ENHANCING WASTE MANAGEMENT WITH IOT TECHNOLOGY: A SMART WASTE COLLECTION SYSTEM FOR EFFICIENT CAMPUS OPERATIONS

A PROJECT REPORT

Submitted by

VAISHNAV P NAMBIAR [RA2111003010797]
N MOHAMMED ASHRAF [RA2111003011346]

Under the Guidance of

Dr. R. Jebakumar

(Associate Professor, Department of Computing Technologies)

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Department of Computing Technologies
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Degree/ Course : B.Tech in Computer Science and Engineering

Student Name : Vaishnav P Nambiar, N Mohammed Ashraf

Registration Number: RA2111003010797, RA2111003011346

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12/5/25

DR. R. JEBAKUMAR
SUPERVISOR
Associate Professor
Department of Computing Technologies

G. Niranjana

DR. NIRANJANA G
PROFESSOR & HEAD
Department of Computing Technologies

Department of Computing Technologies Kattankulathur 603 203 SRM IST

12/5/25

EXAMINER 1

EXAMINER 2

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VAISHNAV P NAMBIAR [RA2111003010797]

N. MOHAMMED ASHRAF [RA2111003011346]

ABSTRACT

In the project titled "Enhanced waste collection using IoT Technology: A smart waste collection system for efficient campus operations," we propose an essential strategy to address the pollution caused by solid waste in our surroundings. By leveraging IoT (Internet of Things) technologies, this project aims to improve the waste collection process on college campuses, fostering a cleaner, more sustainable environment and promoting a healthier, safer atmosphere for students. The proposed system includes the creation of a specialized device that can be mounted on the interior walls of waste bins. This device gathers real-time data on the fill levels of the bins relative to a set threshold. Once the fill level exceeds this threshold, the system sends SMS notifications to the designated phone numbers of the waste collectors. This prompt alert system ensures that waste collection is optimized, leading to a more effective and responsive process. Additionally, with the presence of IR Flame sensors and Gas sensors, it detects the increase in thermal temperature leading to any fire as well as leakage of harmful gases from the collected waste materials. The data collected from this IoT-enabled system is crucial for informed decision-making in waste management. It facilitates the timely placement of extra garbage bins in high-traffic areas and the deployment of additional waste collection teams as needed. This data-driven methodology empowers campus authorities to make strategic and efficient choices, enhancing the overall effectiveness of waste management. Ultimately, the adoption of this innovative waste collection system not only lessens the environmental impact of solid waste but also promotes a clean and sanitary environment on college campuses. A hygienic campus contributes significantly to the health, safety, and security of both students and faculty, making it a vital aspect of an effective educational environment.

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INTRODUCTION

1.1 Overview

The worldwide increase in daily waste generation is emerging as a growing concern, characterized by high growth rates. Inefficient waste management has direct implications for cities, resulting in air, water, and land pollution, which ultimately impacts public health and well-being. Public waste bins overflowing with trash frequently result in waste spilling onto roads, streets, and sidewalks. Besides, unscheduled collections of wastes also lead to indiscriminate dumping along open areas, further contributing to environmental pollution and serious health concerns.

To combat these challenges, a reliable system is necessary to monitor bin fill levels and alert relevant authorities for timely clean-ups and environmental protection. College campuses face similar waste management problems due to extensive project work, canteen food waste, and numerous laboratory projects, which generate large amounts of plastic, food, beverage containers, metals, glass, and more. Student hostels also contribute significantly to household waste.

Despite existing waste collection systems, bins often overflow, creating unsanitary and hazardous conditions for both students and faculty. Furthermore, the study aims to address the high fuel costs linked to frequent garbage collection truck trips, which not only increase campus traffic but also lead to substantial diesel expenses. An intelligent waste management system that checks waste levels in real time and alerts collectors for efficient dispatches is a more effective and cheaper solution. Ineffective waste management is of direct implications for urban regions, causing air, water, and land pollution, which in turn impacts public health and wellbeing.

While technology has made great strides in many areas globally, India still relies heavily on traditional waste management practices. Outdated systems, characterized by large fleets of trucks following daily or weekly schedules, result in inefficient waste collection. IoT technology, which includes various frameworks, smart systems, and intelligent devices and sensors, offers a promising solution. This project utilizes IoT to develop a real-time garbage level detection device.

The main goal of this project is to create an Internet of Things (IoT) device connected to a Wi-Fi-enabled app for effective waste collection to prevent waste spills and save fuel expenses. The project aims to put intelligent waste management in place on campus, creating a cleaner and healthier environment for students.

1.2 Internet of Things

The Internet of Things (IoT) allows devices to be attached to items such as intelligent bins and other stationary objects. The devices may monitor selected parameters and environmental conditions, creating pertinent data that they can send through communication networks.

The IoT environment consists of internet-connected smart devices with embedded systems, such as sensors and communications technology, to collect data and carry out assignments appropriate to their particular purpose. Data from these devices tends to be routed to the cloud via IoT gateways and edge devices for storage or processing. Sometimes, devices interact and respond to each other based on incoming data. While users can adjust settings, send commands, and access data, most devices operate autonomously with minimal human input (Fig.1.1). Regarding connectivity in IoT, sensors connect to the cloud through several methods, such as satellite, cellular, Wi-Fi, Bluetooth, or Ethernet connections. Their primary role is to send gathered data to the cloud or a Human Machine Interface (HMI) for analysis.

IoT facilitates easier information access across various devices and locations, enhancing communication among connected electronic devices. Data transfer over networks saves time, automates tasks for improved service quality, and minimizes the need for human involvement. The systems are designed to capture pertinent data and perform actions that are very closely tied to the desired function or purpose. In most cases, the data that is produced and gathered from the devices is routed to cloud infrastructures via IoT gateways and edge devices where it is processed or stored securely. In some cases, the devices can talk to and respond depending on the data that they produce, allowing for a more integrated setup. Regarding connectivity in the IoT environment, sensors can connect to the cloud via a multitude of means and technologies. Some of these include satellites, cellular networks, Wi-Fi, Bluetooth, and Ethernet connectivity. The main purpose of the sensors is to relay the data that they have gathered to the cloud or to a Human Machine Interface (HMI) where it can be reviewed for different applications and information.

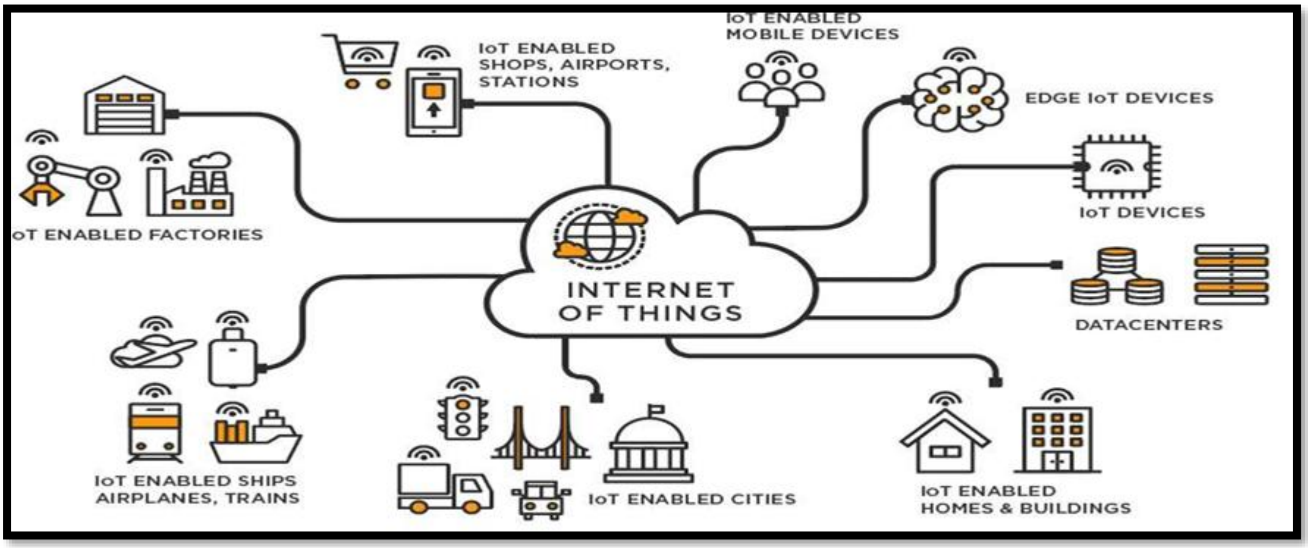

Figure 1.1: IoT Representation

1.3 Motivation

Our main motivation is driven by a goal to streamline and improve waste collection for both the campus and its staff. Discussions with the campus's cleaning staff and insights from the supervisor of the SRM Recycle waste management unit highlighted the potential for a smart bin system, which would be a meaningful initiative for students at a university of this calibre. This project aims not only to uplift the morale of both staff and students but also to positively affect the mental and physical health of campus workers.

Additionally, this initiative stands to deliver notable social benefits, supporting the national Swachh Bharat Abhiyan program, and further enhancing the college's reputation as a 'Green College.' Our main motivation is an intention to simplify and optimize waste collection for the campus and its staff. Discussions with the campus cleaning personnel and observations by the SRM Recycle waste management unit supervisor recognized the potential for a smart bin system, which would be a worthwhile project for students at such a high-quality university. This project is not only intended to improve the morale of staff and students but also to have a positive influence on the mental and physical health of campus employees.

Further, this particular program is also expected to have significant social benefits as it is in consonance with and complementary to the national Swachh Bharat Abhiyan program. In doing so, it not only contributes to the overall mission of sanitation and hygiene but also goes a great distance in further establishing the college's image and standing.

CHAPTER 2

LITERATURE SURVEY

Over the last few years, the amount of solid waste generated worldwide has skyrocketed, especially in cities and on university campuses. Disposal of this waste poses many issues, from environmental to the health and well-being of residents and workers in these regions. Increasing realization of the necessity for effective and sustainable waste management solutions has prompted the implementation of IoT technology, which has great solutions for these multifaceted problems.

The key objective of the literature review here is to consider the essential theories, practices, and technological developments that have informed the evolution and implementation of intelligent waste collection systems, with consideration for college campuses. Through surveying and condensing recent scholarly research and case studies, my intention is to learn from differing approaches and good practices utilized for maximizing waste pickup, lowering ecological footprint, and improving campus resident quality of life.

This research offers a critical overview of the contribution of IoT technology to the redesign of traditional waste management practices. It also analyzes the effect of such systems on the health of campus personnel, students, and the general population. Through this literature review, I hope to create a solid knowledge base that will inform our project's design, implementation, and possible impact. This survey is an important step towards knowing the state of smart waste collection systems today and determining areas for innovation and improvement, leading to a cleaner, greener, and healthier campus environment. Through reviewing and synthesizing existing research and case studies, I hope to learn about different strategies and best practices employed to maximize waste collection, minimize environmental footprint, and improve campus community quality of life. The increasing recognition of the necessity for efficient and sustainable waste management solutions has prompted the use of IoT technology, which provides promising solutions to these intricate problems.

2.1 Self-descriptive smart waste management system with objects

In this study, the authors introduce a smart bin application that utilizes data embedded in tags attached to individual waste items. Leveraging RFID technology, these smart bins can monitor waste autonomously without relying on an external information system. The smart trash can determine the type and composition of the individual material in the waste it holds with accuracy, thus enabling it to report its condition or anomalies to the rest of the recycling process. This self-reporting system enables sophisticated waste types such as electronic waste and hazardous waste to be sorted and labelled for possible hazard.

