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DESIGN AND IMPLEMENTATION OF REAL-TIME SMART WASTE MANAGEMENT SYSTEM (WMS) USING THINGSPEAK DATA BASED

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Abstract:

The fast urbanisation and population growth has contributed to the production of a large volume of municipal solid waste, which has posed serious challenges in the management of waste efficiently. Traditional waste collection systems are typically based on a fixed collection pattern and manual waste monitoring, which can lead to sub-optimal collection processes, bins overflowing with waste, and high collection expenses. This study proposes the design and development of an Internet of Things (IoT)-based smart waste management system, which overcomes these drawbacks by using the NodeMCU microcontroller and ThingSpeak cloud platform. This project aims to manage and analyze real-time dustbin data in a large space such as UiTM campus using a secure database channel. The system combines the hardware, the database platform called ThingSpeak and the mobile app called Telegram to send notifications about the state of the bins, such as location, capacity, motion and wetness. The main controller is an ESP8266 NodeMCU which communicates with ultrasonic, PIR and raindrop sensors for the capacity measurement, pest detection, and wetness detection, respectively, and power the LCD, LEDs, a servo motor and a buzzer to support system operation. Furthermore, the mobile information monitor will be centrally located and will show the notifications for the cleaners who don't have a smartphone or access to a Telegram app. The system collects, processes and shares real-time

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data, which enhances the efficiency of waste collection, lowers the burden on operatives and offers a community-friendly, smart waste management solution.

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Keyword:
Internet Of Things (IoT); Nodemcu; Smart Waste Management; Smart City Monitoring; Thingspeak Cloud Platform

Introduction

The management of waste and waste residues is an important part of environmental sustainability and public health protection. It involves various stages such as waste collection, treatment, recycling, and final disposal, all with the goal of reducing environmental pollution and protecting human health from potential risks (Wang, 2022). The amount of municipal solid waste (MSW) being produced globally has surged with the increasing urbanization and industrialization, posing significant challenges to the management of municipal waste by governments and environmental authorities. In the European Union (EU) in 2016, about 423million tonnes (56%) of the waste generated in the EU was recycled, and about 179 milliontonnes (24%) was disposed of in landfills (EUROSTAT, 2020). The figures highlight the need for effective and eco-friendly waste management practices to cope with the rising waste generation.

Rapid urbanisation, population growth and shifts in consumption patterns are all challenges facing Malaysia. Malaysia produced about 19,000 tonnes of solid waste per day in 2005 with only 5% of that waste being recycled. Although there was an improvement in recycling practices, the amount of waste produced was still around 38,000 tonnes per day in 2018 (Sustainable Waste Management in Malaysia: Opportunities and Challenges, n.d.). With the increasing generation of waste, reducing the available space at landfill sites and rising disposal costs, the need to find efficient and intelligent management solutions to optimise waste collection operations and minimise environmental impacts is growing (Korenfeld et al., 2025; Singh et al., n.d.).

In conventional waste management systems, waste is picked up from specific bins at fixed times, irrespective of the amount of waste they contain (Shukla, 2017). This system is widely used, but it has a number of disadvantages, such as bins running over before collection and bins being collected when they are not full. When bin bags are overfilled, this can result in smelly

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conditions or infestations of pests and even health risks to the surrounding environment (Ajitha, 2024). These restrictions emphasize the importance of implementing a more responsive and data-driven waste monitoring system that could provide real-time data on bin conditions.

The recent advancements of Internet of Things (IoT) have made it possible to embed sensors, microcontroller devices and wireless connectivity in various applications of smart cities (Rajput, 2018) to monitor in real-time. In several studies, it has been suggested to use IoTbased waste management systems to enhance waste collection efficiency by automating its monitoring and data transmission. For example, ultrasonic sensors have been used to measure the level of the bins and report the data to a cloud-based system for analysis and optimization of the scheduling (Sheng et al., 2020). Some other studies have incorporated wireless communications and mobile applications to notify waste management workers about the state of bins and the need for collection (Fahmi et al., 2023). Many current systems, however, tend to have a primary concern of bin capacity monitoring, and lack attention to other environmental factors that can affect the efficiency of waste collection including moisture, pest activity and monitoring data accessibility for operations personnel.

Another aspect is that there are a number of current waste monitoring solutions integrated with the Internet of Things (IoT) that require smartphone applications to alert and engage systems (Chalke, 2018). These methods work in some situations but can restrict access to cleaning people who may not be used to using smartphones or particular mobile apps in operational tasks (Chalke, 2018). Therefore, there is a need for a more extensive and user-friendly smart waste monitoring system, that would combine several environmental sensing functionalities and offer various notification channels for various types of users. In order to meet the above challenges, this research introduces an intelligent monitoring and management system based on the Internet of Things (IoT) that can be used to improve the efficiency of waste collection in large institutional buildings such as university campuses. The system combines several sensors for dustbin moisture, human activity and dustbin capacity respectively and uses an ESP8266 NodeMCU microcontroller to process and send the sensor data to the cloud database platform called ThingSpeak where it is stored and analysed. Telegram mobile applications are used to send SMS notifications in real-time; a centralised information display is installed at strategic points to ensure access to cleaning staff without using a smartphone. The proposed system would offer real-time monitoring and multi-platform notifications, enhancing operational efficiency, minimizing manual inspection requirements, and promoting sustainable waste management practices.

