Enhancing E-Waste Management with IoT-Based Monitoring Solutions

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ABSTRACT

The adoption of smart electronic waste (e-waste) monitoring systems is vital to address an environmental, health, and economic challenges. E-waste is produced when electronic products or devices become unwanted or broken or end their useful life. If not properly managed or monitored, it can release heavy metals and chemicals like lead, mercury and cadmium into the environment hence harming the ecosystem and human health. Recognising the importance of raising awareness about the e-waste management, an IoT-based recycle e-waste monitoring system is proposed in this study. The system monitors the e-waste level and temperature measured by HC- SR04 ultrasonic sensor and LM 35 temperature sensor, respectively and updates to the system user. A NodeMCU acts as the system's microcontroller, while Blynk is the IoT web platform. The system effectively monitored three e-waste levels and temperature, with a warning indicator triggered when distance or temperature thresholds were exceeded. This IoT monitoring system enables real-time data collection, enhancing the efficiency, accuracy and effectiveness of e-waste management. The system was demonstrated for small spaces (hostel) and extended to a broader area to support environmental sustainability and Green Campus initiatives. Small efforts in managing e-waste create a healthier environment and a better quality of life.

Keywords: Smart e-waste management, level, temperature

INTRODUCTION

There is no doubt that effective management and monitoring of electronic waste (e-waste) is crucial due to the increased use and disposal of electronic devices. E-waste is produced when an electronic device becomes unwanted or damaged or ends its useful life. It contains hazardous substances such as mercury, cadmium, lead and is therefore extremely risky to the environment and human health if not properly managed [1]. There are many literatures highlights to the e-waste awareness such discussed in [2]. Meanwhile, emerging smart monitoring systems with technologies like artificial intelligence (AI), Internet of Things (IoT) and cloud computing are increasingly addressed to these challenges and heavily applied for effective e-waste tracking, categorisation and recycling purposes while supporting a circular economy's principles by recovering valuable resources such as gold, silver, and copper [3]. The study of IoT based e-waste management also discussed in [4].

IoT-based systems have revolutionised e-waste monitoring by enabling real-time tracking and management of waste streams. [5] introduces an IoT-based smart e-waste management system with ATMEGA328 microcontroller that aim to improve the efficiency of waste collection and disposal. The system integrates ultrasonic sensor to monitor the waste levels while transmitting real-time data for analysis and further action. Besides, [6] develops a system that provides real-time updates on e-waste level using HC-SR04 ultrasonic sensor and bin temperature with DS18B20. The system also incorporates a KY-026 flame sensor for fire detection. A Raspberry Pi 3 Model B+ served as the microcontroller while Thing Speak was used as the IoT web platform.

In the meantime, a solar-powered IoT-based e-waste monitoring system was explored in [7]. This system monitors fill levels, detects hazardous gases and notifies users and collectors via a mobile app. The integration

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of solar power offers energy-efficient operation. Still, the system's scalability to larger urban environments is limited, and its reliance on solar power may be problematic in regions with low sunlight. To a further extent, the design and implementation of e-waste detection, sorting, and segregation based on a microcontroller (Arduino) have been discussed in [8]. Metal proximity sensors are used to detect e-waste. The sensor detects electronic objects within its range by identifying materials like copper, aluminium, lead and other metals commonly found in e-waste. Detection depends on the type and density of the material. Once identified, the system classifies the e-waste, sorts it and directs for further processing.

Due to machine learning applications, [9] proposes a mobile green e-waste management system for smart campuses. This system employs Raspberry Pi and TensorFlow Lite for object detection, transmitting data to Thing Speak via the MQTT protocol for real-time monitoring. Users interact with the system through an Android app, facilitating machine learning-based precise e-waste categorisation. Other e-waste management with deep learning-based object detection and data-driven decision-making processes can be studied in [10-12]. However, implementing such a system requires a strong understanding of computational processes, which may be a barrier to widespread implementation. Meanwhile, focusing on smart e-waste collection and categorisation, [13] presents a prototype system that uses IoT and machine learning to segregate waste into biodegradable and non-biodegradable categories. Although this system offers high accuracy and provides real-time data updates through cloud integration, it again asks for significant computational resources for machine learning algorithms.

Alternatively, an automated method that allows users to dispose of e-waste and receive payment has been discussed in [14]. A "pay as you toss" mobile app has been developed, encouraging users to dispose of their e-waste responsibly. The system features an IoT-enabled bin that sends real-time notifications to the Collection Team. While this approach encourages user involvement, its heavy reliance on user participation and the very high cost of providing IoT-enabled trash cans pose challenges.