However, the primary limitations of this technology are its high cost and the requirement for a charging port. Unlike traditional systems, this approach does not use sensors or detectors; instead, it relies exclusively on the digital data linked to waste items. The system can also log the contents of the bin and share this data with waste operators, allowing for more efficient waste collection scheduling. If any prohibited waste items are detected, appropriate disposal procedures can be triggered.

Intelligent systems deployed for sorting waste and monitoring bin levels have been successfully applied in previous cases. For instance, a group headed by Yann Glouche developed a system focusing on intelligent waste management that employs self-describing objects.

2.2 IoT based solid waste management system

Having an end-to-end IoT-based system facilitates solid waste collection, monitoring, and management to be automated and regulated in a cost-effective manner. Based on the case study of the solid waste management issue in Bengaluru, India, they have proposed a complete system architecture and protocol stack for an IoT-based system to optimize the efficiency and reliability of the system.

Bharadwaj et al. introduced a waste management strategy aligned with the Swachh Bharat Abhiyan initiative. In their approach, dry waste collection bins are positioned on one side of a transit line, while wet waste collection bins are placed on the other.

2.3 IoT based automatic waste segregator

This project outlines an IoT-based automated waste separation system that is able to identify and sort domestic waste into dry, wet, and metallic waste, and provide real-time monitoring of garbage capacity in bins.

The major objective of the project is to reduce the requirement of human effort in waste segregation, hence facilitating proper separation with minimal effort. The system makes use of an ultrasonic sensor to identify incoming waste, a metal sensor to detect metal components, and a capacitor to differentiate between dry and wet waste. After the identification and detection of waste, wipers sweep waste into corresponding bins, and the platform rotates to its original position. An LCD display incorporated into the system displays the quantity of garbage, and a GSM-activated Arduino provides a cleaning alert when the bin is full.

Machado et al. suggested a comparable IoT framework for real-time monitoring of bin levels and utilized the information to design optimized routes for garbage collection trucks to minimize fuel expenses. The main objective of the project is to reduce the utilization of human labour in segregating waste and enhance effective separation with less effort. The system uses an ultrasonic sensor in order to detect incoming waste, a metal sensor to detect metallic waste, and a capacitor in order to differentiate between dry and wet waste.

2.4 Waste Management as an IoT-Enabling service in smart cities

This suggested solution offers a platform for real-time data sharing between truck drivers with the aim of improving garbage collection activities and enabling dynamic routing optimization, thus alleviating the issues of inefficient garbage collection in inaccessible areas of Smart Cities.

There can be a technologically sophisticated platform for innovative applications, such as waste collection, in Intelligent Transport Services (ITS) and Smart Cities offered by the Internet of Things (IoT). Surveillance systems can enhance Quality of Service (QoS) in waste collection. The key IoT components, such as RFIDs, sensors, cameras, and actuators, are integrated into ITS and surveillance systems in order to facilitate efficient waste collection. In this project, a Decision Support System (DSS) is suggested that facilitates dynamic data sharing among truck drivers for waste collection and route planning, addressing inefficiencies in waste collection in otherwise inaccessible areas within Smart Cities. Surveillance cameras are used to capture these areas, acting as evidence for the authorities.

Alexey Medvedev et al. proposed a similar advanced DSS for optimized waste collection in Smart Cities.

2.5 IoT-enabled smart bin monitoring and solid waste management system for smart cities

An IoT-enabled smart bin monitoring and solid waste management system for smart cities introduces a new approach to enhance waste collection operations. The system uses smart sensors in bins to track fill levels and identify different conditions, including odour, fire hazards, or tampering. The sensors report continuously, which is wirelessly transmitted to a central system using technologies such as Wi-Fi, Lora WAN, or GSM. When a bin reaches a certain threshold, an alert is triggered and sent to waste management teams, allowing them to schedule timely collection. This approach reduces the chances of bins overflowing and enhances overall cleanliness.

The system's core components include sensors that measure bin fill levels, communication modules for data transfer, and a central dashboard that displays real-time data. The dashboard, which is often accessible via mobile apps, provides visual updates on bin status, helping waste management teams to prioritize collections. Mobile integration allows the collector to view bin levels, receive notifications, and see optimised routes. Some advanced systems even use predictive analytics to forecast fill levels by past performance and enable forward planning of waste collection.

This IoT-driven intelligent waste management system is beneficial to smart cities in many ways. Through providing real-time bin status, it facilitates the most efficient waste collection routes, decreasing vehicle fuel usage and emissions. This not only makes operations cost-saving but also eco-friendly. The system further promotes public health by providing timely disposal of waste, minimizing odours and waste spillage in populated regions. Sanitary and odour-free conditions mean improved hygiene and overall quality of life within metropolitan areas.

However, implementing IoT-based waste management systems poses certain challenges. Initial setup costs can be high, as installing IoT infrastructure across a large urban area requires significant investment. Moreover, IoT systems involve sensitive data transfer, so ensuring data security and privacy is crucial. Another challenge is the need for reliable connectivity; some urban areas may face infrastructure limitations that hinder stable data transmission. This IoT-driven intelligent waste management system is beneficial to smart cities in many ways. Through providing real-time bin status, it facilitates the most efficient waste collection routes, decreasing vehicle fuel usage and emissions. This not only makes operations cost-saving but also eco-friendly. The system further promotes public health by providing timely disposal of waste, minimizing odours and waste spillage in populated regions. Sanitary and odour-free conditions mean improved hygiene and overall quality of life within metropolitan areas. This approach reduces the chances of bins overflowing and enhances overall cleanliness.

The suggested solution offers an interface for live data sharing between truck operators in order to improve waste collection operations and enable adaptive route optimization, thus addressing issues related to inefficient garbage collection in hard-to-reach areas of Smart Cities. This introduces a new interface facilitating real-time data exchange between truck operators, aimed at improving the efficiency of overall garbage collection operations. In the process, it makes adaptive route optimization possible, hence addressing the numerous inefficiencies inherent in garbage collection in those hard-to-reach and mostly troubled areas in Smart Cities. Despite these challenges, IoT-driven waste management offers many benefits for smart cities. Real-time bin status updates enable waste collectors to identify which bins are full and ready for emptying. This targeted approach helps determine the most efficient routes for collection trucks. As a result, fewer miles are driven, reducing fuel use and lowering emissions. This makes waste management eco-friendlier and cuts operational costs for city authorities.

The system also promotes better public health. Timely waste disposal prevents bins from overflowing. When trash is collected regularly, unpleasant odours and the risk of pests are minimized in densely populated neighbourhoods. Such conditions lead to cleaner streets and healthier living environments. Ensuring that waste is sealed away safely and managed efficiently improves hygiene standards throughout urban areas. Overall, this approach helps keep city streets cleaner and enhances residents’ quality of life.

The proposed solution often includes an interface for sharing live data among waste collection trucks. This allows truck operators to see each other's locations and waste levels in real time. Such data exchange improves coordination and helps avoid overlapping routes or missed pickups. Shared information also supports adaptive route planning, which reacts to changing conditions during the day. For instance, if one bin fills faster than usual due to a local event, trucks can be rerouted instantly to address the need. This flexibility reduces delays and spreads resources more evenly across different neighbourhoods.

In particular, the system addresses issues faced in hard-to-reach areas, like narrow alleyways or underserved zones. These locations often experience slower or less reliable garbage collection due to distance or access difficulties. The real-time data interface allows trucks to communicate and adjust their routes on the fly, making collection more efficient in such tricky zones. This adaptive approach ensures that even the most remote parts of the city receive prompt waste management services, helping to improve overall cleanliness and sanitation.

CHAPTER 3

RESEARCH GAP / LIMITATIONS

3.1 Power supply

One key challenge requiring attention is ensuring a reliable power supply for the IoT components embedded in the smart bin. Various solutions offer distinct benefits and drawbacks:

1. Solar Energy Panel: The most feasible and cost-effective option is to install a solar panel on the bin's lid. This setup allows the bin to capture solar energy during the day and use any excess power for night time functions. However, this solution can be unreliable during cloudy, rainy, or stormy weather.
2. 9V Battery: Another option is embedding a 9V battery within the bin, providing consistent power over a set period. Yet, this approach requires regular battery replacement or recharging, which is impractical due to the frequent need for replacements throughout the year.
3. Charging Port: The final solution is installing charging ports at each bin location. While feasible, this option is prone to damage and technical issues due to the bins' often crowded and remote locations. It also entails higher setup and maintenance costs.

Careful consideration of these power supply alternatives is essential to determine the most appropriate and efficient solution for ensuring the uninterrupted operation of the smart waste collection system. A hybrid approach, combining solar panels with a backup battery, could offer a balanced solution, leveraging renewable energy while ensuring reliability during adverse conditions. For instance, a small lithium-ion battery could store solar energy and power the bin during low-light periods, reducing dependency on frequent replacements.

3.2 Damage prevention

The primary objective in designing a smart bin is to select a material that ensures durability, resilience, and long-term functionality, capable of withstanding a range of disruptions commonly encountered in urban environments. The material must protect the bin's structure and its embedded IoT components, such as fill-level sensors and communication modules, which are critical for real-time waste monitoring. In order to be able to successfully accomplish this task, it is very crucial that the material possess an exceptionally high level of resistance to corrosion. This is especially critical in regions such as coastal areas or industrial areas, where salt or other contaminants are present and have a tendency to greatly accelerate the process of degradation. Furthermore, the material should have the capability to resist harmful UV radiation in order to prevent problems such as fading, cracking, or overall weakening over a span of time. Furthermore, it is necessary that the material be able to withstand extreme changes in temperatures—ranging from freezing cold to extremely hot—without losing any aspect of its structural integrity. For example, take the smart bins used in cities like Dubai, where temperatures are usually over 40 degrees Celsius; these bins need materials that can continuously maintain their functionality even under such extreme and challenging conditions.

Beyond durability, the material must balance strength with lightweight properties to facilitate easy installation, relocation, and maintenance, especially in large-scale deployments across urban areas. A lightweight yet robust material reduces labour costs and simplifies logistics, allowing municipalities to deploy bins efficiently. Concurrently, it must be capable of supporting the mounting of sophisticated technologies, e.g., sensor housings and antennas, without generating signal interference that would disrupt data transmission to waste management systems. For example, metal materials may interfere with wireless signals, so careful planning must be done so that it is compatible.

CHAPTER 4

SYSTEM ARCHITECTURE

A smart bin prototype is suggested. The smart dustbin is composed of different components which is given below. The prototype is a proof-of-concept for an IoT-enabled, scalable waste management system that can be implemented in urban and rural environments, tackling overflowing dumpsters, fire hazards, and toxic gas emissions.