The structure of this paper is as follows. The second section provides a review related studies on IoT based smart waste monitoring systems. The system design and methodology is described in Section 3 which comprises the hardware configuration and software development. The results and discussions about the developed prototype system are presented in Section 4. Finally, Section 5 summarizes the results of the study and suggests areas for further research.

Literature Review

Due to rapid urban population growth, municipal solid waste generation has increased alarmingly which has become a challenge for proper waste management. Waste collection is typically done using fixed schedules and manual monitoring, which can result in inefficient waste collection systems and overfilled waste bins (Bahria, 2023). All these concerns can lead

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to resource inefficiencies, impacts on public health, and environmental pollution. Thus, researchers have turned their attention to applying the Internet of Things (IoT) technologies to waste monitoring and management processes. IoT systems allow for the use of smart devices equipped with sensors that can capture and transmit data via the internet, which can be used for real-time monitoring and automation of waste management operations (Shukla, 2017).

A number of studies have been presented that have proposed smart waste bin systems based on the use of sensors that enable monitoring the fill level of bins and facilitate efficient waste collection. For example, Fang et al. designed a smart waste-management system based on the use of sensors, RFID tags, and cloud-based platforms to monitor the level of waste in bins and to track waste-collection vehicles. The system can also give real-time data on waste collection activities and can be monitored from the central side via an administrative dashboard, increasing transparency and operational efficiency in urban waste management systems (Shukla, 2017).

Many different strategies have been investigated for enhancing smart waste management systems with the aid of IoT technologies and sensor-based monitoring. For instance, designed a smart bin system on Arduino platform that incorporates load and IR sensors along with WiFi communication to track waste disposal activities. The system shows the possibility of sensor monitoring however, with multiple sensors and mechanical parts in its integration, the system can be more complicated and costly to maintain (Kumar et al., n.d.). Advanced analytics and machine learning approaches have also been integrated into other studies to enhance the efficiency of waste collection (Swathika et al., 2024). Wang, 2022, Ahmed et al. introduced a waste management system using the Internet of Things (IoT) technology which uses data analytics and clustering algorithms for optimizing waste collection paths. These methods are effective for increasing the efficiency of operations, but they can be complex to integrate into the system and demand more computational power

Likewise, there are monitoring systems based on ultrasonic sensors that have been widely used to determine the fill level of bins, and which can be monitored in real time via cloud-based systems and wireless communication networks (Singh et al., n.d.). The systems provide waste management authorities with a means to remotely track bin status and help minimize overflow. But there are many solutions out there that have complicated architectures and require more implementation cost. Hence, the study aims to develop an IoT based smart waste management system using a low-cost and feasible solution which will include integration of NodeMCU, ultrasonic sensor, Cloud platform (ThingSpeak) and Telegram notification to monitor the waste in real time and alert in a timely manner in smart city applications.

The addition of long-range communication technologies and data analytics platforms (Imanudin et al., 2024; Sheng et al., 2020) to the realm of smart waste management has also been observed in recent developments. For example, waste monitoring systems using LoRa can help manage waste bins in urban environments on a large scale, reporting to centralised cloud-based platforms (Imanudin et al., 2024). These enable the authorities to see how waste is being used and disposed of, inform them when there is a waste problem and to work out how this can be cheaper and more effective to collect. But there are issues like network coverage, battery life and scalability that need to be addressed to make it more widely used in practice.
Further, for the more advanced smart bin architectures, multiple sensing layers and cloud computing are added to enable waste monitoring in a comprehensive manner (Sheela et al., 2024). In these systems, waste bin data is gathered by the sensors and sent to fog/cloud layers

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for processing analysis and then delivered to the municipal departments and waste management companies. These designs can enhance operational efficiency and decision-making capabilities by offering real-time data on waste generation and collection needs (Tandon & Bansal, 2020). Nevertheless, these developments have not been applied to many of the current smart waste management systems, which are typically based on complex architectures that rely on a combination of multiple sensors, sophisticated algorithms, or extensive communication networks (Ahsan, 2024). These methods offer valuable insights and advantages in operational practices, but they can be more expensive to implement, difficult to integrate into systems, and complex in terms of technical knowledge. Moreover, many of the proposed systems focus on the city level deployments and not on the simple and low-cost monitoring systems suitable for smaller communities and localized environments (Wardana & Chen, n.d.).

Hence, a practical and cost-effective waste monitoring system using the internet of things (IoT) platform with real-time monitoring and automatic notification capabilities through the simple deployment of hardware and cloud platforms is needed. Therefore, this study introduces an IoT-based smart waste management system which is developed using Nodemcu, ultrasonic sensor, ThingSpeak cloud platform, and Telegram notification. The goal of the proposed system is to facilitate real-time monitoring of waste and automation of notifications with a low cost and practical IoT solution that can be used in smart city applications.

Methodology

Methodology

This section discusses the methodology for designing and implementing the proposed smart waste management system based on IoT. The development process consists of a number of sequential stages: problem identification, system design, circuit simulation, development of hardware and software, setup of communication with IoT, integration of cloud monitoring and system testing. The system combines sensor-based monitoring, microcontroller processing, wireless communication, and cloud-based data visualization to provide real-time monitoring and automated notifications of waste levels. The overall development workflow is shown in **Figure 1.**

The process starts with the problem identification, which involves identifying that traditional waste monitoring systems are not effective enough, and especially that there is no real-time monitoring and ineffective collection schedules, as illustrated in Figure 1. The subsequent phase of the system is the system design phase, during which the general design of the proposed system is established, such as selecting the sensor, microcontroller, communication mode and monitoring platform. Following this, the design and simulation of the circuit is performed using the Wokwi simulation platform to ensure that the proposed circuit is functional before being implemented in the real world. Once the simulation is successful, the system moves on to the hardware development phase, connecting the various components like the NodeMCU ESP8266 microcontroller and sensors to create the prototype system.