Recognising the importance of raising awareness about e-waste monitoring, this study aims to develop a simple e-waste bin to intelligently monitor the level and temperature of electronic waste in real-time. The system was initially started with a prototype size and tested in a small student area (hostel). This system provides an efficient solution to e-waste collection and data generation through the IoT concept. The system was fitted with an ultrasonic sensor and temperature sensor for real-time updating of the level of the e-waste and the temperature inside the bin. Besides, the NodeMCU which is familiarly known for faster performance and cost-effectiveness open source, was used as the main microcontroller while Blynk Apps as an IoT platform for data storing and monitoring purposes.

Project Implementation

The study began with an online survey to evaluate students' and staff's awareness of e-waste management systems. The findings showed that 87.2% of respondents disposed of electronic equipment in regular dustbins instead of designated e-waste bins. Furthermore, many participants noted challenges in locating e-waste collection centres. These results highlight the demand for an efficient e-waste disposal system, prompting the development of a mobile and easy e-waste monitoring system tailored for small spaces like hostels, offices or classrooms, as proposed in this study.

Figure 1 shows the implementation of the e-waste monitoring system, which contains hardware and software development. Meanwhile, the flowchart of the IoT-based e-waste monitoring system is presented in Figure 2.

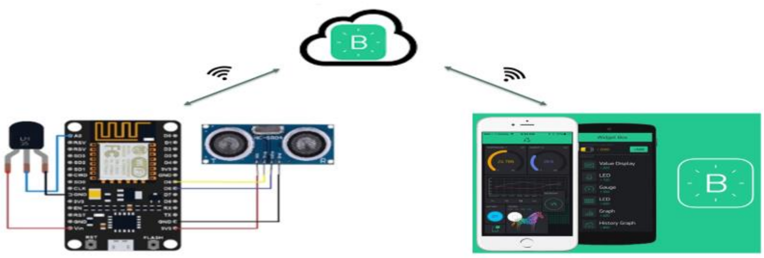

Fig. 1 The implementation of the e-waste monitoring system

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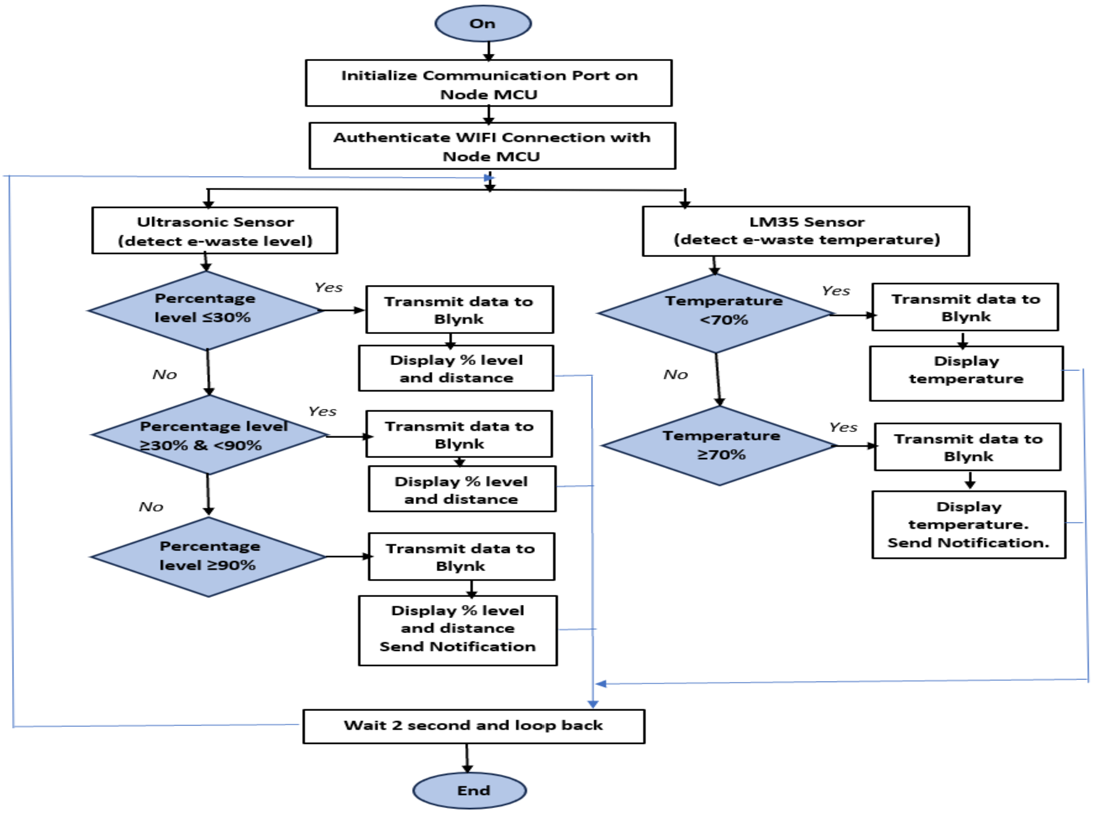