4.1 Architecture Diagram

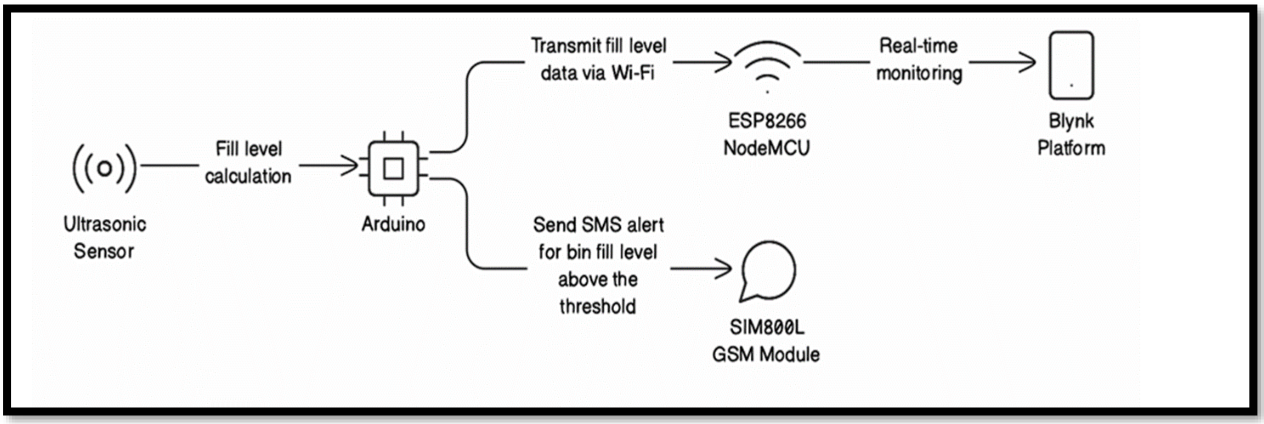

Figure 4.1: Block diagram of the system

The above diagram illustrates the operation of the Internet of Things (IoT) setup. An ultrasonic sensor is mounted on the lid of the waste bin and interfaced with an Arduino Board and a NODE MCU Wi-Fi module, i.e., the ESP 8266. By connecting the ESP 8266 module with the Blynk IoT dashboard, the fill level of the dustbin can be effectively monitored. The Arduino module and the ESP 8266 module are both interfaced with the trigger and echo pins of the ultrasonic sensor (Fig.4.1). Thus, when the threshold value in the Blynk app is 90%, a text message of "Warning: Garbage level is full!" is sent to all the preconfigured phone numbers in the system. Once the data is successfully uploaded to the cloud, additional modules, such as a dedicated mobile or web application, are deployed to provide users with actionable insights.

4.2 Circuit Diagram

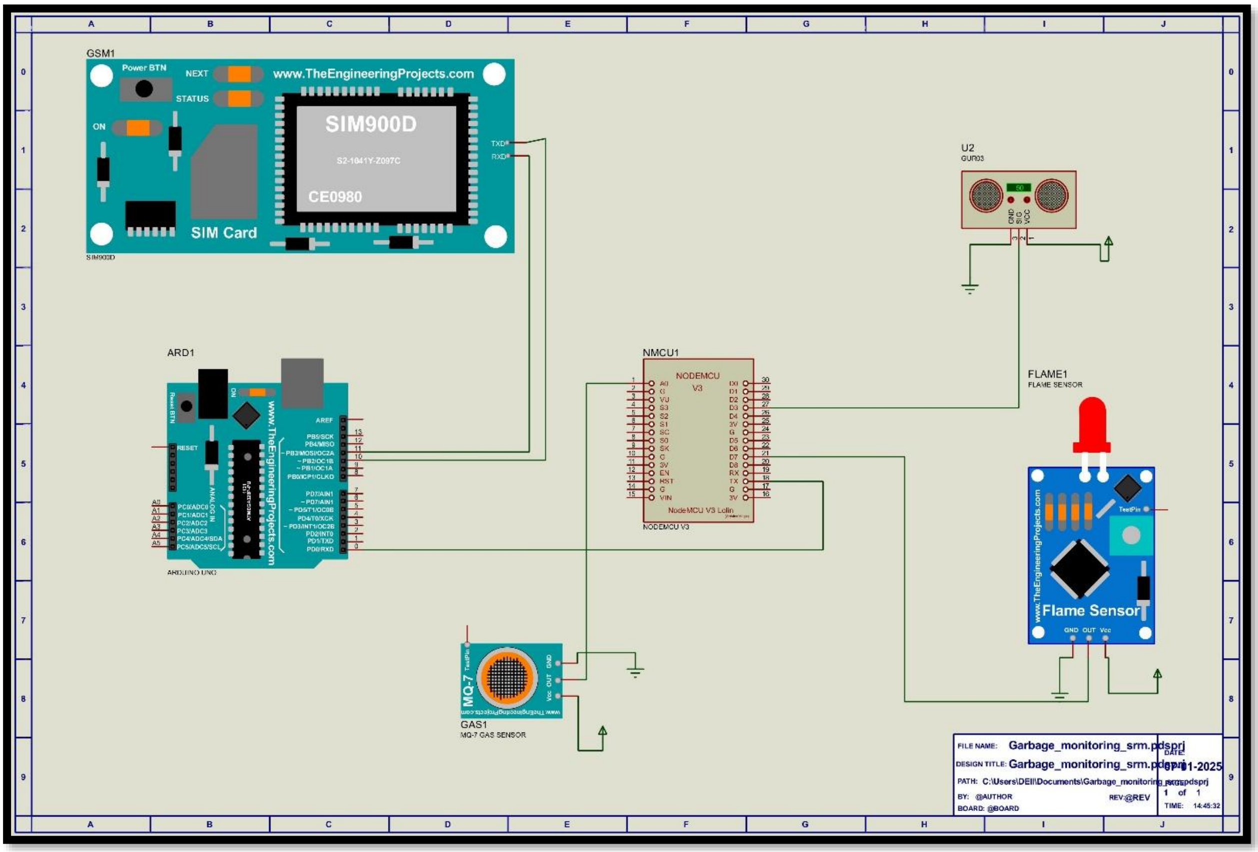

Figure 4.2: Circuit diagram of integrated circuit

This innovative device is designed to be securely affixed to a waste bin, transforming it into a smart waste management system capable of efficiently collecting, processing, and transmitting critical data. The device integrates a suite of sensors and communication modules, including:

a) Ultrasonic Sensor HC-SR04

b) ESP 8266 NodeMCU

c) Arduino UNO Microcontroller

d) SIM900A GSM Module

e) IR Flame Sensor

f) MQ-6 Gas Sensor

g) 9V Battery

h) 16X2 LCD Module

This apparatus will be affixed to the receptacle, thereby facilitating its capability to transmit data and manage information aggregation (Fig. 4.2). Upon collection, the data is relayed to the cloud, where supplementary modules, such as the application, are implemented. The ultrasonic sensor will be installed on the bottom of the lid, anchored to the interior wall of the bin.

4.3 Description of components

4.3.1 Ultrasonic sensor HC-SR04

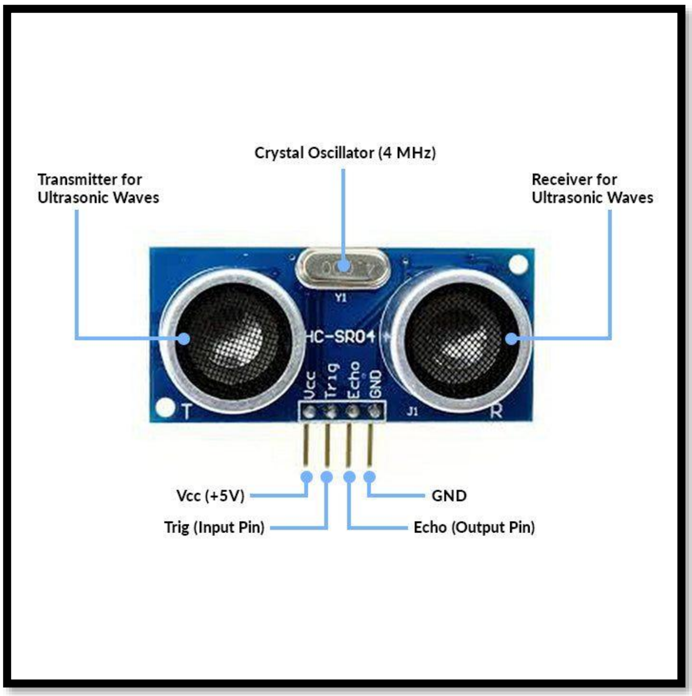

Figure 4.3: Ultrasonic sensor HC-SR04

An ultrasonic sensor is a device that uses high-frequency sound waves beyond the human hearing range to detect distances or locate objects. The sensor operates on the echolocation principle, as employed by bats. The sensor emits a high-frequency sound wave (ultrasound pulse) and calculates the time taken to return after bouncing off a target (Fig.4.3). Based on the travel time, the sensor accurately determines the distance to the target.

A commonly used ultrasonic sensor module is the HC-SR04. It works by emitting a brief pulse of ultrasound and detecting the echo. Here’s how it operates:

a) **Triggering**: The sensor sends a 10-microsecond (μs) trigger pulse to the ultrasonic transmitter, initiating the emission of an ultrasound pulse.

b) **Emission**: The transmitter sends out a pulse that moves through the air until it hits an object.

c) **Reflection**: The pulse bounces off the object and returns to the sensor.

d) **Receiving**: The echo coming back is picked up by the sensor receiver, and the time to return is measured in microseconds.

e) **Distance Calculation**: The sensor calculates the object's distance by dividing the measured time (to the object and back) by two and multiplying by the air speed of sound, approximately 343 meters per second or 0.0343 cm/μs. This gives the distance in centimetres that can be converted to other units as needed.

The HC-SR04 ultrasonic sensor is a basic building block in many applications requiring precise distance measurement, obstacle detection, and motion control, such as robotics, autonomous cars, and smart home devices, due to its simple design, reliability, and affordability. Operating on the basic principle of echolocation, this sensor sends ultrasonic waves at a frequency of 40 kHz, which travel through the air until they reach an object. Upon hitting an object, the waves bounce back as an echo, and the sensor measures the time taken for the echo to travel back. With the speed of sound (about 343 meters per second in air), the sensor calculates the distance to the object using the formula: distance = (time × speed of sound) ÷ 2, thus accounting for the total travel of the waves. This simple method allows the HC-SR04 to deliver consistent readings, typically in the range of 2 cm to 4 meters, with an accuracy margin of about ±3 mm, making it applicable to short-range applications. Its cost-effectiveness, usually selling for less than $5, has made it a favourite among hobbyists, students, and professionals involved in the creation of cost-effective projects. Using this simplicity, the HC-SR04 can provide consistent distance readings within a range from just a few centimeters up to four meters. Its accuracy falls within about three millimetres, making it reliable for many short-range applications. The sensor's ability to give relatively precise measurements at such a low cost makes it ideal for projects with tight budgets. Its price is usually less than five dollars, which helps explain why it is favoured by students developing prototypes, hobbyists building DIY robots, and professionals designing cost-effective electronics.

Many experts highlight the device's ease of use. It is easy to connect to microcontrollers like Arduino or Raspberry Pi models. The sensor's small size allows it to fit into tight spaces, and it requires minimal power to operate.

