

IoT-Integrated Intelligent Platform for Biomedical Waste Classification and Hazardous Emission Alerts

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Abstract

Improper handling of biomedical and bio-waste can result in exposing health care professionals and the surrounding environment to dangerous infections and emission of dangerous gases. Manual sorting and monitoring of waste is also time-consuming and cannot give real-time data on the state of stored waste. This research study proposes an IoT-integrated smart biowaste management system which incorporates waste identification using camera, waste classification using machine learning, gas sensing, and alerts generation. An image of the waste that is placed in the collection device is taken by the camera, while image preprocessing and machine learning is performed for the identification of the category of the waste. Along with this process, the MQ-2 sensor measures the condition of the gas in the surroundings of the collected waste and makes a comparison with the predefined threshold. A microcontroller controls the processing of the image as well as the sensor and sends the processed information to the cloud platform. Upon detecting any abnormal gas condition, the system triggers a local buzzer as well as remote alerts.

Keywords: IoT-Enabled Waste Management, Biowaste Segregation, Machine Learning, Image-based Waste Classification, Hazardous-Gas Detection, Real-Time Monitoring, Alert Generation.

1. Introduction

The rapid growth of healthcare facilities in terms of the rapid growth of healthcare services; this has created problems of proper collection, segregation, storage, and disposal of biomedical and bio-waste. This form of waste includes things such as infected material, consumed goods, biological waste, and recyclable waste that are supposed to be handled using different means. Failure to segregate the waste properly can lead to contamination between different categories of waste, making infections and improper handling possible. The accumulation of organic and biomedical waste may decompose and release toxic fumes, which can pose dangers to all parties involved [5], [9].

The traditional method of segregating wastes involves the manual detection and handling process. It becomes very challenging in situations where the waste materials share some common physical features or in cases where workers need to work in a place with infectious materials. The traditional detection process does not provide sufficient data concerning the condition of the wastes that have been discarded. For example, in case the level of hazardous gases is rising, it might go unnoticed until it reaches a certain point that makes it harmful to the surroundings. Therefore, the waste management process should not only focus on the detection process but also involve continuous monitoring of the environment [7], [8].

With the advancement of low-cost embedded system technology, camera, machine learning and IoT communication, there is an opportunity for overcoming these shortcomings with the use of automatic monitoring. The camera can give visual data on the deposited substance, whereas image analysis using machine learning will help in determining its type. On the other hand, gas sensing can serve as an independent indicator of the environmental situation inside the garbage bin. Connecting these technologies by means of an IoT solution will make it possible to monitor the data obtained remotely and issue an alarm in case of any hazard.

The development of a smart biowaste management system using IoT technology in this paper is achieved through the combination of biowaste identification using camera and gas monitoring using sensors. This particular system has been designed to identify biowaste based on the type such as infectious, non-infectious, and recyclable wastes, whereas the gas sensors monitor hazardous gas conditions. The microcontroller is responsible for managing data

collection and responses, and the communication module will help to remotely monitor and notify about the status of biowaste management using IoT technology. An additional system feature is to include a local alarm that gives alerts regarding abnormal gas conditions.

The main aim of this proposed study would be to come up with an automated and IoT-enabled biowaste management system that would be capable of combining waste classification and hazardous gas detection along with alerts. The prototype implementation and experimental evaluation presented in the subsequent sections demonstrate the feasibility of this integrated approach.

2. Literature Survey

In the recent days, researchers have paid greater attention to the use of IoT, machine learning, and sensors in waste management operations. An IoT technique that was employed in waste segregation and management highlighted the possible uses of a connected system in waste management during the collection process [1]. Other work has been conducted on the subject of smart waste management that involved the use of IoT and the K-Nearest Neighbor algorithm, which is a machine learning tool [2].