Arduino IDE (Integrated Development Environment) is then used to program the software. The microcontroller is programmed to take in data from the sensors, process the data, and take signals from the sensors to control the action of the system according to the predetermined conditions. It then connects the IoT, and the NodeMCU can send the data collected from the sensors to the ThingSpeak cloud service via the WiFi network, to monitor and visualise the

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data in real-time. To increase system responsiveness, a Telegram notification system has been integrated to alert when the waste level is achieved at a predefined level. Lastly, system testing and system validation are conducted to assess the performance and reliability of the prototype system, making sure the system can effectively deliver the monitoring and alert generation of waste data in real-time.

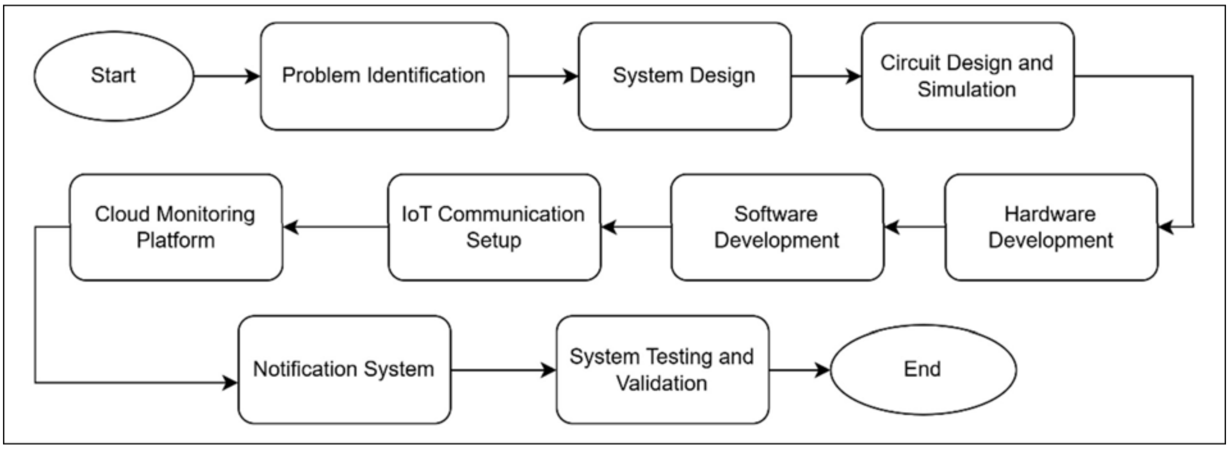

Figure 1: Methodology Flow Chart of System Design

System Architecture

The system architecture is typical of an Internet of Things (IoT), comprising sensing, processing, communication and monitoring layers. The sensing layer detects the level of waste in the bin by an ultrasonic sensor. The NodeMCU microcontroller is used to process the data from the sensor and send it to the cloud platform via a Wi-Fi connection.

The communication layer is used to send wireless data to the ThingSpeak cloud platform via HTTP. The sensor data is stored in a cloud database, called ThingSpeak, which also visualizes the waste level information in graphical form. Moreover, a Telegram bot is also connected to the system that can automatically alert users when waste is at a certain level.

This architecture can enable the waste monitoring process to be done remotely and in real time, letting the waste management staff to monitor the waste bin without having to go and inspect it.

The smart waste monitoring system is divided into four sections: input, microcontroller, cloud system, and output, as shown in Figure 2. Gives an overview of the main parts and how they interact. The system is structured in four layers: sensing, processing, communication and monitoring. The sensing layer is constructed using an ultrasonic sensor, which is used to measure the level of the waste in the waste bin, the processing layer is built using NodeMCU microcontroller, which is used to process the sensor data and calculate the level of the waste in the waste bin.

The data is then sent to the ThingSpeak cloud through the Wi-Fi communication layer, allowing the bin to be monitored remotely. Furthermore, the system is equipped with a Telegram bot that alerts the waste management staff in real-time when the bin level exceeds a threshold. This will ensure efficient management of waste collection, while offering timely alerts and monitoring.