4.3.2 ESP8266 NODE MCU

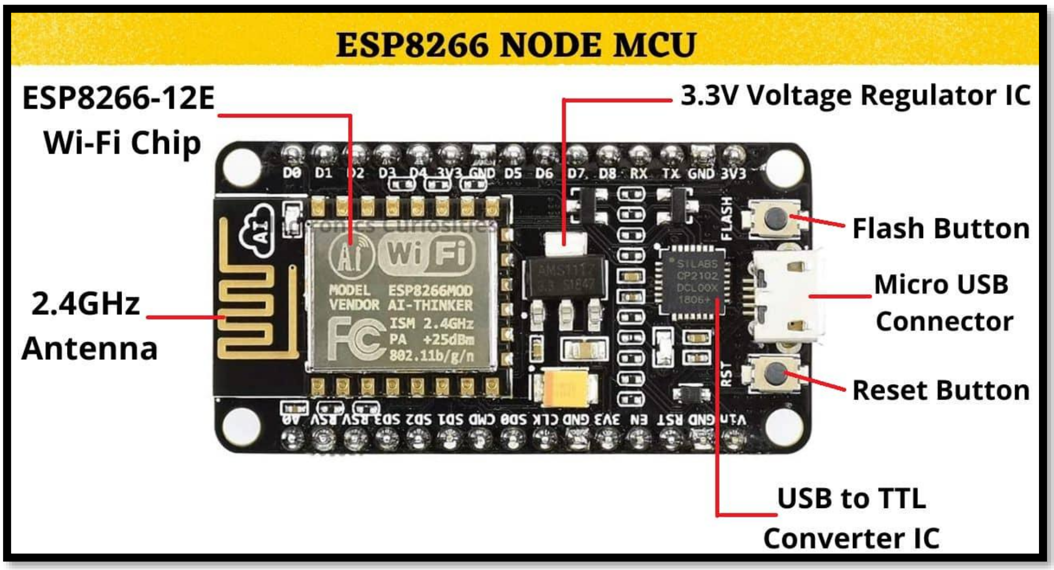

Figure 4.4: ESP 8266 NodeMCU

The ESP8266 NodeMCU is a small and flexible Wi-FI module that includes the ESP8266 microcontroller with built-in Wi-Fi capabilities. The NodeMCU is a popular option for IoT and embedded systems projects due to size, low cost, and ease of use. Here are some of its feature highlights:

a) **Microcontroller**: Includes the ESP8266 microcontroller with Tensilica Xtensa LX106 processor, this low-cost, low-power microcontroller is great for a variety of tasks, especially IoT applications.

b) **Wi-Fi Connectivity**: Built-in Wi-Fi means the NodeMCU can connect to local networks, access the internet, and communicate with other devices and services, making it useful for projects that involved remote control or data transfer.

c) **Development Environment**: The NodeMCU is programmable via the Arduino IDE, and provides an easy development platform for those familiar with Arduino, it even supports various programming languages and development environments.

d) **GPIO Pins**: General Purpose Input/output (GPIO) pins provide the ability for the module to interface with a wide range of sensors, actuators, and peripherals. This allows for flexible IoT applications.

e) **USB Interface**: The NodeMCU can be powered and programmed using a USB interface. This makes startup and testing very easy. For example, it easily connects to your computer for code uploading and debugging.

f) **Community Support**: The popularity of NodeMCU means there is a very large community with ample libraries, tutorials, and forums for resources and help.

g) **Cost-Effective**: The low cost of NodeMCU makes it accessible for hobbyists, students, and professional developers in the field of IoT.

The NodeMCU ESP8266 is a cornerstone for IoT projects like home automation, remote monitoring, and data acquisition, prized for its compact size, built-in Wi-Fi, and user-friendly programming. Its USB interface simplifies development by allowing seamless connection to computers for powering, uploading code, and debugging, making it ideal for rapid prototyping and testing. Priced often below $10, the NodeMCU's affordability democratizes IoT development (Fig.4.4) for hobbyists, students, and professionals, enabling innovative projects without significant investment. Its widespread adoption has cultivated a robust community, offering extensive libraries, tutorials, and forums that provide invaluable resources for troubleshooting and learning. For instance, developers leverage NodeMCU to build smart home devices, such as Wi-Fi-controlled lighting or temperature sensors, which transmit real-time data to cloud platforms. The open-source Lua firmware, combined with Arduino IDE compatibility, enhances its flexibility, supporting diverse applications from environmental monitoring to wearable tech. Despite its low cost, the NodeMCU delivers reliable performance, with a 32-bit microcontroller and 4MB flash memory, ensuring efficient handling of IoT tasks. This blend of accessibility, community support, and technical capability makes the NodeMCU an indispensable tool for creating scalable, connected solutions in educational, industrial, and personal IoT endeavours. The broad adoption of the NodeMCU has created a strong community of users around the world. This community provides a wealth of resources, like ready-to-use libraries, step-by-step tutorials, and discussion forums. These resources make it easier to troubleshoot issues and learn new skills. For example, a new user might follow tutorials to make a simple weather station that records temperature and humidity levels. Others can share tips on improving device stability or connecting sensors more effectively. This vibrant support network accelerates learning and reduces the time needed to complete projects.

Many developers use the NodeMCU to build smart home gadgets. Common examples include Wi-Fi-controlled lights, which can be turned on or off with a smartphone app, or temperature sensors that send real-time data to cloud platforms.

4.3.3 ARDUINO UNO

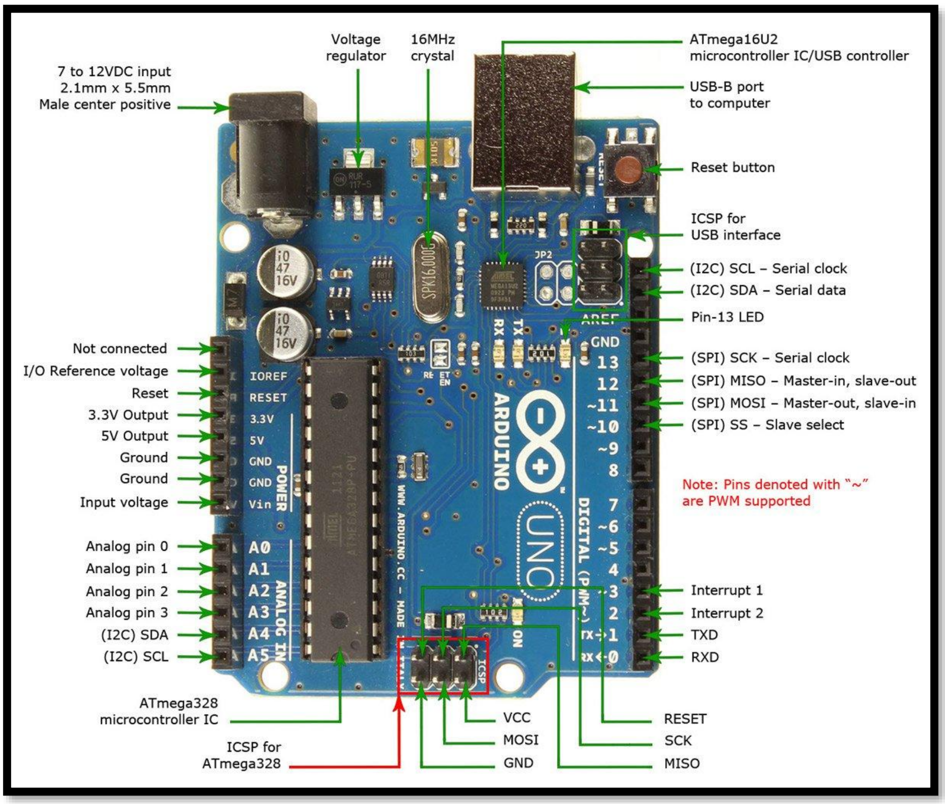

Figure 4.5: Arduino UNO

The Arduino UNO is a popular and versatile microcontroller development board that is part of the open-source Arduino ecosystem, which provides both hardware and software tools for straightforward prototyping and electronics projects. Here's an overview of the Arduino UNO's features:

a) **Microcontroller**: Powered by the ATmega328P microcontroller based on AVR architecture, the Arduino UNO has 32KB of flash memory for code storage, 2KB of SRAM for data storage, and 1KB of EEPROM for non-volatile data storage.

b) **Input / Output Pins**: The board includes 14 digital and 6 analog input/output pins that can be used to connect sensors, actuators, and other electronic components, supporting both digital and analog input/output functionality.

c) **USB Connectivity**: Equipped with a USB interface, the Arduino UNO can easily connect to a computer for programming and serial communication with the microcontroller. The USB connection also powers the board, eliminating the need for an external power source.

d) **Power Supply**: The Arduino UNO can be powered via USB, an external DC power supply, or a battery, with support for various input voltage levels.

e) **Clock Speed**: The Atmega328P microcontroller operates at 16 MHz, providing a good balance between performance and power efficiency.

f) **Integrated Development Environment (IDE)**: The open-source Arduino IDE offers a user-friendly environment for programming Arduino boards, making it accessible to beginners and advanced users alike.

g) **Open Source**: As part of the open-source Arduino platform, the UNO's hardware and software designs are freely available, allowing users to modify and expand its capabilities.

The Arduino UNO is a highly versatile and accessible microcontroller platform (Fig.4.5), ideal for a wide range of projects, including robotics, home automation, data collection, and interactive art installations, due to its simplicity, flexibility, and affordability. Powered by the ATmega328P microcontroller, it offers 14 digital I/O pins and 6 analog inputs, enabling seamless integration with sensors, motors, and displays. Its user-friendly design, supported by the Arduino IDE, allows beginners and professionals alike to program it easily using C/C++, making it perfect for rapid prototyping and embedded systems development. Priced around $20, the Arduino UNO is cost-effective, broadening access for hobbyists, students, and educators. For example, it powers DIY weather stations that collect temperature and humidity data or animatronic art installations at festivals, showcasing its creative potential. Its open-source ecosystem, bolstered by a vast community, provides extensive libraries, tutorials, and forums, simplifying troubleshooting and innovation. The UNO's compatibility with shields and modules enhances its functionality, supporting Wi-Fi, Bluetooth, or motor control applications. At the same time, it can be programmed using the Arduino Integrated Development Environment (IDE), a familiar platform for many electronics enthusiasts. This dual compatibility increases the device's flexibility, making it suitable for many different applications. Whether building a system to monitor air quality or designing a wearable device that tracks activity levels, users can adapt the NodeMCU to fit their needs. It supports industry efforts to build smarter, more connected equipment. For personal projects, it offers a straightforward way to add internet connectivity. These qualities make the NodeMCU a powerful tool for creating new solutions across many fields. These devices can be part of larger home automation systems, giving users more control over their environment. In industrial settings, engineers use NodeMCUs to monitor equipment or collect environmental data in factories.

