential E-waste continues to rise at a growing rate. The situation surrounding this issue calls for new strategies to address problems in the E-waste industry, aiming to prevent health and environmental degradation while reinforcing a balance between the generation, collection, and recycling rates of E-waste[2,3,8,9].

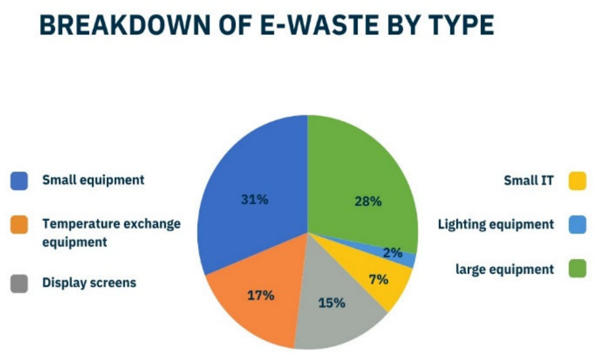

Fig. 3: Breakdown of E-waste by type

Several studies have been conducted to establish smart management in the cities and states of India [10, 11, 12,13]. AI and IoT based mechanisms were proposed to perform waste Learning based techniques such as management at the household level[14,15,16,17,18], which lead A sustainable IoT. Machine learning techniques are good for municipal solid waste management (MSWM) [19, 20]. Authors in[21] used a deep learning CNN model for a smart trash bin that employs a microcontroller, IoT and Bluetooth technology. Other in texts[22, 23,24,25] used microcontrollers like Raspberry Pi and Arduino to control the sensors and used GPS to send location data of the smart bin. A concept of smart bin was proposed to send the alert message to users. Concept was implemented in state Odisha (India) with the help of random forest algorithm. Accuracy of algorithm was observed 95.8%[26]. One waste management technique monitored smart bins using IoT, the LoRa communication protocol, and TensorFlow for object detection to perform waste identification and classification[27,28]. While various IoT and machine learning-based waste management techniques predict waste and send alerts, a study proposed an alert-based smart bin in [29,30,31] that can be monitored by waste management agencies and corporations. In another work[32], an integrated online framework for waste management was proposed, where the Collector collects waste from the 'kabadiwala' and deposits it to the Recycler. Additionally, CNN-based smart waste management techniques were proposed in[28,33] which were based on TensorFlow Lite and LoRa-GPS Shield in IoT Environment.

Most of the literature supports smart bins as a solution for general waste management. However, electronic waste management has not been thoroughly discussed, despite gaining recent attention due to the exponential growth in electronic devices[34]. Reference[35] proposed the concept of CVM for E-waste management. However, CVM lacks the implementation details. E-waste collection can potentially be facilitated through vehicles of local delivery services and interactive online maps based on users' requests for recycling[36]. A cloud enabled system offers to analyze patterns and trends for garbage prediction[37] which can make efficient to proposed system. Recycling of E-waste offers an economic viability to generate revenue [38, 39]. Moreover, a crucial emphasis should be on sustaining the environment, necessitating enhanced waste management techniques through the utilization of emerging technologies[40,41,42]. Effective waste management was employed to minimizing the Green House Gas (GHG) emissions [43].

While several approaches have been developed for general waste management, E-waste management remains an unresolved problem that continues to impact the environment. E-waste contains hazardous substances that affect both the environment and human health [2,44]. Toxic elements such as lead (Pb), cadmium (Cd) and copper (Cu) exist in E-waste when mixed in air, soil, water, etc., causes harmful effects to the environment and human health[45,46]. Therefore, new techniques, solutions and services are essential to address the challenges of E-waste management. This motivation has led the author to propose the extended CVM concept for the efficient and secure management of E-waste.

3. Proposed IoT Based Framework for Waste Management

An intelligent and cost-effective solution has been proposed to ensure a smart, efficient and reliable way of E-waste disposal: the Collector Vending Machine (CVM) for handling E-waste. Unlike conventional vending machines, the proposed prototype, which is a smart and self-operating model, functions as a reverse vending machine. User interaction begins when the QR code is generated, the obtained product is sorted, analyzed, and information regarding the contents is recorded in the database for further processing. The system's workflow is initiated when the user interacts using the app or the website as represented in Fig. 4

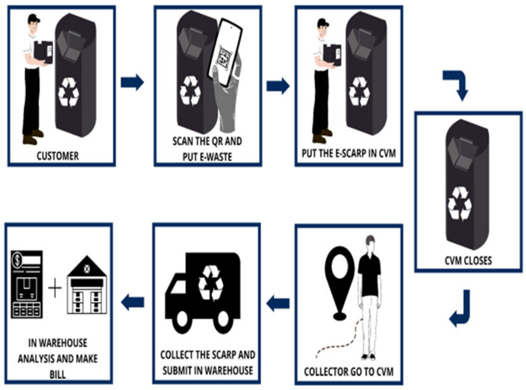

Fig. 4: Work Flow of CVM

1) The customer who wishes to sell their E-waste has to register with the proposed model to acquire a QR code. The QR code encrypts all information related to the customers[47].
2) The customer or user has a 'TRACK' option in the software system, which uses Google API.
3) The Customer scans the QR code, and CVM produces a receipt with a barcode. The customer attaches that receipt to his packaged item and disposes it in the CVM.
4) Next, Collector will collect E-waste items from CVM and deposit them in the warehouse for recycling and billing.
5) After dismantling and disassembling the packaged item, the customer receives the specified token amount in the associated account.