Machine learning-based classification of waste has also been studied through the use of a number of traditional algorithms. Random Forest, Gaussian Naïve Bayes, Support Vector Machine, and Multilayer Perceptron have been used for waste classification, showing the practicality of supervised learning techniques in automated waste recognition [3]. The use of IoT in conjunction with machine learning has also been explored in relation to household waste management, illustrating the possibility of integrating classification with IoT [4]. Classification of healthcare waste and disposal of the same has been studied too; and this is quite pertinent in situations where unsafe handling of waste may be an issue [5].

Besides classification and segregation, IoT technology has been used for environmental monitoring related to waste. The use of IoT and machine learning for waste management and air pollutant prediction has also been investigated, indicating the possibility of having intelligent systems that include environmental data [6]. Hazardous gas detection and alarm generation using embedded systems has also been done [7]. A smart bin system that uses IoT for detecting garbage gases is another application of gas sensing to improve hygiene and waste management

[8].

Increasing attention to biomedical and medical waste management is making this process increasingly integrated. IoT-monitored and fuzzy-classification method has been suggested for biomedical waste management [9]. Deep learning has been considered for automatic segregation of solid waste, showing the potential of neural networks for improving classification results [10]. IoT-enabled intelligent waste-management systems have made this integration process more advanced [11]. Recently, some research has focused on hazardous medical waste management based on IoT [12] and smart medical waste management systems based on IoT technologies [13].

In recent times, there has been a trend to merge sensor systems and deep learning technology in automated waste segregation processes [14]. Likewise, a concept has been advanced using convolutional neural network (CNN)-based architectures in order to improve automated waste segregation processes [15]. Nonetheless, it should be noted that the above-discussed works mainly concentrate on waste classification, waste segregation, environmental sensing, or gas sensing as independent or partially merged functionalities. It means that there is a need to develop an integral system with the combination of waste identification using a camera, gas sensing, processing, IoT connectivity, and alerting.

3. Proposed Methodology

The proposed system will be designed to function as a smart IoT-based platform for bio-waste detection, segregation assistance, and hazardous gas detection. It aims at minimizing the risk of contamination due to human intervention with waste that could be hazardous and ensuring continuous monitoring and timely warnings of dangerous situations. The proposed approach utilizes a camera, image classification using machine learning, gas sensors, microcontroller, wireless communication, and cloud technology together within a single system.

The system functions using two paths of sensing. The first sensing path involves an imaging process where the camera detects the waste that has been put into the collecting area and uses a machine learning classifier for waste classification using the obtained image. The other sensing path is the environmental sensing, in which the gas sensor monitors the environment surrounding the waste for any harmful gas conditions. The results of the two paths are evaluated to determine the operational status of the system.

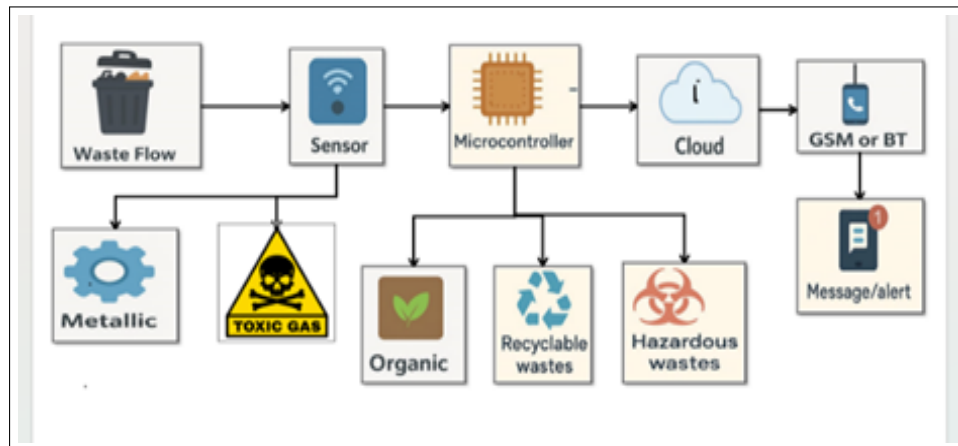


Figure 1. Schematic representation of the waste segregation and monitoring system

The overall interaction between the waste input, sensing unit, microcontroller, cloud server, and communication interface in terms of hardware is shown in Figure 1. The process of information flow in terms of the proposed design takes place from the input of waste to its sensing, classification, and then further to the monitoring of the waste on the cloud server.