4.3.4 SIM900A GSM MODULE

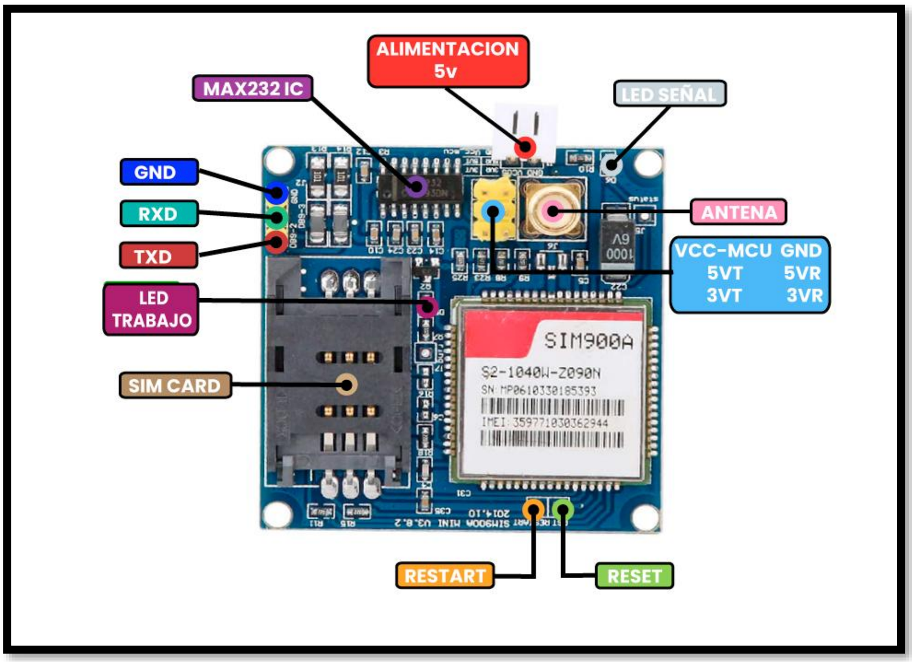

Figure 4.6: SIM900A GSM module

The SIM900A GSM Module is a compact, versatile communication module with GSM (Global System for Mobile Communications) and GPRS (General Packet Radio Service) capabilities, making it suitable for various applications. Here's a brief description of its features:

GSM and GPRS Connectivity: The SIM900A module provides GSM connectivity for making voice calls and sending SMS messages. Additionally, it supports GPRS, enabling data transfer and internet connectivity for applications like remote monitoring and IoT devices.

a) **Compact Size**: The SIM900A has a small form factor, making it ideal for projects with limited space or where portability is important.

b) **Wide Voltage Range**: Operating within a voltage range of 3.4V to 4.4V, the module offers flexibility in power options.

c) **Serial Communication**: It communicates with a microcontroller or host system via a UART (Universal Asynchronous Receiver-Transmitter) serial interface, simplifying integration into electronic projects.

d) **SIM Card Slot**: The SIM900A includes a slot for a standard SIM card, essential for establishing cellular connectivity.

e) **Antenna Interface**: An antenna interface allows for connecting an external antenna to enhance signal reception, especially in low-coverage areas.

f) **Applications**: The SIM900A is widely used in applications such as remote monitoring, asset tracking, security systems, and IoT devices requiring cellular data transmission.

The SIM900A GSM Module is a cost-effective and versatile solution for integrating cellular communication into electronic projects, enabling remote connectivity for IoT devices, vehicle tracking systems, and environmental monitoring solutions (Fig.4.6). Priced often below $15, it supports quad-band GSM/GPRS frequencies (850/900/1800/1900 MHz), ensuring compatibility with mobile networks worldwide, which makes it ideal for global deployment in diverse applications. The module's compact size, approximately 24 mm x 24 mm, allows seamless integration into space-constrained designs, such as wearable devices or compact IoT sensors. Its ability to make calls, send SMS, and transfer data over GPRS empowers applications like remote home security systems that send alerts via text or fleet management tools that transmit real-time GPS data. Equipped with an onboard SIM card holder and UART interface, the SIM900A integrates effortlessly with microcontrollers like Arduino or Raspberry Pi, using simple AT commands for programmatic control of functions like dialling or data transmission. For example, developers use it in rural weather stations to send climate data to cloud servers. However, its 2G-only connectivity limits performance in regions transitioning to 4G/5G networks. The compact size of the module, roughly 24 millimeters by 24 millimeters, allows it to fit easily into tight spaces. This makes it perfect for devices where space is limited, such as wearable health monitors, small IoT sensors, or compact embedded systems. The module can perform several key functions. It can make voice calls, sending or receiving clear audio signals. It can also send and receive SMS messages, useful for alerts and notifications. Additionally, it supports data transfer over GPRS, enabling constant communication with remote servers or cloud services.

This level of communication opens many possibilities. For instance, it can power home security systems that alert homeowners via text when sensors are triggered. Fleet management devices can transmit real-time vehicle location data to control centres. Farmers can use it in remote weather stations to send temperature, humidity, and rainfall data directly to cloud-based databases. The onboard SIM card holder simplifies the setup process, allowing users to insert a standard SIM card without additional equipment. Its UART interface provides an easy way to connect it to microcontrollers like Arduino or Raspberry Pi.

4.3.5 IR Flame Sensor

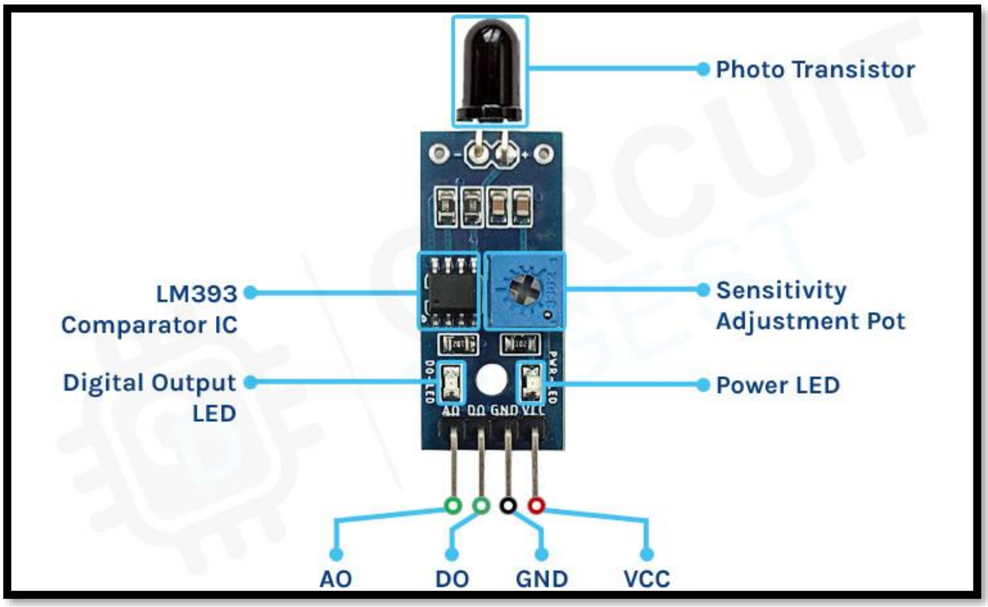

Figure 4.7: IR Flame Sensor

The IR Flame Sensor Module is a compact and versatile electronic device designed to detect flames or light sources emitting infrared (IR) radiation within a specific wavelength range, typically between 760 nm and 1100 nm. This makes it highly effective for identifying fire or other intense light sources, such as a lighter or candle flame, while remaining sensitive enough for use in various applications like fire alarms, firefighting robots, and flame monitoring systems (Fig.4.7). Its affordability, ease of use, and compatibility with microcontrollers like Arduino make it a popular choice for both hobbyists and professionals.

(a) **IR Phototransistor (e.g., YG1006)**: The core sensing element, typically a high-speed, high-sensitivity NPN phototransistor coated with black epoxy to enhance its sensitivity to infrared radiation. It detects IR light emitted by flames and converts it into an electrical signal.

(b) **LM393 Comparator IC**: An operational amplifier that compares the voltage from the phototransistor with a reference (threshold) voltage. It ensures stable and reliable output by processing the sensor's signal into either a digital (high/low) or analog form.

(c) **Potentiometer (Variable Resistor)**: A 10k trimmer pot allows users to adjust the sensitivity of the sensor. By turning the knob clockwise, sensitivity increases, enabling detection of weaker flames or greater distances; counter clockwise reduces it for more precise, close-range detection.

(d) **Power LED**: A small indicator (often red) that lights up when the module is powered, confirming it is operational.

(e) **Output LED**: Typically, green, this LED illuminates when the sensor detects a flame or IR source above the set threshold, providing a visual cue of detection.

(f) **Resistors and Capacitors**: Supporting components that stabilize the circuit, filter noise, and ensure proper functioning of the phototransistor and comparator.

(g) **Pin Headers**: The module usually features a 3-pin or 4-pin interface:

VCC: Power supply input (3.3V to 5V).

GND: Ground connection.

DO: Digital output (high or low signal based on detection).

AO (optional, in 4-pin versions): Analog output (variable voltage proportional to IR)

Operating by detecting IR radiation through a photodiode, it converts light intensity into electrical signals, which can be processed by microcontrollers like Arduino or Raspberry Pi via analog or digital outputs. Its small size, typically around 40 mm x 15 mm, and affordability—often under $5—make it a popular choice for hobbyists, students, and professionals. The sensor's sensitivity enables applications such as fire alarms in smart homes, firefighting robots that navigate toward flames, and industrial flame monitoring systems to ensure safety. For ex Its compatibility with standard 5V or 3.3V systems and simple wiring enhance ease of integration, supported by extensive online tutorials and libraries. This IR sensor is notably compact, typically measuring around 40 millimeters in length and 15 millimetres in width. Its small size allows it to be easily integrated into various devices and projects without taking up much space. Its affordability further adds to its popularity, with prices often falling below $5, making it accessible for a wide range of users. Hobbyists find it ideal for DIY projects, students appreciate its simple design for learning, and professionals use it in advanced systems due to its reliability.

The sensor's high sensitivity is a key feature that broadens its use in many fields. For example, it can be part of a fire alarm system in smart homes, alerting residents immediately when a flame or excessive heat appears. Firefighting robots rely on IR sensors to detect and move toward flames in smoky or dark environments, helping to locate and extinguish fires more quickly.

4.3.6 MQ-6 Gas Sensor

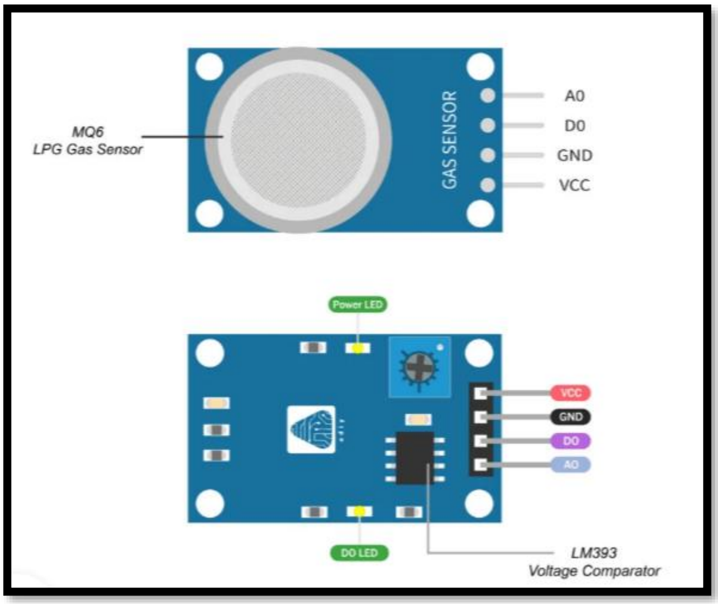

Figure 4.8: MQ-6 Gas Sensor

The MQ-6 Gas Sensor Module is a widely used electronic component designed to detect flammable gases, with a particular sensitivity to liquefied petroleum gas (LPG), propane, and isobutane. It operates by measuring changes in the electrical resistance of a sensing material when exposed to target gases, making it an effective tool for gas leak detection, air quality monitoring, and safety systems in homes, industries, or DIY projects. Known for its affordability, compact size, and ease of integration with microcontrollers like Arduino, the MQ-6 is a popular choice for both hobbyists and professionals working on gas detection solutions.

(a) **MQ-6 Sensor Element**: The core of the module, this is a tin dioxide (SnO_2) semiconductor sensor with low conductivity in clean air. When exposed to flammable gases like LPG or propane, the sensor's conductivity increases, reducing its resistance and producing a detectable signal.