3.1 Proposed Architecture Design of IoT-Based CVM

CVM architecture is the combination of hardware and software components. Hardware components are essential parts of an IoT based CVM. CVM hardware consists of devices for controls, networks, bridges, sensors, gates and motors. Related software component facilitates connecting hardware devices and the exchange of data with other devices and systems over the Internet. Administrators can manage, control and monitor CVM efficiently and effectively.

The internal organization of the CVM is shown in Fig. 5. The built-in mobile device, which acts as a display screen meant for user interaction, communicates with ESP32 with the help of BLE. Commands are forwarded to the motor drivers and laser sensor forto initiate gate operation and to notify if the CVM is functional to accept E-waste. There are three gates: gate 1 (the inlet gate), gate 2 (the outlet gate), and gate 3 (the internal gate in the CVM machine). Gate 1 is used by the customer, gate 2 is utilized by the Collector, and gate 3 transfers contents received from the customer from the first chamber to the middle chamber. The built-in mobile device, designed as a display screen for user interaction, communicates with ESP32 through BLE. The complete process of the CVM machine categorized based on the user, who can be a customer or a collector. The next section explains the various hardware modules used in the CVM architecture, which synchronizes all its components to work coherently.

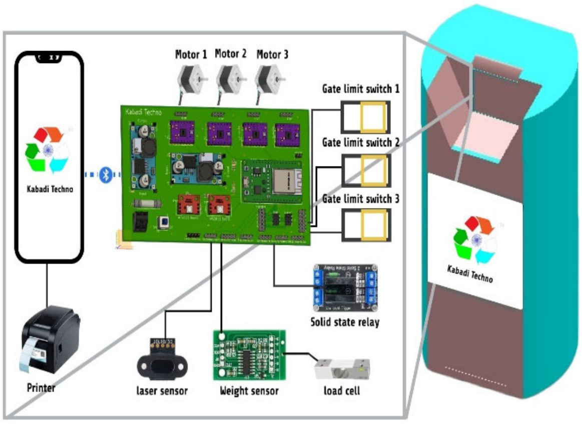

Fig. 5: Mechanical structure of CVM

CVM is an IoT-based prototype where two sensors namely laser sensor and weight sensor, are connected to a Bluetooth network and data is collected and transmitted to the cloud. The data flow of the proposed CVM is illustrated in Fig. 6.

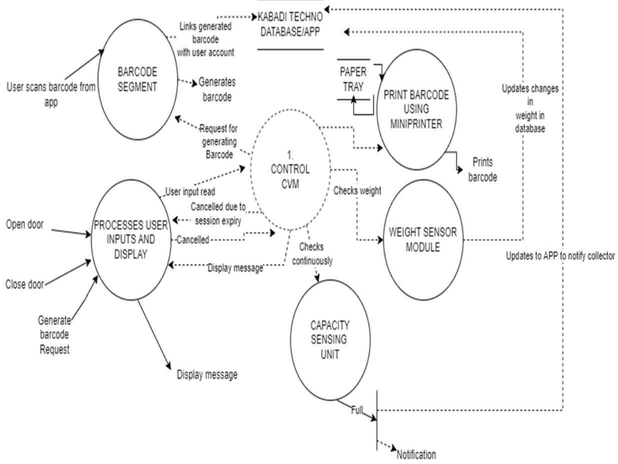

Fig. 6: Data flow diagram depicting the working of CVM

3.1.1 Proposed Architecture Design of IoT-Based CVM

ESP32

The ESP32 is a dominant, versatile WiFi-BT-BLE MCU module designed for a wide range of applications. It serves as a user-friendly master controller, eliminating the need for external interfaces to establish WiFi or Bluetooth connections. Using Bluetooth, users can connect to their phones, and for detection, users can broadcast low-energy beacons. The use of WiFi enables an extensive physical range and provides the capability to connect to the Internet through a router. The ESP32 module incorporates the ESP32 wroom chip, designed for scalability and adaptability. It features 2 CPU cores that can be individually controlled or powered, with an adjustable clock frequency ranging from 80MHz to 240MHz. The ESP32 chip consumes less than 5uA. Additionally, this module supports data rates of up to 150Mbps and an output power of 22dBm at the power amplifier, allowing for a comprehensive range. The CPU is constantly powered off and uses the low-power coprocessor to monitor the peripherals for changes or alterations in thresholds. The module provides a broad set of peripherals, including capacitive touch sensors and Hall sensors, while supporting other sensors such as weight sensors, solid-state relays, motor drivers, or RGB LEDs, etc.

PCB Board

We designed the PCB board using Autodesk Eagle software for the hardware architecture requirements, and the PCB has been manufactured following the simulation. We soldered the components onto the PCB, such as the switch, fuse, male header, female header, small registers, capacitors, and transistors. The PCB board was created by the Kabadi Techno Team.