Once the waste is put into the allocated area of waste, an image is taken by the camera module. The image acquired is then used as input to the classification process. Preprocessing of the image is done before the classification process. Preprocessing of the image is done to enhance the quality of the captured image and reduce any unwanted effects. Noise reduction is also included in the pre-processing process. Preprocessing of the image is necessary since the quality of the image can affect the classification process.

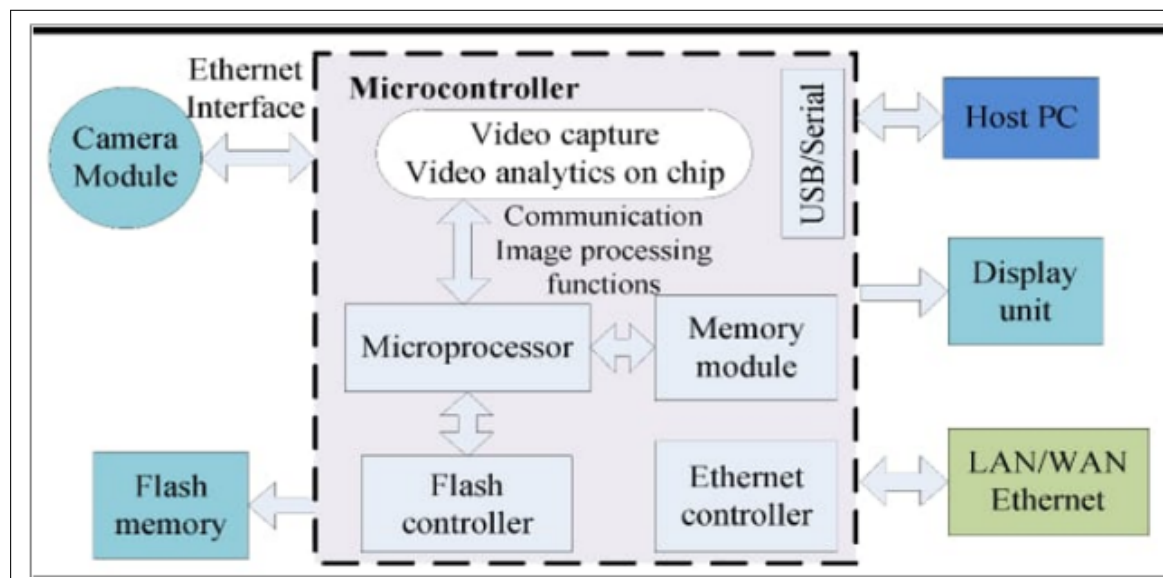


Figure 2. Camera-based image acquisition and processing architecture

The prototype's camera-processing interface includes the camera module, processing unit, memory, and communication interfaces. The relevant system architecture is presented in Figure 2, depicting the relationship between the camera, processing components, memory, host/display interfaces, and network interface. This step sets the groundwork for the image processing of the waste classification system proposed.