(b) **Heating Element**: An internal heater coil that maintains the sensor at an optimal operating temperature (around 200-300°C). This ensures consistent sensitivity and response to target gases, powered by a 5V supply to the heater pins (VH).

(c) **Load Resistor**: A fixed resistor (typically 10kΩ to 47kΩ) connected in series with the sensor to form a voltage divider circuit. The voltage across this resistor changes with gas concentration and is measured as the output signal.

(d) **LM393 Comparator IC (in some modules)**: Found in modules with digital output, this IC compares the sensor's voltage to a reference threshold, providing a digital HIGH/LOW signal when gas levels exceed a set limit.

(e) **Potentiometer (in some modules)**: An adjustable resistor that fine-tunes the sensitivity or threshold for digital output versions, allowing users to calibrate the module for specific gas concentrations or environments.

(f) **Power LED**: A small indicator (often red) that lights up when the module is powered, confirming it is operational.

(g) **Pin Headers**: The module typically has a 4-pin interface:

VCC: Power supply for the circuit (5V).

GND: Ground connection.

DO: Digital output (HIGH/LOW based on gas detection, if equipped with a comparator).

AO: Analog output (variable voltage proportional to gas concentration).

The MQ-6 is widely used in gas leak detection systems for homes, industrial air quality monitoring, and DIY safety projects, such as smart kitchen alarms that alert users to LPG leaks. For example, it's integrated into portable gas detectors for construction sites to ensure worker safety. Its simple 5V operation and compatibility with standard microcontroller platforms, supported by extensive libraries and tutorials, simplify integration. However, it requires calibration for precise detection and may be sensitive to non-target gases like alcohol vapours, necessitating careful setup. In the smart bin prototype, the MQ-6 is strategically positioned to monitor the internal environment of the bin, detecting hazardous gases that could indicate improper waste disposal or decomposition processes. The analog output is read by the Arduino UNO, which processes the data and triggers alerts via the ESP8266 NodeMCU or SIM900A GSM module if gas levels exceed safe thresholds. These alerts are transmitted to a cloud platform and displayed on the 16x2 LCD module, notifying maintenance teams of potential risks. The module's 5V operation aligns with the smart bin's power system, powered by a 9V battery through a voltage regulator, ensuring consistent performance.

However, effective use of the MQ-6 requires careful consideration of its limitations and setup requirements. The sensor must be calibrated to establish a baseline resistance in clean air, which involves running it in a controlled environment for 24–48 hours (preheating) to stabilize its readings. Calibration also accounts for the sensor's sensitivity to non-target gases, such as alcohol vapors or carbon monoxide, which can cause false positives if not addressed. In the smart bin, the sensor's placement must avoid direct exposure to moisture or waste particles, which could degrade its performance. Regular maintenance, such as cleaning and recalibration, ensures long-term reliability. Additionally, the heater's power consumption may necessitate a robust power management strategy in battery-powered systems like the smart bin to extend operational life. In DIY projects, it enables hobbyists and developers to build their own safety devices, such as smart kitchen alarms. For example, these alarms can alert users immediately if LPG leaks are detected, preventing potential fires or explosions. The sensor is also featured in portable gas detection devices used at construction sites where workers handle gas cylinders or operate heavy machinery involving combustible gases. Its lightweight design and ease of use make it a practical component for such devices, which must be reliable and quick to respond to potential hazards. Its compatibility with microcontroller platforms like Arduino or ESP8266 simplifies integration, as it uses a straightforward 5-volt power supply and is supported by numerous tutorials and libraries. This support accelerates development and allows users to customize their systems more easily.

However, the MQ-6 does require calibration for accurate results. Calibration involves running the sensor in a clean air environment for at least 24 to 48 hours, allowing it to preheat and stabilize its readings. This process helps ensure the sensor's baseline resistance is accurate, which improves precision when detecting gas levels. It is also necessary because the MQ-6 is sensitive to gases other than its target, such as alcohol vapors or carbon monoxide. These non-target gases can cause false alarms if not properly accounted for. Hard-wiring or placing the sensor incorrectly can further affect its readings. In the smart bin project, position matters; the sensor is placed inside the bin to monitor the vapors generated during waste decomposition. Proper placement avoids direct exposure to moisture or dust from waste, which can damage the sensor or impair its ability to detect gases accurately. Regular maintenance, including cleaning and recalibration, helps maintain sensor accuracy over time. Since the MQ-6 includes a heating element that consumes power during operation, managing power consumption is crucial in battery-operated systems, like the smart bin. A proper power setup ensures the sensor remains active without draining the battery quickly. In the smart bin design, the MQ-6's analog output feeds directly into an Arduino UNO. This microcontroller processes the voltage signals produced by the sensor, converting them into readable data. When gas levels rise above safe thresholds, the system activates alerts via connected modules, such as the ESP8266 NodeMCU or the SIM900A GSM module. These modules transmit notifications to a cloud platform or send SMS alerts to maintenance personnel.

CHAPTER 5

CODING AND TESTING

In this chapter, we explore the intricacies of programming and validating the functionality of our innovative waste collection system. Key components, including the Arduino UNO, ESP8266, and SIM900A GSM module, are essential in creating a comprehensive and efficient solution.

The Arduino UNO, a widely-used microcontroller platform, serves as the core of the project, managing various tasks and facilitating communication with sensors and actuators. Through detailed coding, the Arduino UNO is programmed to collect data, monitor bin fill levels, and oversee the overall system operation.

With its Wi-Fi capabilities, the ESP8266 complements the Arduino UNO by enabling data communication and providing internet connectivity. This module is responsible for relaying critical information to a central server, enabling real-time data monitoring and analysis.

The SIM900A GSM module enhances the system's range by enabling mobile communication. This addition improves the system's ability to send alerts and updates to relevant authorities and stakeholders, ensuring timely waste collection and maintenance.

This chapter provides a comprehensive overview of the code developed for each component, explaining the programming logic and functionality. It also addresses the integration of these codes, ensuring seamless interaction among components to achieve project goals.

Testing plays a crucial role, as it allows us to validate the system's performance under various conditions. The system was rigorously evaluated for its ability to monitor fill levels, transmit data over Wi-Fi and cellular networks, and issue alerts when necessary.

The coding and testing phase were a pivotal moment in developing this smart and efficient waste collection system. It marks the shift from theoretical planning to practical application, showcasing how technology can transform waste management on university campuses and contribute to a cleaner, more sustainable, and healthier environment for everyone involved.

5.1 Framework and libraries

5.1.1 ARDUINO IDE

The Arduino Integrated Development Environment (Arduino IDE) is an open-source software designed specifically for programming and developing code for Arduino microcontroller boards. As the primary tool for creating, uploading, and managing code on Arduino boards, the Arduino IDE is a popular choice for electronics and embedded systems projects.

Here are some key features and uses of the Arduino IDE:

a) **Code Writing**: The Arduino IDE allows programmers to write and edit code in C/C++. Its intuitive code editor offers features like syntax highlighting, auto-completion, and code navigation, making it accessible to both beginners and experienced developers.

b) **Library Support**: The IDE comes with a rich collection of pre-written libraries and code snippets that streamline development. Users can also add or create custom libraries to expand the Arduino board's functionality.

c) **Compile and Upload**: The IDE compiles code into a format compatible with the selected Arduino board. With a USB connection, users can easily upload the compiled code to the board.

d) **Serial Monitor**: The IDE includes a Serial Monitor feature, which lets users view real-time data from the board and debug code by displaying output directly from the connected Arduino.

e) **Board Management**: The Arduino IDE supports a wide range of Arduino-compatible boards. Through the Board Manager, users can easily configure the IDE for different boards, allowing for code adaptation across various hardware.

f) **Project Management**: Users can organize larger projects by creating multiple files and managing libraries within the IDE, which is particularly helpful for complex projects.

g) **Open Source**: As open-source software, the Arduino IDE allows users to customize the tool to their needs and contribute to its development.

The Arduino IDE is a versatile and powerful tool, essential for programming and managing Arduino boards, making it a valuable resource for electronics enthusiasts and professionals alike.

The Arduino IDE is a flexible and user-friendly platform for programming and developing projects on Arduino-compatible microcontroller boards. It is extensively used in the maker community, educational settings, and various industries for creating a wide range of electronic applications and embedded systems.

For this project, the following libraries were used:

- **Blynk**: A library that supports IoT applications by enabling remote control and monitoring through the Blynk app.
- **BlynkNpcDriver**: A driver library used for interfacing with specific networking capabilities in IoT projects.
- **ESP8266**: Essential for enabling Wi-Fi communication when working with the ESP8266 module, allowing for seamless data transfer and internet connectivity.
- **CP210_Windows**: A driver for the CP210x USB to UART Bridge, necessary for enabling communication between the computer and microcontroller.

These libraries provided critical functionality and connectivity, allowing for smooth integration and enhanced performance of the Arduino-based project.

5.1.2 Blynk IoT Platform

Blynk is an Internet of Things (IoT) platform that facilitates the development of mobile applications to manage and monitor various IoT projects and devices. Its user-friendly interface and cloud-based infrastructure enable developers and creators to design custom apps for their connected devices without needing extensive programming or mobile application development knowledge (Fig.5.1).

Here are some key features and aspects of Blynk:

a) **User-friendly**: Blynk provides a drag-and-drop app builder, allowing users to create customized mobile app interfaces for their IoT projects. This accessibility makes it suitable for both beginners and experienced developers to control and monitor connected devices.

b) **Cloud Connectivity**: Operating on a cloud-based platform, Blynk allows for remote access and control of IoT devices from anywhere with an internet connection, enabling users to check device statuses and issue commands in real time.

c) **Hardware Support**: Blynk is compatible with various microcontroller platforms, including Arduino, Raspberry Pi, ESP8266, and more. This flexibility allows users to connect their hardware to the Blynk platform and create applications tailored to their specific needs.

d) **Widgets and Controls**: The platform offers a wide range of widgets and controls, such as buttons, sliders, graphics, and notifications, which can be easily integrated into mobile app interfaces. These tools enable users to interact with their devices and visualize sensor data.

e) **Energy Efficiency**: Blynk is designed to minimize power consumption, making it suitable for battery-powered IoT applications and enhancing energy efficiency.

f) **Real-time Data Visualization**: Users can monitor real-time data from their IoT devices through customizable dashboards and widgets, making it easier to analyse and manage information.

g) **Open Source and Extensible**: As an open-source platform, Blynk allows users to modify and extend its functionality according to their requirements. This feature makes it a flexible and accessible tool for developing mobile applications that control and monitor IoT devices.

Blynk is widely used by hobbyists, manufacturers, and professionals in various IoT applications, including home automation, smart devices, and industrial monitoring. Its user-friendly approach and cloud-based infrastructure streamline the development and management of IoT solutions.