POLOLU Motor Driver

For driving the gate motors, we are using the Pololu DRV8834 low-voltage stepper motor driver carrier. This breakout board is designed for micro-stepping bipolar stepper motor drivers, with an operating voltage of 2.5-10.8V. Despite the stepper motor being powered with a low voltage, it can deliver almost 1.5 amps per phase continuously without a heat sink or forced airflow. Additional features include adjustable current limiting, over-current and over-temperature protection and six micro-step resolutions. These features make it highly effective for our CVM machine application.

NEMA 17 Motor

The 1.6 kg-cm Motor is suitable for our Pololu motor driver. The Nema 17 stepper motor supplies 16 kg-cm of torque at 0.31A current per phase. Using the Pololu motor driver, the motor's position can be changed through commands to move or stay at rest in one position. The stepper motor provides an instant response to the input pulse from the stepper motor drivers, swiftly stopping, starting, and modifying RPMs. This is suitable and efficient for our Pololu driver.

Limit Switch

It is essential to confirm the proper status of our CVM gate, whether it is open or closed. This functionality ensures and verifies the operation of the gate and motor driver.

Weight Sensor

An HX711 weight sensor has been employed for converting an analog signal into a digital signal. It has a dual-channel 24-bit precision that can be used as a weight, pressure sensor load cell amplifier, and ADC-HX711 module is a small breakout board for the HX711 IC that allows you to easily read load cells to measure weight by connecting it to our ESP32 module, and This allows us to detect changes in the resistance of the load cell. In our case, we need to calculate the calibration factor, which is -95. After determining the calibration factor, we can insert the value into the code, enabling us to obtain very accurate weight measurements. The HX711 weight sensor uses a two-wire interface (clock and data) for communication. Our microcontroller's GPIO (ESP32) pin should work for this purpose, and numerous libraries have been written, making it easy to read data from the HX711. Therefore, HX711 can obtain the analog data from the load cell and send digital data to the ESP32 module.

Load Cell

It functions as a force transducer, converting the weight or pressure placed on it, up to 40kg, into an electrical signal. Its physical design corresponds to a straight bar, with a support structure necessary for accurately reading applied forces. Load cells are designed to measure the changes in electrical resistance, which is proportional to the strain applied to the bar. These load cells have four strain gauges arranged in a Wheatstone bridge formation. It is equipped with four lead wires that can be connected to the HX711 sensor. The load cell is user-friendly, requiring a driving voltage of 5-10V and generating output voltage proportional to the applied force changes. Installing the sensor with the support structure is a straightforward task. The load cell needs to be positioned between the upper and lower plates in such a way that one end, between the upper plate and the upper side of the load cell, is fixed with a screw and bolt to the plate, while the other end is left floating. Similarly, between the lower plate and the bottom side of the load cell, the end on the same side as the top (fitted to the upper surface with a screw) should be left floating, while the other side is secured with a screw and bolt to ensure contact of this end with the lower surface. It is crucial to handle the load cell with care and avoid direct pressure on the white plastic cover part to prevent damage to the load cell.

Distance Laser Sensor

We have used a laser ranging TOF10120 sensor module UART/12C and a voltage range of 3-5V, capable of measuring distances within the range of 10-180cm. This sensor plays a crucial role in calculating the CVM volume to monitor its capacity. The TOF10120 range sensor offers precise, repeatable long-range distance measurement. The TOF10120 sensor employs time-of-flight sensing technology, utilizing Sharp's unique SPAD (single-photon avalanche diodes) through a low-cost standard CMOS process. This technology enables accurate ranging results, increased immunity to ambient light, and improved robustness against cover-glass optical cross-talk, thanks to a special optical package design.

Solid State Relay

We have incorporated a 5v two-channel SSR G3MB-202P sol-id-state relay module for controlling device charging and printer charging when their battery levels are low. The relay module comes equipped with a resistive-type fuse. Solid state relays are credited for longer lifespan and efficiency in generating no noise The module is operated and controlled by an ESP32 microcontroller that supplies a 5V digital signal. The relay can switch AC voltages between 100V and 240V with a 2A current rating. Each relay comprises three terminals: NO (Normally Open), COM (Common), and NC (Normally Closed). When the input voltage is supplied to the coil, NC disconnects from the COM, and conductivity between them is interrupted. Simultaneously, NO establishes a connection with the COM, establishing conductivity between them. This configuration is utilized to determine the state of the connected load.

RGB Led

To indicate different states or functions performed during communication between the peripheral module and ESP32 chip, CJMCU-123 WS2811RBG LED Breakout module has been used. The integrated driver of the LED allows the user to control the color and intensity of the LED light. The pixels of RBG colors have the capacity to use 256 brightness levels. The module features an inbuilt electric reset circuit and a power loss reset circuit. The scan frequency is approximately 400Hz/s.