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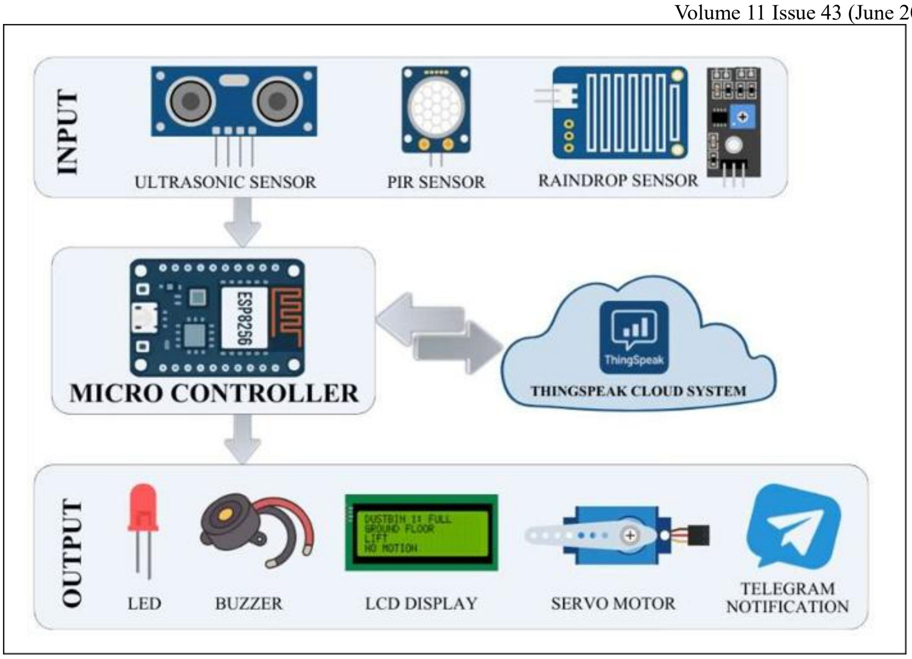

Figure 2: Block Diagram of The Smart Waste Monitoring System

The flow chart of the smart waste management system is shown in Figure 3. Initialisation of serial communication at 9600 baud is the first step in the system operation. After the start of the system, the microcontroller will constantly receive data from various sensors such as ultrasonic sensor, PIR motion sensor, and raindrop sensor, to monitor different environmental conditions related to the waste bin.

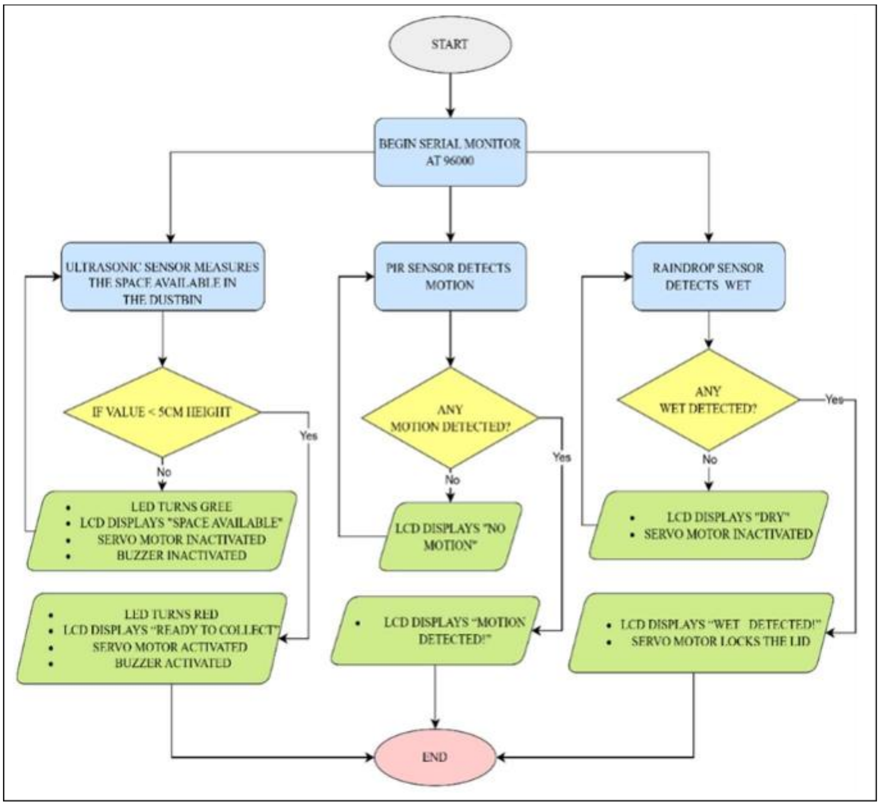

Figure 3: Operational Flow Chart of System Design

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The ultrasonic sensor is used to detect the amount of garbage in the dustbin, based on the space that is left. If the distance is greater than the set distance, the LED indicator will turn on to green, the LCD will display “SPACE AVAILABLE”, and the servo motor and buzzer will not operate. The LED turns red, the LCD reads “READY TO COLLECT” and the servo motor is activated, and the buzzer is sounded to warn the user that the bin needs to be collected when the distance is detected to be less than 5 cm, meaning that the bin is almost full.

Besides, the PIR sensor is used to detect the motion near the dustbin. If there is no movement, the LCD will show “NO MOTION.” If motion is detected, the LCD changes to “MOTION DETECTED”, which means there is a person close to the bin. The system also comprises a rain drop sensor to sense the wetness. If moisture is not detected, the LCD will show “DRY” and the servo motor will not move. However, if there are wet conditions, the LCD will flash “WET DETECTED”, and the servo motor will lock the lid and keep rainwater out of the bin.

Overall, the operational flow chart illustrates how several sensors and the actuators are connected together to provide an automated system for monitoring and detecting the environment and for providing response to it in the smart waste management system.