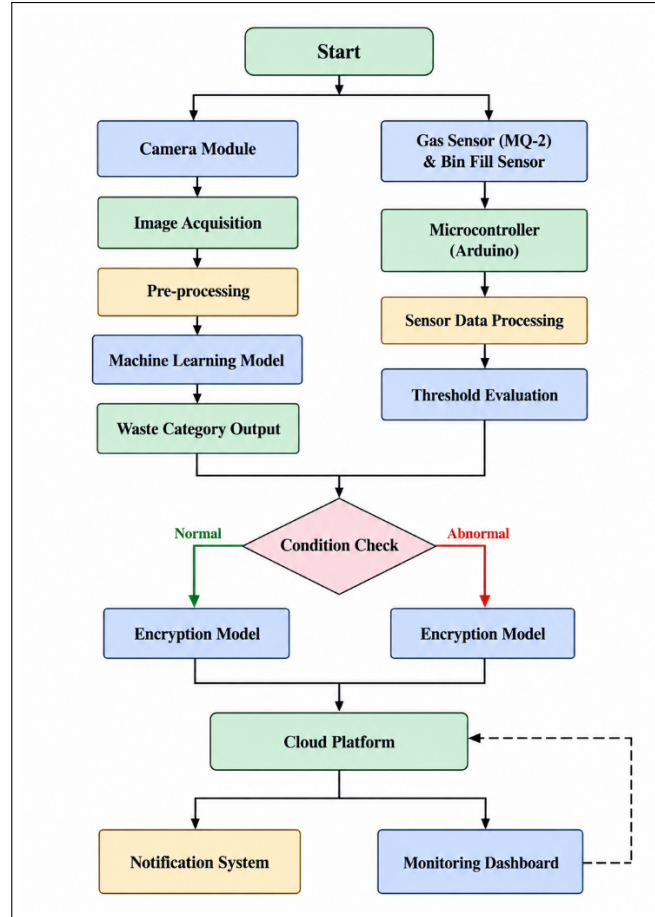


Figure 3. Overall workflow of the proposed IoT-enabled biowaste management and monitoring system

The operational steps have been detailed in Figure 3, where first the camera takes the image of the waste and then it goes through the preprocessing stage. The preprocessed image is fed to the machine learning model for classification of the waste. The classification step is designed to classify the waste into the various categories that have been defined in the proposed scheme. The output of the classification process is then taken up by the decision-making stage of the system. A correctly identified waste will go into its correct category, whereas the other case may be related to the warning process.

Alongside with image classification for waste sorting, the system also constantly checks the gases that exist in the waste environment. An MQ-2 gas sensor is embedded in the system prototype to sense whether there is a hazardous gas condition. The gas sensor sends out an electrical signal based on the gas condition, which is then processed by the microcontroller.

The sensor readings are then analyzed based on the pre-set threshold criteria. If the measured reading falls within the acceptable range, then the system continues monitoring as usual. In case the condition detected by the system surpasses the threshold limit, then the system recognizes this as an abnormal condition and then activates the appropriate alarm system. For monitoring of the hazardous gases, the threshold limit for the prototype is set at 250 ppm. The condition of having a measured gas level less than or equal to 250 ppm will be regarded as a normal operating environment while the measured value greater than 250 ppm is categorized as a hazardous operating condition.

After processing the relevant waste-classification and sensor information is transferred using the communication interface to the cloud platform. Cloud platform acts as a medium for storage and monitoring of the data collected and enables remote access of system status. In case of any abnormality in gas status, the system triggers the local alarm along with a remote notification to the concerned user/authority. Hence, the presented methodology provides a complete flow of operation from waste detection/classification to environmental monitoring, decision-making, cloud communication, and notification.

4. Implementation

Implementation of the design involved ensuring continuous monitoring of the state of biowaste along with automation of waste identification and gas detection. The main hardware and software elements were configured in such a way as to allow local acquisition of data from sensors, processing of the information via the controller, and communication with the cloud platform.

4.1 Hardware Implementation

The hardware implementation includes a microcontroller, gas sensor, camera-based picture capturing module, local indication and alarm components, communication link, and power source. The microcontroller acts as the central processor that performs all activities

including data gathering, threshold comparison, local indication, and data transmission to the IoT portal. The gas monitoring subsystem involves using a MQ-2 sensor placed at the biowaste deposition area. The sensor gives an analog signal representing the status of the gas level that is then collected by the microcontroller and converted into a digital signal for further processing. The sensing module is designed to detect any abnormal status of the gas associated with biowaste accumulation.