Voltage Regulator

The LM2596S DC-DC buck converter power supply is used to operate the peripheral or the ESP32 module. It is capable of converting input voltages within the range of 18V to 12V or 5V.. Named a buck converter, it works by having the inductor 'buck' or oppose the input voltage, stepping it down. Therefore, it is a step-down module and functions as a switch-mode power supply. The output range can be fixed at 3.3V, 5V, 12V, or adjusted within a specific range. Operating at a switching frequency of 150kHz, this converter features a high-precision potentiometer, enabling efficient driving of loads up to 3A.

Mini Printer

This is interfaced with the microcontroller to print the receipt for the user, which they can then attach to the surface of their E-waste before submitting it into the CVM. The printer requires a 3.3V to 5V TTL serial output from the microcontroller. Positioned within the CVM enclosure, this mini printer serves the function of a receipt printer commonly seen in ATM machines.

3.1.2 Description of Software modules

Thonny IDE

Thonny IDE is a development platform environment for Python. In order to program the ESP32 with micro python firmware, we have used this IDE. It can be installed on Windows PC, Linux, and MAC OS X.

Android Studio (IDE)

We have used Android Studio to develop the customer and collector app interfaces. The Flutter project was built using Android Studio. Android Studio IDE is an integrated development platform for Android apps based on IntelliJ IDEA build.

QR Code

QR(Quick Reference) code link the user to their customer account when they scan the code through the mobile App. QR codes find their application in tracking information about the product in an organization or workflow. It is a type of barcode typically used for storing information up to 3kB of data. QR codes consist of an array of black-and-white modules or squares. The largest version of this model is version 40, which has a size of 177 x 177 modules. QR codes are known for their reliability due to advantages such as data recovery during events of damage equal to or less than a 30% threshold, faster performance in retrieving data during scanning, and efficient data storage. They can be read from top to bottom and left to right.

3.2 Implementation of CVM

The complete implementation of the CVM machine is divided according to the user, who can be a customer or a collector. Refer to Fig. 7, illustrating the operation of CVM in terms of Customer and Collector. The customer is an external entity who wishes to sell their E-waste through this proposed CVM. The collector is also an external entity that interacts with CVM to collect the E-Waste from the CVM. Hence, the proposed CVM has two primary algorithms: one for customers who wish to sell their E-waste and another for collectors who collect the E-waste from the CVM and submit it for recycling. A detailed description of Fig. 7 is provided in sections 3.2.1 and 3.2.2.

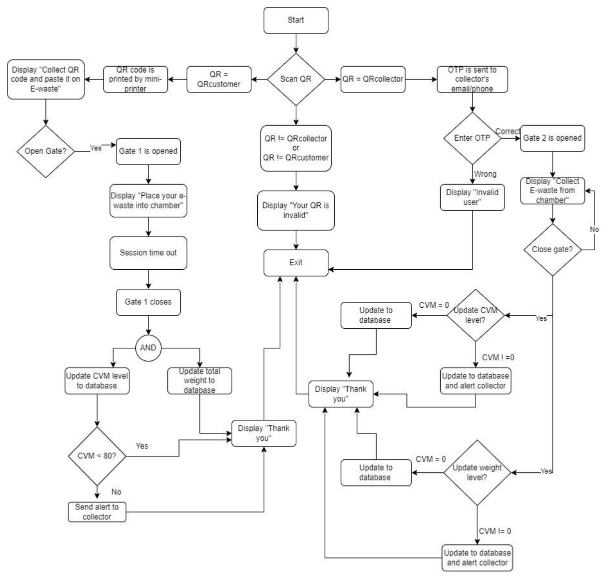

Fig. 7: Flow chart depicting the working of CVM for Customer and Collector

3.2.1 Algorithm for Customer

To locate the CVM, the customer can use the company app, Kabadi Techno App, or the web application kabaditechno.com. The customer needs to register with the application according to Algorithm 1. The user will interact with the CVM using the built-in user interactive screen of the machine. At the backend, the CVM machine sends a request hosted in a cloud service. Consequently, a unique QR code is generated for that CVM machine, and the unique ID is embedded in the QR code. The generated QR code is displayed on the user panel with instructions guiding the user on how to scan the code. The customer scans the code using the customer app, and the app requests the backend code to authorize and link the QR code to their Kabadi Techno account. This way, the team can track the status and provide the maximum calculated value for the E-waste. The backend code provides acknowledgement at both the client end and the developer end. The QR code is then printed for the customer. The nature of the QR code printout is a sticky note, and the user will have to attach it to their E-waste. The customer is guided to the create screen, which instructs them to click the gate button, opening the upper gate of the machine (inlet gate), as shown in Fig. 4. The customer should place their E-waste in the inlet chamber, and the door closes after a set time. Internally, Gate 3, located between the inlet and outlet gates, opens to transfer the E-waste to the next chamber. If the user cannot place the E-waste within the session, they can open the gate again to place their E-waste in the next session. Internally, the weight sensor records the cumulative weight after every disposal of E-waste. In other words, the weight is summed up after the particular session to measure the total weight of the contents in the CVM. The customer can check the price details and track the status through the app. The algorithm for the overall working of the customer for the CVM is shown in Table 1 and visualized in Fig. 8.