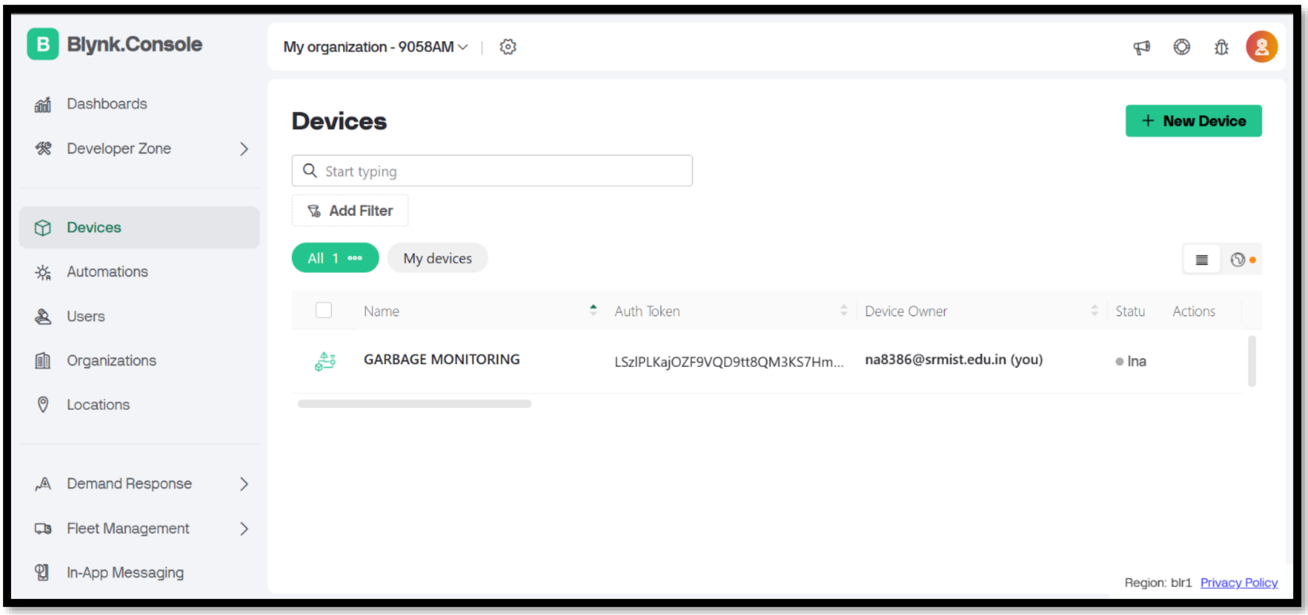

Figure 5.1: Blynk Dashboard

This is the page that is setup once you create your account and login. Steps to follow to create your new device:

Templates > New Template > [Enter the details] > Create > Come back to Dashboard > New Device > From Template > [Select Template]

This would lead to the creation of a personalized dashboard for your project wherein you can add the required elements which would become the meter for the modules attached to the IoT board.

5.2 Software modules

5.2.1 Program for Esp8266 connected to all sensors and Blynk IoT platform

```
#define BLYNK_TEMPLATE_NAME "GARBAGE MONITORING"
#define BLYNK_AUTH_TOKEN "LSzlPLKajOZF9VQD9tt8QM3KS7HmQeBb"
#define BLYNK_TEMPLATE_ID "TMPL3c133mphW"
#include <LiquidCrystal_I2C.h>
#include <BlynkSimpleEsp8266.h>
#include <ESP8266WiFi.h>
LiquidCrystal_I2C lcd(0x27, 16, 2);
#define BLYNK_PRINT Serial
char ssid[] = "Mohammed";
char pass[] = "12345678";

const int trigerpin = 14;
const int echo = 12;
long duration;
int distance;
int percent;

#define TANK_MAX_HEIGHT 20  // Maximum height of the tank in cm
#define gas A0
#define flame D7
```

```
BlynkTimer timer;

void setup() {
  Serial.begin(9600);
  pinMode(trigerpin, OUTPUT);
  pinMode(echo, INPUT);
  pinMode(flame, INPUT);
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("    GARBAGE    ");
  lcd.setCursor(0, 1);
  lcd.print("   MONITORING   ");
  delay(3000);
  lcd.clear();
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);
  timer.setInterval(1000L, sendUltrasonicData);  // Interval to send ultrasonic data to Blynk app
}

void loop() {
  Blynk.run();
  timer.run();
  sendUltrasonicData();
}

void sendUltrasonicData() {
  int gas_value = analogRead(gas);
  int gas_value1 = map(gas_value, 0, 1023, 0, 100);
  int flame_state = digitalRead(flame);

  digitalWrite(trigerpin, LOW);
```

```
  delayMicroseconds(2);
  digitalWrite(trigerpin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigerpin, LOW);

  duration = pulseIn(echo, HIGH);
  distance = duration * 0.034 / 2;

  percent = ((float)distance / TANK_MAX_HEIGHT) * 100;
  lcd.setCursor(0, 0);
  lcd.print("Capacity=");
  lcd.print(percent);
  lcd.print(" %    ");

  //Serial.print("\t gas: ");
  //Serial.println(gas_value);
 /*  Serial.print("Distance: ");
  Serial.println(distance);
 Serial.print(" cm, Filled: ");
  Serial.print(percent);
  Serial.println(" %");
   Serial.print("flame: ");
  Serial.print(flame_state);
  Serial.print("\t gas: ");
  Serial.print(gas_value);
  Serial.print(",\t  ");
  Serial.println(gas_value1);
*/

  Blynk.virtualWrite(V0, percent);
  Blynk.virtualWrite(V2, gas_value1);
```

```
  if (flame_state == 0) {
    Blynk.virtualWrite(V1, "FLAME DETECTED");
     Serial.println("E");

  } else if (flame_state == 1) {
    Blynk.virtualWrite(V1, "NO FLAME DETECTED");
     Serial.println("F");
  }
  if (percent < 15.00) {
      Serial.println("A");
  } else if (percent > 15.00) {
     Serial.println("B");
  }

  if (gas_value1 > 60) {
     Serial.println("C");
  }
   else if (percent < 60) {
    Serial.println("D");
  }
Serial.println(distance);
 Serial.print(" cm, Filled: ");
  Serial.print(percent);
  Serial.println(" %");
   Serial.print("flame: ");
  Serial.print(flame_state);
  Serial.print("\t gas: ");
  delay(300);
}
```

5.2.2 Program for ARDUINO UNO connecting all sensors and SIM900A GSM

```
#include <SoftwareSerial.h>
SoftwareSerial SIM900A(10,11);

void setup()
{
  SIM900A.begin(9600);   // Setting the baud rate of GSM Module
  Serial.begin(9600);    // Setting the baud rate of Serial Monitor (Arduino)
  Serial.println ("SIM900A Ready");
  delay(100);

}

void loop()
{
  if (Serial.available()>0)
  {
     char data = Serial.read();
  if(data=='A')
  {
    SendMessage_garbage();
    delay(5000);
  }
  if(data=='E')
  {
    SendMessage_flame());
    delay(5000);
  }
  if(data=='C')
  {
```

```
    SendMessage_gas();
    delay(5000);
  }
  }
}

 void SendMessage_garbage()
{
  Serial.println ("Sending Message");
  SIM900A.println("AT+CMGF=1");    //Sevts the GSM Module in Text Mode
  delay(1000);
  Serial.println ("Set SMS Number");
  SIM900A.println("AT+CMGS=\"+919489040350\"\r"); //Mobile phone number to send message
  delay(1000);
  Serial.println ("Set SMS Content");
  SIM900A.println("Warning:Garbage is Full!");// Messsage content
  delay(100);
  Serial.println ("Finish");
  SIM900A.println((char)26);// ASCII code of CTRL+Z
  delay(1000);
  Serial.println ("Message has been sent ");
}

void SendMessage_flame()
{
  Serial.println ("Sending Message");
  SIM900A.println("AT+CMGF=1");    //Sets the GSM Module in Text Mode
  delay(1000);
  Serial.println ("Set SMS Number");
  SIM900A.println("AT+CMGS=\"+919489040350\"\r"); //Mobile phone number to send message
  delay(1000);
```

```
  Serial.println ("Set SMS Content");
  SIM900A.println("Warning:Flame Detected");// Messsage content
  delay(100);
  Serial.println ("Finish");
  SIM900A.println((char)26);// ASCII code of CTRL+Z
  delay(1000);
  Serial.println ("Message has been sent ");
}

void SendMessage_gas()
{
  Serial.println ("Sending Message");
  SIM900A.println("AT+CMGF=1");    //Sets the GSM Module in Text Mode
  delay(1000);
  Serial.println ("Set SMS Number");
  SIM900A.println("AT+CMGS=\"+919489040350\"\r"); //Mobile phone number to send message
  delay(1000);
  Serial.println ("Set SMS Content");
  SIM900A.println("Warning:poisonous Gas ");// Messsage content
  delay(100);
  Serial.println ("Finish");
  SIM900A.println((char)26);// ASCII code of CTRL+Z
  delay(1000);
  Serial.println ("Message has been sent ");
}
  Serial.println ("Sending Message");
  SIM900A.println("AT+CMGF=1");    //Sets the GSM Module in Text Mode
  delay(1000);
 }
```

CHAPTER 6

RESULTS AND ANALYSIS

This system is an affordable solution built with readily available components like ultrasonic sensors, the NodeMCU ESP8266, Arduino UNO, and the SIM900A GSM module. It offers a practical and cost-effective approach to enhancing waste management on campus, supplying essential data and real-time notifications to the waste collection system. Adopting this system could significantly benefit universities, supporting broader initiatives to promote cleanliness and environmental responsibility nationwide.

6.1 Real time fill level on computer

The HC-SR04 ultrasonic sensor, mounted on the bin's lid, continuously monitors the fill level, enabling precise tracking of waste accumulation. The MQ-6 gas sensor and IR flame sensor enhance safety by detecting hazardous gases, here when there is no material present within the bin, the levels can be shown below (Fig.6.1).

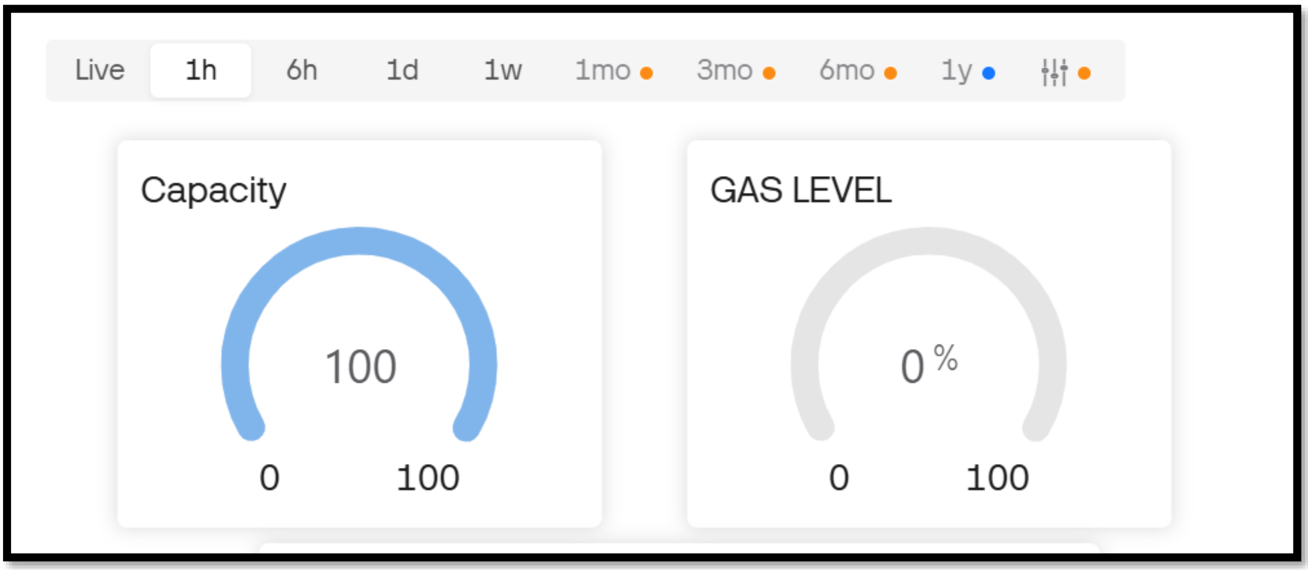

Figure 6.1: Capacity and Gas Levels (empty)

This real-time monitoring reduces overflow incidents, minimizes unnecessary collection trips, and enhances operational efficiency, ultimately lowering costs and environmental impact (Fig.6.2). The system's reliance on a 9V battery further ensures portability and functionality in areas without fixed power sources, making it suitable for diverse campus settings.