Simulation

The proposed circuit was drafted and simulated on the Wokwi platform before getting into the hardware development work. This virtual environment allowed for comprehensive testing and validation of the system's components and overall functionality. One of the most important advantages of Wokwi is the ability to test software and communicate with IoT devices; with Wokwi, both hardware and software interactions can be simulated in one place. We could emulate the NodeMCU microcontroller and ultrasonic sensor on the platform to evaluate how the data from the sensors was processed and transmitted to the ThingSpeak cloud platform.
Furthermore, Wokwi provides live communication between the simulated components which was crucial for testing the data transfer and notifications through a Telegram bot. In the virtual phase, potential issues in software / hardware integration were identified and solved by simulating the whole system including the communication capabilities of IoT devices. The simulation process was comprehensive, allowing the system to be optimized and tested thoroughly before moving on to the hardware development phase, reducing the likelihood of mistakes in the actual implementation.

Hardware Components

The design was made into actual hardware after a successful simulation. The proposed circuit was initially designed and simulated on the Wokwi platform and once it was determined that the circuit will work as intended, a PCB (Printed Circuit Board) was created and assembled. The PCB has been designed using a PCB design software (e.g., Eagle, KiCad, etc.), to ensure the correct positioning of components and the optimal routing of the circuit. The components were then soldered in self-segmental parts, and each segment was carefully tested for open and short circuits to assure proper connection before it was assembled.

The hardware design comprises multiple components, each designed to play a crucial role in the operation of the system to detect waste levels and relay the gathered information to the cloud platform. The main controller of the system is a NodeMCU ESP8266 microcontroller. It

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was chosen because of its inbuilt Wi-Fi feature, ease of use, and its compatibility with IoT applications.

The distance between the ultrasonic sensor and the surface of the waste in the bin is measured using an ultrasonic sensor (HC-SR04). The sensor sends out ultrasonic waves and measures the time taken for them to bounce back and find the distance and consequently the level of waste inside the bin. The distance measurement from the ultrasonic sensor is received by the NodeMCU, processed and the percentage of filling in the bin is calculated. If the waste level is above the set limit, the system alerts about it through the built-in communication module.
The hardware components are supplied to the power supply with an appropriate power supply so that the supply power has a stable output. The system design was carefully worked out to accommodate for the same sensor readings and reliable communication with the cloud platform.

Software Development

For software development, the Arduino Integrated Development Environment (Arduino IDE) was used for the system, following the concept of the hardware components and system architecture described in the previous section. Embedded C programming was used to program the NodeMCU microcontroller, which was used to control the ultrasonic sensor, process the data from the sensor and send the data to the cloud platform. The programme constantly reads the distance measurements from the ultrasonic sensor in order to convert them to values for the corresponding bins.

The bin-level values are then sent to the ThingSpeak cloud platform via Wi-Fi network, through the given application programming interface (API). The API key is used to verify the authenticity of the device and enables the automatic transfer of data to the assigned cloud channel so that you can monitor it in real time.

Also, the software features an algorithm that monitors conditions. Once the waste value is reached and it is above a specific value, the system automatically sends a notification through a Telegram bot. This feature allows real-time alerts, which helps to ensure that waste is picked up on time and the waste management system is more efficient.

Cloud Monitoring Using ThingSpeak

After the system design and software development, the waste level data is transmitted to cloud-based ThingSpeak, which is used to store, visualise and monitor the data. The platform allows data to be sent to it using HTTP protocols and allows real-time visualisations of the data collected in the form of graphics. Every NodeMCU device is linked to a channel, and the data collected from the sensor is saved and graphed as a time series. Users can access the monitoring dashboard through the ThingSpeak interface, where they can remotely monitor the level of waste.

The system can be further enhanced by integrating with ThingSpeak, which allows remote monitoring from anywhere with an Internet connection, thus increasing the efficiency of the waste management system. Moreover, the data stored can be used to analyze and maximize the efficiency of waste collection planning and management. This cloud-based solution enhances

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the scalability and flexibility of the system, guaranteeing its long-term effectiveness and operational efficiency.

Telegram Notification System

The system's responsiveness was enhanced to make the system more user friendly by adding a Telegram notification system to the cloud monitoring service. Telegram is a cloud-based messaging system that can be integrated using application programming interfaces (APIs). A Telegram bot has been set up to send automatic notifications when waste level is detected by the ultrasonic sensor is above a certain threshold. When this is done, the NodeMCU will send the message to the Telegram API, which will then forward the message to the user's Telegram account.

The automated notification system adds to the system's usability and efficiency, allowing waste management staff to receive timely notifications and take action before bins become overflowing. Telegram notifications further enhance the responsiveness and efficiency of the smart waste monitoring system, promoting seamless and timely operations.

Results and Discussion

The outcomes of the implementation and testing of the proposed IoT based smart waste management system are presented in this section. The prototype was developed and tested to determine how well it can detect a level of waste, send this data to the cloud-based platform and issue a notification when the waste bin reaches a specific level. The outcomes show the effectiveness of the system for waste management in real-time monitoring and automated alerts.

Circuit Simulation

Proposed system was initially validated by circuit simulation using Wokwi platform. The simulated configuration shown in **Figure 4** is meant to mimic the relationship between the NodeMCU microcontroller, sensor elements, and communication components which would be used to send data to the cloud platform. The simulation environment allowed for the pre-testing of the system logic without making the actual implementation.