Fig. 2 The flowchart of the IoT-based e-waste monitoring system

According to Figure 2, the process development of the e-waste monitoring system starts with initialising the communication port on the Node MCU. Next, the system establishes and authenticates a Wi-Fi connection for the Node MCU to enable communication between sensors and the Blynk application. Once the setup was complete, the sensors began to operate. The HC-SR04 sensor measures the e-waste level while the LM35 sensor monitors the temperature inside the bin.

The collected data on e-waste levels and bin temperature is transmitted to the Blynk server. Depending on the e-waste level detected by the HC-SR04 sensor:

- Below 30%:
  - The dashboard displays the percentage and distance.
  - Indicating low e-waste level.
- 30% to 90%:
  - The dashboard displays the percentage and distance.
  - Indicating moderate e-waste level.
- Above 90%:
  - The dashboard displays the percentage and distance.
  - Indicating high e-waste level.
  - Warning indicator triggered, prompting e-waste management actions.

For temperature measurement:

- Below 70°C:
    - The dashboard displays the temperature.
- Above 70°C:
    - The dashboard displays the temperature.
    - Warning indicator triggered due to high temperature, avoid fire risks.

Finally, the system delays for 2 seconds before looping back in, measuring the e-waste level and temperature. This process continues until the system is manually turned off.

METHODOLOGY

Hardware Development

As discussed in the Project Implementation section, two sensors were used as input for the system: the HC-SR04 ultrasonic sensor and the LM35 temperature sensor while NodeMCU as a main microcontroller. It initially included firmware that runs on the ESP8266 Wi-Fi and gives microcontroller access to the Wi-Fi network. NodeMCU was powered by 3.3V output power as a power supply. The data received from the NodeMCU were analysed through the Blynk Dashboard. The waste level is measured in the distance in centimetres (cm) and the percentage (%) of the e-waste in the bin. Meanwhile, the temperature is measured in Celsius (°C).

The NodeMCU is located on the top of the box, as shown in Figure 3(a)-3(b), while the sensors are located on the lid of the container (inside the box), as shown in Figure 3(c). Figure 3(d) presents the prototype development of the e-waste system. For demonstration purposes, electronic devices such as batteries, calculators, power banks, phone chargers and electrical components have been thrown into the e-waste bin. It is noted that the e-waste comes in various sizes and shapes therefore distance measurements are taken in a best effort to represents the level of e-waste in the bin.

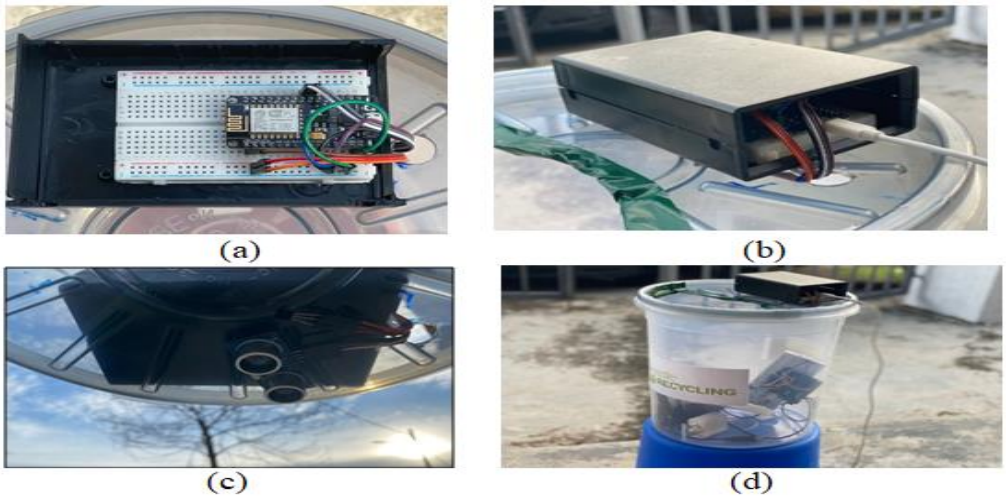

Fig. 3 (a)-(c) Sensor’s installation (d) e-waste bin

Software Development

Regarding software development, the Blynk dashboard is always up to date for data analysis for every 2 seconds of the percentage level and temperature in the bin in a graph chart. An automatic notification will be sent to the user for safety and cleaning purposes if the bin’s level exceeds 90% and/or the temperature is above 70°C. Figure 4(a) shows the project dashboard on the website view, while Figure 4(b) shows the project dashboard on the mobile application view.