Algorithm 1: Working of CVM for Customer

```
if Customer login is correct then
    CVM displays "Generate QR code";
    Customer press generate button;
    Customer-specific QR code is generated;
    if QR code is true then
        CVM displays "Collect your QR print and paste on your E-waste item";
        Mini printer prints the sticky note;
        CVM Scan the QR code;
        CVM Gate 1 will be opened;
        Dispose your e- waste to the CVM chamber" ;
        Display " Click on Close Button";
        Compute CVM Level and item weight;
        Add Weight from the current session to WeightTotal;
        totalweight ← totalweight + weight;
        if CVM_level ≤ 0.8 then
            Update database
        else
            Update database and send alert to admin
        end
    else
        CVM displays "QR code is invalid";
    end
else
    You are not authenticated Customerr;
end
```

3.2.2 Algorithm for Collector

The CVM machine constantly monitors the weight and volume of its storage. A notification is sent to the collector through their app account whenever the machine reaches 80% full capacity. The collector then proceeds to empty the machine, following the subsequent steps while interacting with the CVM. The collector generates the QR code using the display module of the machine. At the backend, the CVM machine sends a request hosted in a cloud service, generating a unique QR code for that CVM machine with the unique ID embedded. The generated code is sent to the CVM machine, displayed to the user along with instructions to scan the code through the app. After the collector scans the QR code, the app requests the backend code to authorize and link the QR code to their Kabadi Techno account. The backend code verifies that the user is the Collector by sending an acknowledgement to the CVM machine. A six-digit OTP code is sent in the Kabadi Techno app and the registered email for entering the same in the CVM machine for confirmation. If the entered OTP is invalid, a respective message is displayed for the user. After the user is acknowledged as the Collector, they must open the outlet gate. The Collector should click the button and collect the E-waste. After emptying the storage, the CVM machine checks the weight and volume of the storage using the weight and laser sensor and updates the status in the backend cloud. If any item is left accidentally in the machine, the weight will not tally to zero, alerting the admin about the discrepancy. The Collector scans the QR code pasted on the E-waste while taking it out of the machine as a means of acknowledgement. The overall working of the collector side for the CVM is represented as Algorithm 2.

Algorithm 2: : Working of CVM for Collector

```
Result: Collector collect the E-waste
initialization;
if collector login is correct then
    CVM displays "Generate QR code";
    Collector press generate button;
    Collector-specific QR code is generated;
    if QR code is true then
        CVM displays "Enter the OTP";
        if OTP is correct then
            CVM Gate 2 will be opened;
            Collect your e- waste from the chamber" ;
            Display " Click on Close Button";
            Compute CVM Level and weight;
            if CVM_level=0 and weight=0 then
                Update the Data Base
            else
                notify the authorized Collector about the
            end
        else
            CVM displays "Invalid OTP";
        end
    else
        CVM displays "QR code is invalid";
    end
else
    You are not authenticated Collector;
end
```

3.2.3 Concept for Measuring CVM level

Further, it is important to compute the level of CVM to send an alert message to the nearest Collector and update the weight of the CVM. The distance laser sensor is required to calculate the CVM volume left after the E-waste is placed inside the chamber. A laser sensor (TOF10120) is used for measuring the CVM level, while a weight sensor (HX711) is employed to measure the weight of the E-waste placed on the tray for storage in the database. The HX711 weight sensor uses a load cell to translate the weight placed on it into an electrical signal.

The computation of the level of Concentrated

Vaporization Medium (CVM) plays an integral role in sending the alert message to the nearest collector and updating the weight of the CVM. Once the E-waste is placed inside the chamber, the distance laser sensor calculates the residual CVM volume. A particular laser sensor, TOF10120, is used to measure the CVM level. The weight of the E-waste placed on a tray is measured with the help of the weight sensor HX711, which is later, stored in the database. This specific weight sensor uses a load cell to convert the weight placed on it into an electrical signal for the sensor.

The process of measuring the CVM level using a TOF10120 laser sensor, which assesses the depth in centimeters, requires the setup of an I2C (Inter-Integrated Circuit) bus. This entails the connection of the clock and data lines to specific pins on the ESP32 microcontroller. The I2C bus, with an operating speed of 100 kHz, facilitates communication with the sensor.

The system scans the I2C bus upon initiation to identify the unique address of the TOF10120 sensor. Subsequently, the data on the depth of the CVM is obtained and stored within a designated byte array. This arrangement enables the creation of a 16-bit word that very precisely represents the measured distance. The sensor responds to the query with two bytes of data Once these bytes are processed, they extract the precise measurement of distance. Following this, the percentage fill of the CVM container, which is a crucial parameter, is calculated utilizing the Eq 1. This data acquisition and processing journey results in transmitting the gathered information to the primary controller.

$$\text{Percentfill} = \frac{(\text{Full\_depth} - \text{Present\_depth})*100}{\text{Full\_depth}} \qquad (1)$$

Accurately measuring CVM requires a meticulous examination of the I2C bus setup, which involves gathering and analysis of necessary data. This process provides valuable insights into the workings of the CVM system.

4. Result and Discussion

The proposed solution relies on the accuracy of the distance measured by the laser sensor used to determine the CVM level. This precision is essential because, when the remaining volume of the CVM reaches the limit, the system sends an alert to the Admin, and this information is recorded in the database. The threshold point is set at 80% of the overall length of the CVM container. This threshold is designed to bridge the time gap between the moment the collector receives an alert message for E-waste collection and the actual collection.