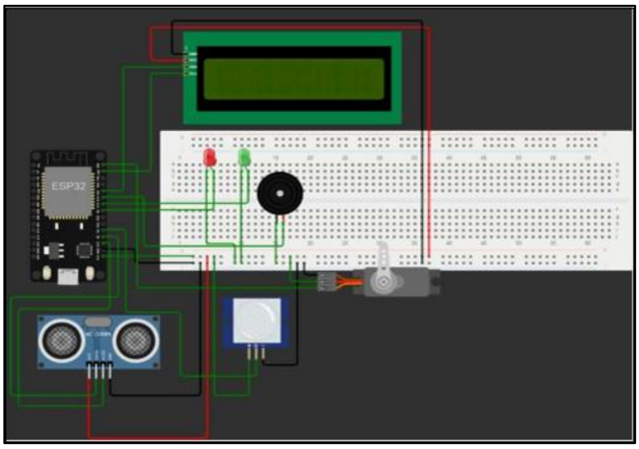

Figure 4: Simulation Circuit on Wokwi Desktop Application, Demonstrating the Virtual Representation of The System's Components

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The microcontroller was able to receive and act on the sensor data during simulation without errors of communication. The cloud interface was simulated to send data to it, and the results showed that the IoT communication framework could function as designed. The preliminary validation is necessary because it allows for the correct interaction between the sensing, processing and communication components prior to fabrication of the hardware prototype.

The successful simulation results have shown that the system architecture is structurally functional for the real-time waste monitoring application. This simulation process minimized the chances of hardware implementation mistakes by revealing possible integration problems at the virtual testing phase and increased the overall reliability and robustness of the developed prototype.

Prototype Implementation

Given the successful simulation stage, the prototype was tested in real operating conditions to determine the sensing and processing capabilities. The monitoring system was able to consistently respond to changes in waste levels as measured by a ultrasonic sensor. The measured distance between the sensor and the waste surface was precisely interpreted by the NodeMCU and the system could determine the status of the waste bin.

The overall electrical architecture of the system is depicted in **Figure 5**, where the connections between the sensing, processing, and output components are shown. The signal was tested in the system and stable transmission was noted between these modules, allowing for continuous data collection from the sensors and reliable connection with the monitoring system. Finally, the circuit layout and fabricated board of the electronic system are presented in **Figure 6**. The board was able to keep the electrical connections stable for the entire testing period, which ensured the continuity of the system's operation during the continuous monitoring.

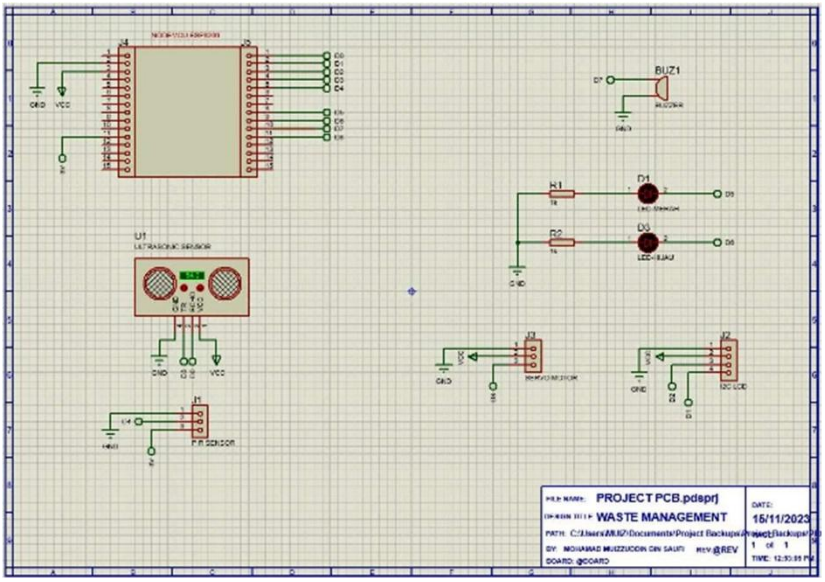

Figure 5: Circuit Schematic Diagram on Proteus, Outlining the Electrical Connections for The Smart Waste Management System

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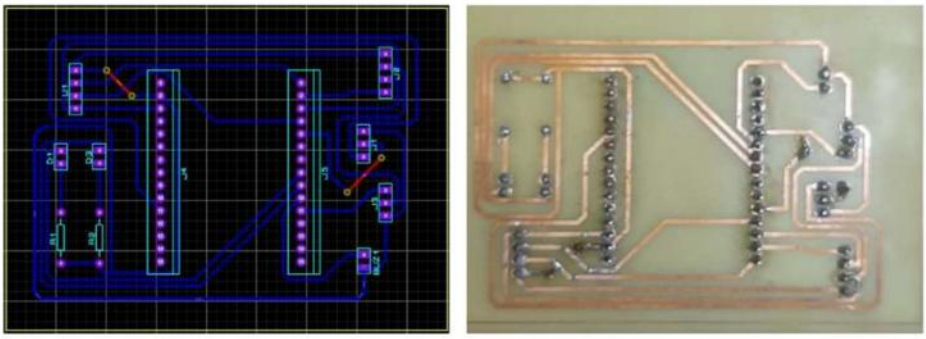

(a) (b)

Figure 6: PCB Design Layout (A) and The Fabricated PCB (B) for The Smart Waste Monitoring System, Showing the Electrical Circuit and Component Placement

In **Figure 7**, physical integration of the sensing and control modules is observed. The bin-mounted sensing unit allowed the detection of waste accumulation without exposing the electronic components. The system has shown sensitivity to the changes of bin condition during test, indicating the good configuration of the physical setup to ensure reliable monitoring in real applications.