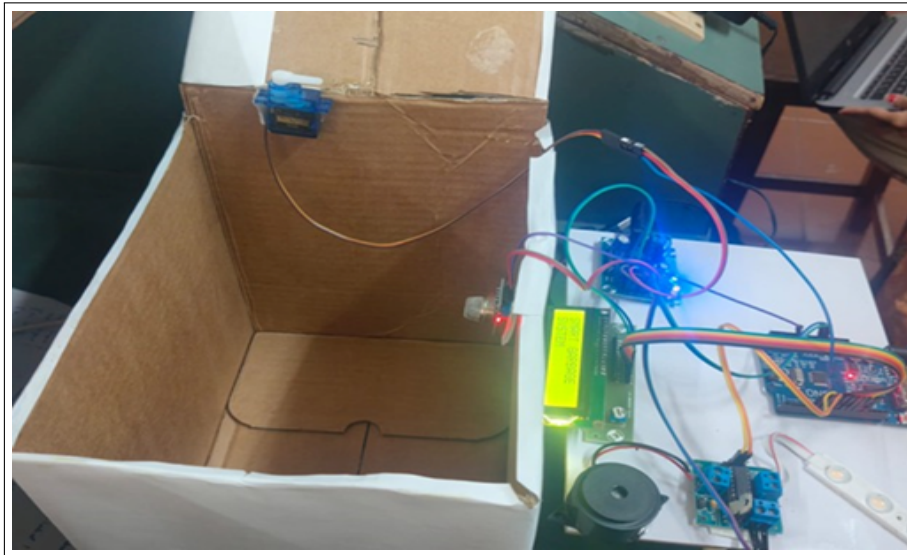


Figure 4. Experimental prototype of the proposed biowaste monitoring and hazardous-gas detection system

A buzzer is also installed to give instantaneous alarm whenever the monitored concentration of gas becomes higher than the set threshold limit. The LED indicators will serve as visual indication for the working state of the system. A display unit will also indicate the monitored parameter locally and will give a chance to see the status of the system without accessing the remote system. The hardware setup for hazardous-gas monitoring is illustrated in Figure 4. This system combines the waste container along with the sensing and electronic control components, which gives an example of a physical implementation of the system proposed for monitoring.

4.2 Software Implementation

The embedded software was implemented using the Arduino IDE and performs the role of regulating the whole process of monitoring. Initially, the microcontroller sets up the connection between the connected modules and sets the sensing and alarming devices for their function. After that, the program runs a loop that performs monitoring constantly. During

each iteration, the sensor values are acquired and then processed to minimize the impact of fluctuations in the initial values. After processing, the values are compared against the preset safety thresholds. In case the values are within the acceptable range, the monitoring continues normally. Once any threshold is exceeded, the corresponding warning state is detected and the local alarm is triggered. The module for detection of waste via camera works simultaneously with the environmental monitoring subsystem. The waste being introduced to the area is detected by the camera and the image is processed following the image classification algorithm.

4.3 Communication and Cloud Integration

The data acquired through the sensors undergoes processing before it is sent via the communication interface to the cloud platform. The communication sub-system acts as a connection channel between the local monitoring sub-system and the remote monitoring system. The cloud platform facilitates storage and remote access to the acquired information, hence making continuous monitoring of the waste-management system possible. The system is programmed in such a way that it sends information regarding the observed gas condition and the status of the waste. It ensures that individuals are able to monitor the operating condition remotely without having to be in the waste-collection site.

4.4 Alert Mechanism and System Operation

The alerting system offers both local and remote alerts in the event of unusual system states. In case the gas concentration exceeds the set threshold level, the microcontroller triggers the buzzer and sends out an alert through the communication system. The alert allows the concerned people to react accordingly without the need of physically checking on the state of the waste bin. Thus, the developed system works as a closed-loop system whereby the sensors and camera collect the data, the microcontroller analyzes the data, the decision-making module analyzes the current status of the system, and the communication module passes the data to the cloud server.