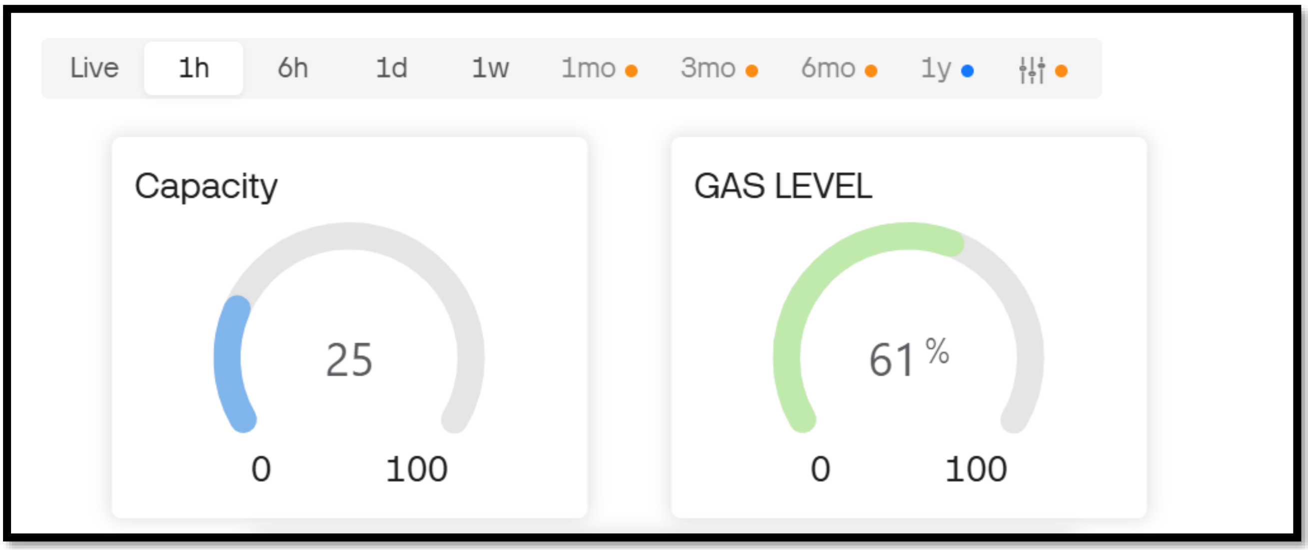

Figure 6.2: Capacity and Gas levels (filled)

6.2 IR Flame Detection

Flames produce a distinct IR signature due to the combustion process, which releases energy in the form of heat and light, including infrared wavelengths typically in the range of 700–1100 nm. The IR flame sensor is engineered to identify these wavelengths, making it an effective tool for fire detection in applications such as safety systems, industrial monitoring, and, in the case of the smart bin, waste management to prevent fire hazards caused by flammable materials or chemical reactions within the bin (Fig.6.3). When a flame is present, it emits IR light that strikes the sensor's detection element, generating an electrical signal proportional to the intensity of the detected radiation. This signal is then processed by the sensor's circuitry to produce either an analog or digital output, which can be interpreted by a microcontroller like the Arduino UNO used in the smart bin system. The IR flame sensor is specifically designed to pick up these wavelengths. It works by sensing the infrared light that is emitted when a flame is present. Sensors like this are used in many safety systems because they can detect fires quickly and accurately. They are often installed in places where fires could be a serious hazard, such as factories, warehouses, and even in household appliances. In the case of a smart waste bin, the IR flame sensor plays a key role in waste management. It helps prevent fires caused by flammable materials or chemical reactions inside the bin.

Figure 6.3: Flame Detection (OFF)

By providing real-time flame detection, the sensor enables rapid response to potential fire hazards, protecting the bin, surrounding infrastructure, and campus community. The system's ability to transmit fire alerts to a cloud platform and notify personnel via SMS ensures that emergencies are addressed promptly, minimizing damage and safety risks.

Figure 6.4: Flame Detection (ON)

Beyond the smart bin, IR flame sensors are widely used in fire alarms, industrial safety systems, and home automation projects, such as kitchen fire detectors. Their simplicity, reliability, and low cost make them ideal for enhancing safety in diverse applications. The sensor may respond to non-flame IR sources, such as intense heat or certain lighting conditions. The smart bin's software can implement flicker detection algorithms to filter out steady IR signals, improving accuracy.

CHAPTER 7

CONCLUSION

This smart bin system represents a highly cost-effective and innovative solution for transforming waste management, leveraging readily accessible and affordable components such as the HC-SR04 ultrasonic sensor, NodeMCU ESP8266, Arduino UNO microcontroller, SIM900A GSM module, MQ-6 gas sensor, IR flame sensor, 9V battery, and 16x2 LCD module. By utilizing these widely available, open-source-compatible components, the system minimizes development and deployment costs, making it an economically viable option for large organizations, particularly college campuses in India, where budget constraints often limit infrastructure upgrades. The ultrasonic sensor monitors the bin's fill level with precision, the NodeMCU enables Wi-Fi connectivity for cloud-based data transmission, the Arduino UNO processes sensor inputs, and the GSM module facilitates SMS alerts, while additional sensors like the MQ-6 and IR flame sensor enhance safety by detecting hazardous gases and potential fires. The system's reliance on a 9V battery ensures portability and operation in areas without fixed power sources, and the LCD module provides on-site status updates, creating a robust, user-friendly solution for waste management.

The system's design prioritizes practicality, with the SIM900A GSM module playing a pivotal role in sending real-time SMS alerts to waste management supervisors, prompting timely waste disposal to prevent overflow and littering. For instance, when the ultrasonic sensor detects that the bin is nearing capacity, the Arduino UNO triggers an alert via the GSM module, notifying supervisors to schedule collection. This proactive approach reduces the incidence of overflowing bins, minimizes littering on campus, and ensures a cleaner environment for students, staff, and visitors. By addressing these challenges, the system aligns seamlessly with India's "Swachh Bharat Abhiyan" (Clean India Mission), a nationwide initiative launched in 2014 to promote cleanliness, sanitation, and environmental responsibility. The smart bin's ability to optimize waste collection and prevent environmental hazards supports the mission's goals of fostering sustainable urban and rural ecosystems, making it a valuable tool for advancing national cleanliness efforts.

The implementation of this smart bin system offers substantial benefits to college campuses and contributes significantly to India's broader cleanliness and sustainability objectives. On campuses, the system streamlines waste management by providing data-driven insights into fill levels, gas emissions, and fire risks, transmitted to a cloud platform via the NodeMCU ESP8266. A mobile or web application, integrated with the cloud, empowers facility managers with real-time notifications and historical data, enabling efficient scheduling of waste collection and rapid response to hazards. This reduces operational costs, enhances campus aesthetics, and promotes a culture of environmental responsibility among students and staff. Nationally, the system's scalability and affordability make it a model for other institutions and municipalities, supporting "Swachh Bharat Abhiyan" by encouraging the adoption of smart technologies to address waste management challenges across India's diverse urban and rural landscapes.

Recognizing the critical importance of environmental cleanliness in today's world, we developed a comprehensive end-to-end waste management system that seamlessly integrates hardware and software to enable large organizations, such as college campuses, to manage waste systematically and efficiently. The hardware components—sensors, microcontrollers, and communication modules—work in tandem to monitor and report the bin's status, while the software layer, including cloud storage and a mobile application, provides an intuitive interface for waste management teams. When a bin approaches full capacity or detects a hazard (e.g., flammable gases or flames), the system sends timely alerts via the mobile app or SMS, ensuring prompt action to maintain a clean and safe environment. This integrated approach not only addresses immediate waste management needs but also furthers the mission of "Swachh Bharat Abhiyan" by promoting sustainable practices and reducing the environmental impact of improper waste disposal.

Looking ahead, future improvements to the smart bin system will enhance its functionality and scalability, further aligning it with national and global sustainability goals. One key enhancement is the development of a route optimization feature for municipal waste collection, utilizing the Google Maps API to analyse location tags from multiple smart bins and suggest the most efficient collection routes. By prioritizing bins that are full and minimizing travel distances, this feature will reduce fuel consumption, lower operational costs, and decrease carbon emissions, contributing to greener waste management practices. Additionally, the system can be expanded to include waste classification capabilities, enabling the bins to identify and segregate different waste types, such as e-waste, metals, plastics, and organic materials. This could be achieved by integrating additional sensors (e.g., capacitive or optical sensors) or machine learning algorithms to analyse waste composition, facilitating recycling and proper disposal. These enhancements will make the system more comprehensive, supporting circular economy principles and further advancing India's cleanliness and environmental objectives.

Given the pressing need for environmental cleanliness and sustainable waste management, we developed this smart bin system as a holistic solution tailored to the needs of large organizations like college campuses. By effectively integrating hardware components (ultrasonic sensor, NodeMCU, GSM module, etc.) with a robust software ecosystem, the system enables systematic waste management through real-time monitoring and mobile alerts. The mobile application provides facility managers with a user-friendly interface to track bin statuses, receive notifications, and analyze waste generation patterns, empowering data-driven decision-making. This proposal addresses critical waste management challenges, such as overflow, littering, and safety hazards, while advancing the goals of "Swachh Bharat Abhiyan" by fostering cleaner, safer, and more sustainable environments. By adopting this system, colleges and other institutions can lead by example, demonstrating the power of technology-driven solutions to create a cleaner and greener India.

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With the rapid urbanization and population growth in modern cities, efficient waste management has become a critical challenge. Traditional waste management systems often suffer from inefficiency, resource overuse, and environmental hazards. This Smart Waste Collection System (SWCS) explores the integration of Internet of Things (IoT) technology to revolutionize waste management practices by enhancing operational efficiency, sustainability and automation. Through real-time data collection and analysis, IoT-enabled smart bins can monitor waste levels, optimize collection routes, and improve resource allocation. The SWCS solution aims to reduce fuel consumption, lower carbon emissions, and minimize human intervention. Moreover, the system promotes eco-friendly waste disposal practices by providing data-driven insights that can aid in better decision-making for urban planning. The results demonstrate significant improvements in reducing costs and environmental impact, paving the way for smarter and cleaner cities.

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- na8386@srmist.edu.in
- jebakumr@srmist.edu.in

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2. Mr. Vaishnav Nambiar	Indian	Student, Department of Computing Technologies, School of Computing, SRM institute of Science and Technology, Kattankulathur, Chengalpattu, India, Tamil Nadu, PIN. 603203
3. Mr. Mohammed Ashraf	Indian	Student, Department of Computing Technologies, School of Computing, SRM institute of Science and Technology, Kattankulathur, Chengalpattu, India, Tamil Nadu, PIN. 603203

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