(a) (b)

Figure 7: Hardware Prototype with Circuit Connection Between Nodemcu and Sensors (A) View from The Back of The Bin (B) View from The Inner Side of The Bin

The fully functional prototype is shown in **Figure 8.** The system was tested and was able to process the sensor readings and send the sensor data to the ThingSpeak cloud platform over Wi-Fi. The data transmitted was regularly updated on the online dashboard of the system, and the waste level status could be monitored remotely. This finding shows that the IoT communication architecture works well and enables real-time monitoring functions.

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Figure 8: Developed a Prototype of The Smart Waste Monitoring System, Showcasing the Physical Implementation of The Project

The LCD display is used to show user interaction with the system, as shown in **Figure 9**, with various messages displayed depending on the detected bin condition. For the various tests, the following messages appeared: “Ready to Collect” message appeared in the display when the corresponding sensor condition was detected; “Motion Detected” message appeared in the display when the corresponding sensor condition was detected. When the lid-locking mechanism was activated by detecting motion, it was found that the sensing and control functions work well and enhance the system function.

The experimental evaluation demonstrates its reliability in terms of stable sensing performance and a consistent data transfer to the cloud platform. The fact that it can be remotely monitored and automatically updated with the status of the waste indicates the convenience of the proposed system. This type of capability can help waste management authorities to better plan for waste collection and minimise unnecessary collection trips, thereby enhancing operational efficiency.

Figure 9: LCD Display Showing the Status “Ready to Collect” And “Motion Detected,” Where the Dustbin Lid Is Automatically Locked *Real-Time Monitoring Using ThingSpeak*

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Bin conditions were continuously monitored by integrating with the ThingSpeak cloud platform. The readings from the sensor were being uploaded to the cloud channel automatically as part of the code on the NodeMCU, allowing the status of the bin to be displayed using time-series graphs. The monitoring dashboard presented in **Figure 10** offers a graphic window to watch the changes in the level of waste over time. Visualisation helps users to easily detect the approaching capacity limit of the bin and make timely decisions regarding waste collection. Waste management staff no longer have to manually check the status of bins by physically visiting them, as they can check the status from the cloud interface instantly. This functionality illustrates the benefit of communicating IoT devices through cloud platforms, which provide data storage, visualisation and access in a consolidated monitoring space.

The monitoring interface in ThingSpeak can serve as a valuable tool to visualize real-time data from sensors and track the behavior of systems over time. Using the graphical output, the waste management employees can monitor the situation of the bins remotely and assist in making decisions based on the data.

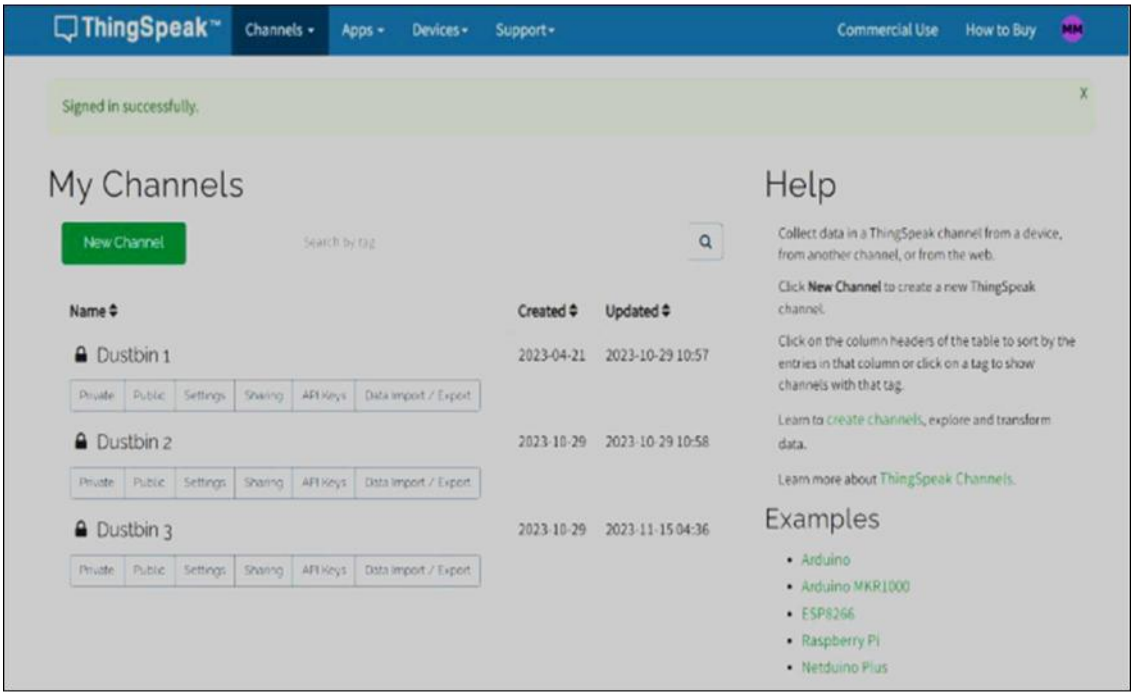

Figure 10: Waste Level Monitoring Dashboard on The Thingspeak Platform, Displaying Real-Time Data Visualisation of The Bin's Waste Level

The real-time monitoring graph is another useful way to see the performance of the system in that it displays the waste levels along with the motion detection status, as shown in **Figure 11.** The available space in the dustbin data comes from the waste level data collected by the ultrasonic sensor. The more waste that's collected, the less space will be left, and the graph will show how the space is decreasing. At the same time the data gathered from the PIR sensor depicts whether people are present close to the bin.