5. Results and Analysis

The developed prototype was evaluated to verify the camera-based waste detection, hazardous-gas monitoring, and IoT alert mechanisms.

5.1 Camera-Based Waste Detection

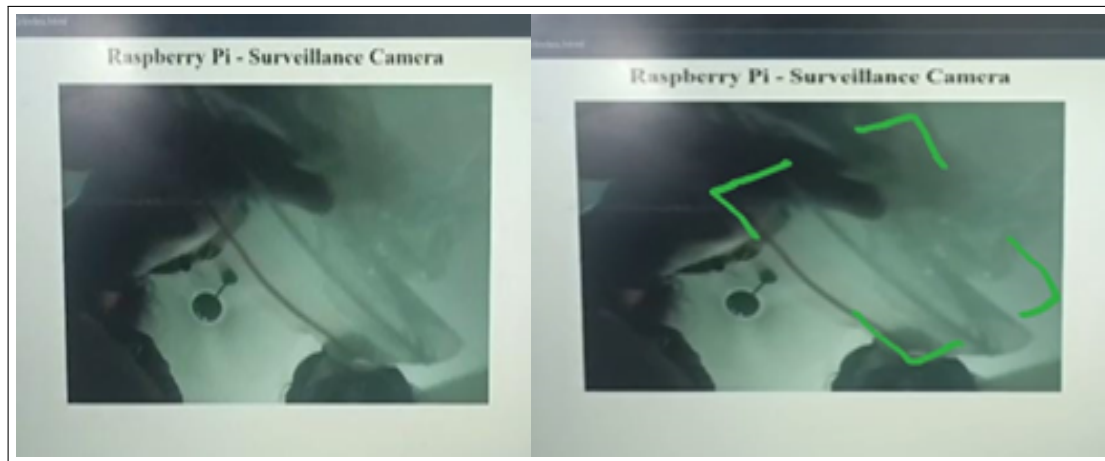


Figure 5. Raspberry Pi camera output for waste detection

Figure 5 demonstrates that there is waste in the observed area using the experimental camera output. The image captured from this experiment acts as a reference point in recognizing the deposited waste, which then serves as the input for the classification procedure. In other words, this method allows for waste recognition without constant manual observation.

5.2 Integrated Waste Classification and Gas Monitoring

The classification and gas-monitoring functions were tested through the developed monitoring interface. On the screen, the detected type of waste is displayed along with the gas sensor readings, enabling the simultaneous observation of both the outputs. Under the presented test conditions (see Figure 6), the detected waste type was classified as infectious with the probability of 92%, while the waste-level reading was 45% (Normal). On the other hand, the MQ-2 sensor gave gas readings of 320 ppm, which was higher than the set threshold of 250 ppm. As a result, the environment was classified as hazardous. Thus, one can see how the waste detection and environmental monitoring systems work together as planned, whereby the image processing component provides data on the waste, and the gas sensor checks the surrounding environment.

5.3 Alert Generation and Remote Monitoring

When the gas reading exceeded the configured threshold, then the alert was generated. The interface used for generating alerts is shown in Figure 6. It gives the message, “Hazardous Gas Detected!” together with the value of the gas detected, the threshold value, detection time, and unsafe condition. The output obtained clearly indicates the successful integration of the

threshold based decision making with the alert interface.