The weight sensor serves as a crucial secondary check on the contents of the system. To achieve expected results and ensure proper operation, seamless interaction among the Customer, Collector, vending machine, Admin, and database is essential. The Admin receives alerts through the App and can monitor the status of the CVM. The Admin is responsible for dispatching the Collector to the specific CVM to clear its contents. The database maintains separate records for customer and collector accounts, linking them to QR codes upon generation. Customers can view the cost of their disposed items by logging into the App account after a set time following their interaction with the CVM.

The QR code serves to connect the user to their customer account when scanned through the mobile App. QR codes are reliable for tracking information about products in an organization or workflow, offering advantages such as data recovery during events of damage equal to or less than the 30% threshold, faster performance in retrieving data during scanning, and efficient data storage. Proposed work advocates the formation of QR code for corresponding E-waste which user wish to sell. The QR code encrypts all evidence related to the users which is efficient and secure.

The proposed framework is user-friendly and cost-effective, reducing expenses related to organization, operations, and maintenance. Leveraging the recorded statistics, the proposed system can contribute to the enhancement and benefit of the E-waste industry by playing a role in building smart city environments. Moreover, this work has the potential for extension with the incorporation of blockchain technology, providing a transparent, secure, and trackable system[48,49,50].

5. Conclusion

E-waste management is one of the most challenging problems globally. E-waste issues become a serious environmental and health concern when they are not disposed of properly. The proposed IoT-based CVM is designed for E-waste management, incorporating hardware components such as an ESP32 microcontroller, a laser sensor (TOF10120) to compute the E-waste volume, an HX711 Weight Sensor for measuring the weight of E-waste, a solid-state relay, a Motor driver, and a limit switch The PCB is designed by using Auto-desk eagle software. The customer disposes off their E-waste in CVM, and CVM transmits information over the Internet, notifying the Collector at an 80% threshold. The projected CVM-based prototype model is a fast, robust, cost-efficient, and eco-friendly mechanism for E-waste management and environmental sustainability.

In future, this model could be extended with the capability of data analytics and blockchain. Data analytics enable the prediction of E-waste generation patterns in different locations of CVM, while blockchain will ensure transparency, traceability and immutability of E-waste supply chain.