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Fig. 4 E-waste monitoring in (a) website view (b) mobile phone view

RESULT DISCUSSION

According to system flowchart illustrated in Figure 2, four case studies have been investigated. Observation due to case studies are presented in Figure 5(a) – 5(d).

Case I:

The first case is where the level of e-waste in the bin is at 'Low Level' with a percentage below 30%. Here, the distance between the e-waste and lid is 21cm; which is 24%. The temperature was measured to 27°C. No warning alert has been activated.

Case II:

The second case is where the level of e-waste in the bin is at 'Moderate Level' with percentage between 30% and 90%. Here, the e-waste was located to 16cm; which is 44%. The temperature was recorded to 28°C. Again, no warning alert has been activated.

Case III:

The third case is where the level of e-waste in the bin is at 'High Level' with a percentage more than 90%. The distance between the e-waste and lid is 3cm; which is 96%. The temperature was measured to 30°C. Notice that the warning alert has been activated that shows the bin is full.

Case IV:

The fourth case is dedicated to temperature monitoring where the temperature is above 70 °C. The temperature inside e-waste bin was tested to 72°C. Again, the warning alert has been activated that shows the high temperature.

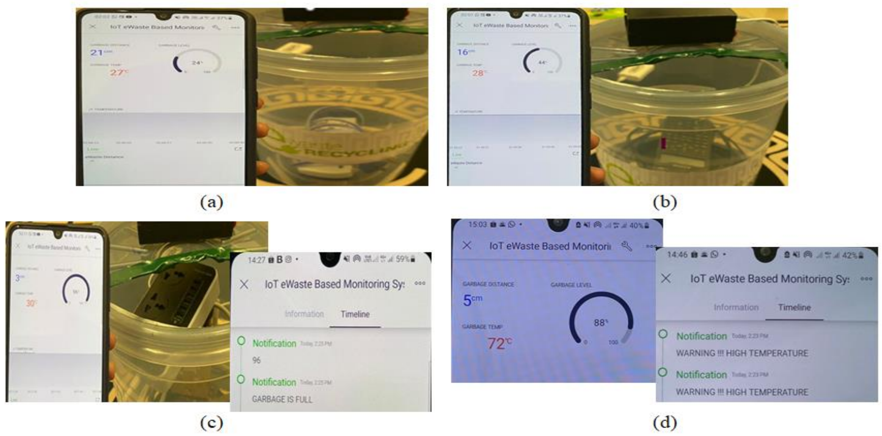

Fig. 5 E-waste monitoring system (a) Case I (b) Case II (c) Case III (d) Case IV

Overall, a simple IoT-based e-waste monitoring system was successfully developed. It effectively measures the e-waste levels and temperature while warning when threshold values are exceeded. Regarding the notification function, only two conditions were activated: Cases 3 and 4. Case 3 refers to full e-waste inside the bin, where 96% of e-waste was detected, while Case 4 is due to the high temperature measured. Notification warns the users to take immediate action for e-waste collecting and safety alerts. The system was successfully tested in a small hostel area that can be scaled to cover more prominent locations.

CONCLUSION

This study emphasises the importance of raising awareness about e-waste monitoring for recycling. A simple construction of IoT-based e-waste monitoring system has been proposed. The system was developed using a bin equipped with embedded devices to monitor e-waste levels and temperature with alert notification capabilities.

A HC-SR04 ultrasonic sensor has been used to monitor the e-waste level while LM 35 temperature sensor monitors the internal bin's temperature. This data was then transmitted to a NodeMCU and displayed to Blynk platform. Users receive notifications when the maximum levels of e-waste and/or temperature limits are exceeded.

The e-waste system was demonstrated tracking three e-waste levels includes low, moderate and high level of e-waste and temperature reading while notification function has been activated when threshold values are crossed. The study contributes to development of a simple e-waste monitoring system, easy maintenance and low-cost requirements make it suitable to be implemented in small area like hostels, offices or classrooms.

In summary, the proposed IoT-based e-waste monitoring system proves an effective approach for e-waste collection and provides real-time information of the e-waste level and temperature. However, it was studied that high temperatures can cause fires or explosions, especially in materials such as lithium-ion batteries hence release harmful chemicals. Therefore, it is recommended to integrate a flame sensor in the system. The integration of flame sensor helps detect potential fire hazards, improving system safety and performance while supporting a good e-waste management system.

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