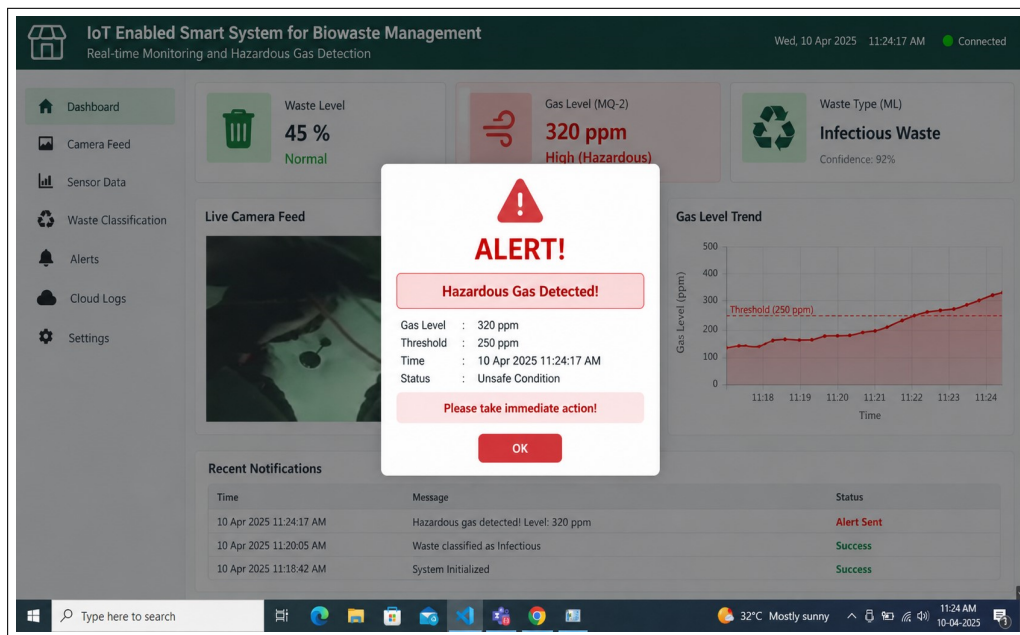


Figure 6. Alert-generation interface indicating hazardous-gas detection and notification status

The dashboard also records the event in the recent-notification section, providing a trace of the generated warning. This is important for monitoring because the user can determine not only the current gas condition but also whether an alert has already been generated. The combination of the live sensor value, threshold indication, and notification status provides a direct representation of the system response to an abnormal condition.

5.4 Application Advantages and Limitations

The most prominent benefit illustrated through the prototype is the combined use of waste detection and environmental monitoring in one system. While the camera serves as a source of information about the deposited waste, the MQ-2 sensor gives a separate signal regarding the presence of hazardous gases. The IoT interface combines those results and presents them in a remotely available monitoring system. This eliminates the need for staff to continuously monitor the waste bin and gives an immediate alert whenever the gas threshold set up is surpassed. This device can also be used in the waste rooms of hospitals, biomedical laboratories and any controlled waste bins that require waste classification and environmental monitoring to go hand-in-hand.

However, there are some disadvantages in the current prototype. The MQ-2 sensor has a generic gas detection ability and therefore needs calibration before deploying to the actual

biomedical waste scenario. It means that the value displayed should be taken as the output of the sensor and not the lab-accurate quantitative concentration of the gas without calibration. Likewise, the confidence level of 92% displayed in the interface is just the output of the displayed model and not the accuracy of the model itself. Further testing with an independent dataset under varying light, biomedical waste appearance, and operational conditions is needed. The current prototype also relies on electricity and network connection for operation.

6. Conclusion

This experiment utilized a smart biowaste management system that incorporates camera-based identification of waste, machine learning for classification, hazardous gas detection, and generation of alerts. The prototype indicates the possibility of combining all these features in one monitoring platform for safer handling of hazardous waste. Visual data is obtained using the camera module to identify the waste while the machine learning feature is used for classification of waste. In addition, the MQ-2 sensor monitors the gas composition of the waste management environment. A threshold-based decision-making process initiates automatic actions if the level of gases exceeds the predetermined threshold. Combination of a local alarm system and IoT-based notification systems allow communicating abnormal situations to the relevant persons who are in charge. Experimental findings confirm the integration of waste classification and environmental monitoring. However, further validation of the prototype is required. Future studies need to increase the robustness of waste classification, calibrate the gas detection sub-system, as well as evaluate detection performance, the rate of false alarms, and reaction time.

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