References

1) R. M. R. Turaga, K. Bhaskar, S., Sinha, D., Hinchliffe, M., Hemkhaus, R., Arora, S. Chatterjee,D.S. Khetriwal, V. Roduvolic,P. Singhal, and H. Sharma, "E-waste management in India: Issues and strategies," Vikalpa, **44**(3) 127-162 (2019). https://doi.org/10.1177/025609091988065.
2) L. Saha, V., Kumar, J., Tiwari, S., Rawat, J., Singh, and K. Bauddh, "Electronic waste and their leachates impact on human health and environment: Global ecological threat and management," Environmental Tech-nology & Innovation, **24** 102049 (2021). https://doi.org/10.1016/j.eti.2021.102049.
3) V. Murthy and S. Ramakrishna, "A review on global E-waste management: urban mining towards a sustainable future and circular economy," Sustainability, **14**(2) 647 (2022). https://doi.org/10.3390/su14020647.
4) S. Kumar, R. Kumar, & A. Pandey, (Eds.). "Current Developments in Biotechnology and Bioengineering: Strategic Perspectives in Solid Waste and Wastewater Management," Elseviers, (2021).
5) M. E. E. Alahi, A. Sukkuea, F. W. Tina, A. Nag, W. Kurdthongmee, K. Suwannarat, & S. C. Mukhopadhyay, "Integration of IoT-Enabled Technologies and Artificial Intelligence (AI) for Smart City Scenario: Recent Advancements and Future Trends. Sensors," **23**(11), 5206, (2023).
6) S. Vishwakarma, V. Kumar, S. Arya, M. Tembhare, D. Dutta, & S. Kumar, "E-waste in Information and Communication Technology Sector: Existing scenario, management schemes and initiatives. Environmental Technology & Innovation," **27**, 102797, (2022).
7) D. Dutta, S. Arya, S. Kumar, & E. Lichtfouse, "Electronic waste pollution and the COVID-19 pandemic," Environmental chemistry letters, 1-4, (2021).
8) S. Arya, and S. Kumar, "E-waste in India at a glance: Current trends, regulations, challenges and management strategies," Journal of Cleaner Production **271**, 122707 (2020). https://doi.org/10.1016/j.jclepro.2020.122707.
9) P.R. Kaushik, and S. Herat, "Current state of e-waste management in India," International Journal of Environment and Waste Management, **25**(3) 322-339 (2020). 10.1504/IJEWM.2020.106293.
10) N. Abdullah, O. A. Alwesabi, and R, Abdullah, "IoT-based smart waste manage-ment system in a smart city," In International conference of reliable information and communication technology, 364-371 Springer, Cham, (2018, June). https://doi.org/10.1007/978-3-319-99007-1_35.
11) V. S. Cheela, V. P. Ranjan, V. P. Goel, M. John, and B. Dubey, "Pathways to sustainable waste management in Indian Smart Cities," Journal of Urban Management, **10**(4) 419-429 (2021). https://doi.org/10.1016/j.jum.2021.05.002.
12) B. Esmaeilian, B. Wang, K. Lewis, F., Duarte, C. Ratti, and S. Behdad, "The future of waste management in smart and sustainable cities: A review and concept paper," Waste management, **81**, 177-195 (2018). https://doi.org/10.1016/j.wasman.2018.09.047.
13) D.V. Koraganji, R. Garimella, and P. Kandra, "Current trends and future challenges in smart waste management in smart cities," In Advanced Organic Waste Management, 395-406. Elsevier, (2022). https://doi.org/10.1016/B978-0-323-85792-5.00027-7.
14) T. Bakhshi, and M. Ahmed, "Iot-enabled smart city waste management using machine learning analytics," In 2018 2nd International Conference on Energy Conservation and Efficiency (ICECE),Lahore Pakistan, 66-71 (2018, October). 10.1109/ECE.2018.8554985.
15) S. Dubey, P. Singh, P., Yadav, and K.K. Singh, "Household Waste Management Sys-tem Using IoT and Machine Learning," Procedia Computer Science, **167**, 1950-1959 (2020a). https://doi.org/10.1016/j.procs.2020.03.222.
16) S. Dubey, M.K. Singh, P. Singh, and S. Aggarwal, "Waste management of resi-dential society using machine learning and IoT approach", In 2020 International Conference on Emerging Smart Computing and Informatics, Pune India, 293-297, IEEE, (2020, March). 10.1109/ESCI48226.2020.9167526.
17) T. Anh Khoa, C. H. Phuc, P. D. Lam, L. M. B. Nhu, N. M. Trong, N. T. H. Phuong, ... & D. N. M. Duc, "Waste management system using IoT-based machine learning in university. Wireless Communications and Mobile Computing," 2020, 1-13, (2020).
18) B. Fang, J. Yu, Z. Chen, A. I. Osman, M. Farghali, I. Ihara, ... & P. S. Yap, "Artificial intelligence for waste management in smart cities: a review," Environmental Chemistry Letters, 1-31, (2023).
19) W. Xia, Y. Jiang, X. Chen, & R. Zhao, "Application of machine learning algorithms in municipal solid waste management: A mini review," Waste Management & Research, **40**(6), 609-624, (2022).
20) Namoun, A.Tufail, M. Y. Khan, A. Alrehaili, T. A. Syed, & O. BenRhouma, "Solid waste generation and disposal using machine learning approaches: a survey of solutions and challenges," Sustainability, **14**(20), 13578, (2022).
21) M. W. Rahman, R. Islam, A. Hasan, N. I. Bithi, M. M. Hasan, and M. M. Rahman, "Intelligent waste management system using deep learning with IoT," Journal of King Saud Uni-versity-Computer and Information Sciences, **34**(5) 2072-2087 (2022). https://doi.org/10.1016/j.jksuci.2020.08.016.