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Figure 11: Real-Time Monitoring Graph on The Thingspeak Platform Showing the Waste Level (Available Space in The Dustbin) And Motion Detection Status

The two parameters can be viewed together to get a full picture of bin usage patterns. For instance, higher motion activity in the vicinity of the bin might be linked to higher waste disposal actions, potentially resulting in a quicker filling rate for the bin. The simultaneous monitoring of these parameters allows a more comprehensive study of the behaviour of wastegeneration and the way of the user interacting with the bin, which can provide important information to optimize the waste collection in high traffic areas.

Besides the monitoring of the waste level, the system also assesses the conditions inside the dustbin (environmental conditions). The raindrop sensor was used to measure the wetness parameter, and the real time monitoring graph is shown in **Figure 12**. The graph shows moisture levels in the bin environment based on the detection of water droplets. This is important to monitor as it can impact the make-up of the waste, cause odors, and speed up the bacteria growth.

Figure 12: Real-Time Monitoring Graph on The Thingspeak Platform Indicating the Wetness Condition Within the Dustbin Based on Water Droplet Level Measurements

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Wetness monitoring is included to improve the usability of the proposed system beyond just detecting the level of fill. Maintenance workers can recognize when the bin is wet and take corrective action to make the bin dry, such as inspecting the bin lid or making the bin's drainage conditions better. The integration of multiple sensors into a waste management platform powered by IoT shows the added value of environmental monitoring.

The ThingSpeak monitoring interface has proven to be an effective way to represent real-time sensor data and observe the behavior of the system over time. The graphical outputs allow waste management staff to monitor the condition of bins from a distance and help them make informed decisions based on data when planning waste collection.

Automated Notification System

Once the ultrasonic sensor detects the waste level above the preset value, the NodeMCU microcontroller will automatically send a message to Telegram messaging service. The following are examples of alert messages produced by the system as the bin is filling up: **Figure 13 (a) and Figure 13 (b).** All these notifications are sent directly to the user's Telegram app, notifying the waste management staff to attend to the bin. The alerts contain a clear status message, which tells the user the condition of the bin and reminds them to carry out waste collection.

(a) **(b)**

Figure 13 (A) And (B): Telegram Notification Alert Generated When The Bin Reaches The Threshold Level, Providing Real-Time Alerts for Waste Management Personnel

The automated notification system also enhances operational efficiency by replacing traditional waste monitoring methods that rely on periodic visits. When an inspection trip is required, waste collection staff can respond, minimizing unnecessary trips and providing more efficient resource allocation. Messaging apps like Telegram also increase accessibility to the system, as notifications can be received on popular cell phone devices.

System Performance Discussion

The experimental results showed that the proposed IoT based waste monitoring system could successfully realize reliable sensing, data transmission, and real-time monitoring. The NodeMCU microcontroller was able to receive sensor data and transmit the sensor data to the

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cloud database in the ThingSpeak cloud via a Wi-Fi network, allowing the status of the bin to be monitored remotely at all times. During testing, the ultrasonic sensor proved to have a stable measurement of distance, enabling the bin capacity to be estimated accurately. Data visualisation created with the ThingSpeak platform gave a clear picture of whether the system was working or not and the Telegram notification system notified users to the bin when it used to cross the set threshold.

The developed system is one of the key benefits due to the cost-effective implementation of the system. By leveraging commercially available IoT components like the NodeMCU microcontroller and ultrasonic sensors, the system can be implemented at a relatively low cost compared to more sophisticated smart waste management solutions. Moreover, cloud-based monitoring and automated messaging offer a viable solution for enhancing the efficiency of waste collection without the need for significant changes in infrastructure.

Although these are encouraging findings, there are some practical concerns that should be noted. The system should be stable for Wi-Fi connectivity for the transmission of sensor data to the cloud platform. Communication delays or interruptions can impact real-time monitoring performance in environments with less than reliable Internet connections. In addition, the accuracy of the ultrasonic measurement could be affected by irregular surfaces or obstructions within the waste bin, which may cause errors in the measurement of distance.

The developed prototype shows the potential of the use of IoT technologies for smart waste management applications. The proposed system integrates sensor-based monitoring, cloud-based data visualisation, and automated notifications, offering a scalable and practical solution to enhance waste monitoring efficiency and aid in the creation of smart city infrastructure.

Conclusion

In this paper, the design and implementation of an IoT based smart waste management system is presented that uses multiple sensors, NodeMCU microcontroller, ThingSpeak cloud platform and a telegram notification system to perform real-time waste monitoring. The experimental results show the accuracy of the prototype in the measurement of the waste level, the transmission of the data to the cloud platform and the automatic notification when the bin reaches a set threshold. Cloud-based monitoring enables waste management staff to remotely view the condition of bins using graphical dashboards, and the automatic alert system significantly improves operational efficiency by minimizing the need for manual checks. Moreover, the employment of low cost IoT components enables the system to be practical for installation in the institutional setting like university campuses. Overall, the proposed system offers a viable and effective solution to enhance waste monitoring and management. The proposed solution is well-suited for implementing more intelligent waste management solutions in future smart city infrastructures.

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