22) Anitha, "Garbage moni-toring system using IoT," In IOP Conference Series: Materials Science and Engineering, **263**(4) 042027 (2017, November). 10.1088/1757-899X/263/4/042027.
23) K. Pardini, J. J. Rodrigues, O. Diallo, A. K. Das, V.H.C. de Albuquerque, and S. A. Kozlov, and "A smart waste management solution geared towards citizens," Sensors, **20**(8), 2380 (2020). https://doi.org/10.3390/s20082380.
24) U. Soni, A. Roy, A. Verma, and V. Jain, "Forecasting municipal solid waste generation using artificial intelligence models—a case study in India," SN Applied Sciences, **1**(2), 162 (2019).
25) N. M. Yusof, A. Z. Jidin, and M. I. Rahim, "Smart garbage monitoring system for waste management" In MATEC web of conferences, **97**, 01098, EDP Sciences (2017). 10.1051/matecconf/20179701098.
26) S. Mishra, L. Jena, H. K. Tripathy, & T. Gaber, "Prioritized and predictive intelligence of things enabled waste management model in smart and sustainable environment," PloS one, **17**(8), e0272383, (2022).
27) T. J. Sheng, M. S. Islam, N. Misran, M.H. Baharuddin, M. H., H. Arshad, M. R. Islam, ... and M.T. Islam, "An internet of things based smart waste management system using LoRa and tensorflow deep learning model," IEEE Acc ess, **8**, 148793-148811 (2020). 10.1109/ACCESS.2020.3016255.
28) N. C. A. Sallang, M. T. Islam, M. S. Islam, and H. Arshad, "A CNN-Based Smart Waste Management System Using TensorFlow Lite and LoRa-GPS Shield in Internet of Things En-vironment", IEEE Access, **9**, 153560-153574 (2021). 10.1109/ACCESS.2021.3128314.
29) S. Murugaanandam, V. Ganapathy, and R. Balaji, "Efficient IOT Based Smart Bin for Clean Environment," In 2018 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 0715-0720 IEEE (2018). 10.1109/ICCSP.2018.8524230.
30) R. Khan, S. Kumar, A. K. Srivastava, N. Dhingra, M. Gupta, N. Bhati, & P. Kumari, (2021). "Machine learning and IoT-based waste management model," Computational Intelligence and Neuroscience, 2021.
31) M. M. Ahmed, E. Hassanien, & A. E. Hassanien, "IoT-based intelligent waste management system. Neural Computing and Applications," **35**(32), 23551-23579, (2023).
32) kuldeep, S. Saini, P. Singh, and R. Singh, "Integrated online framework for waste management," In 2019 International Conference on Innovative Sustainable Computational Technologies (CISCT), Dehradun, India, 1-4. IEEE, (2019). 10.1109/CISCT46613.2019.9008143.
33) J. Liu, A. S. Prabuwono, A. W. Abulfaraj, S. Miniaoui, & N. Taheri, "Cognitive cloud framework for waste dumping analysis using deep learning vision computing in healthy environment," Computers and Electrical Engineering, **110**, 108814, (2023).
34) M. A. Danish, T. Mosaberpanah, M. U. Ozbakkaloglu, K. Salim, M. Khurshid, Bayram, ... & D. N. Qader, "A compendious review on the influence of e-waste aggregates on the properties of concrete," Case Studies in Construction Materials, **18**, e01740, (2023).
35) K. Singh, G. Arora, P. Singh, A. Gupta, "IoT-based collection vendor machine (CVM) for E-waste management," Journal of Reliable Intelligent Environments, **7**(1), 35-47 (2021). https://doi.org/10.1007/s40860-020-00124-z.
36) T. Shevchenko, M. Saidani, Y. Danko, I. Golysheva, J. Chovancová, and R. Vavrek, "Towards a smart E-waste system utiliz-ing supply chain participants and interactive online maps," Recycling, **6**(1), 8, (2021).
37) M. Farjana, A.B. Fahad, S. E. Alam, & M. M. Islam, "An iot-and cloud-based e-waste management system for resource reclamation with a data-driven decision-making process," IoT, **4**(3), 202-220, (2023). https://doi.org/10.3390/iot4030011.
38) T. M. Mostafa, and D. S. Sarhan, "Economic feasibility study of E-waste re-cycling facility in Egypt," EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, **5**(2) 26-25 (2018). https://doi.org/10.5109/1936214.
39) L. Srivastav, Markandeya, N. Patel, M. Pandey, A. K. Pandey, A. K. Dubey, A. Kumar… & V. K. Chaudhary, "Concepts of circular economy for sustainable management of electronic wastes: challenges and management options," Environmental Science and Pollution Research, **30**(17), 48654-48675, V. K. (2023).
40) R. G. Anuardo, M. Espuny, A. C. F. Costa, & O. J. Oliveira, "Toward a cleaner and more sustainable world: A framework to develop and improve waste management through organizations, governments and academia," Heliyon, **8**(4), (2022). https://doi.org/10.1016/j.heliyon.2022.e09225.
41) M. Yang, L. Chen, J. Wang, G. Msigwa, A.I. Osman, S. Fawzy, ... & P. S. Yap, "Circular economy strategies for combating climate change and other environmental issues," Environmental Chemistry Letters, **21**(1), 55-80. (2023). 80 https://doi.org/10.1007/s10311-022-01499-6.
42) Sadinov, & S. Rajabov, "Utilizing digital technologies for waste management," In E3S Web of Conferences (Vol. 381). EDP Sciences, (2023).
43) Berisha, & L. Osmanaj, "Kosovo scenario for mitigation of greenhouse gas emissions from municipal waste management," (2021).
44) Lin, Siyi, Muhammad Ubaid Ali, Chunmiao Zheng, Zongwei Cai, & Ming Hung Wong. "Toxic chemicals

from uncontrolled e-waste recycling: Exposure, body burden, health impact," Journal of Hazardous Materials 426 (2022): 127792. https://doi.org/10.1016/j.jhazmat.2021.127792Get rights and content.

45) D. Beula, & M. Sureshkumar, "A review on the toxic E-waste killing health and environment–Today's global scenario," Materials Today: Proceedings, **47**, 2168-2174, (2021).
46) M. E. Dockrell, D. Purchase, & R. G. Price, "E-waste and metal contamination in the environment-Health effects," (2023).
47) R. Focardi, F. L. Luccio, & H. A. Wahsheh, "Usable security for QR code," Journal of Information Security and Applications, **48**, 102369, (2019).
48) D. Mishra, P., Singh, and N. Singh, "Role of blockchain in achieving solutions in ambiguous supply chain operations," In Blockchain in a Volatile-Uncertain-Complex-Ambiguous World- Elsevier, 57-73 (2023). https://doi.org/10.1016/B978-0-323-89963-5.00012-5.
49) S.P. Krishna, and P. Singh, "Security Challenges in Building Blockchains Bridges and Countermeasures." EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, **10**(3), 1558-1569 (2023). doi.org/10.5109/7151703
50) U. R. Khan, & R. W. Ahmad, "A blockchain-based IoT-enabled E-Waste tracking and tracing system for smart cities," IEEE Access, **10**, 86256-86269, (2022).