DEVELOPING A SMART DRAINAGE WASTE MANAGEMENT AND NOTIFICATION SYSTEM: INNOVATING SUSTAINABLE URBAN WASTE MANAGEMENT

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***Abstract* – Efficient solid waste management (SWM) is crucial for attaining Sustainable Development Goals (SDGs), particularly amid the challenges posed by rapid urbanization, which are acutely felt in the Philippines and Iligan City. The accumulation of drainage waste exacerbates SWM issues, necessitating innovative solutions to address these environmental concerns. This study delves into the application of IoT technology to enhance SWM, focusing on the development and evaluation of a Smart Drainage Waste Collector Notification and Management System (SDWMNS). By amalgamating traditional and agile methodologies, the research strives to bridge identified gaps in drainage waste management practices. Through meticulous analysis and thorough user evaluation, the SDWMNS prototype showcases heightened efficiency and effectiveness in waste collection and management processes. The findings underscore the transformative potential of technological advancements in revolutionizing drainage waste management practices, thereby offering tangible benefits for local authorities and environmental agencies. These innovative solutions are pivotal for promoting sustainable urban resilience in the face of evolving environmental challenges, ensuring the well-being of communities and the preservation of ecosystems. As cities grapple with the complexities of waste management, embracing IoT-driven solutions can pave the way for more sustainable and resilient urban environments, aligning with broader efforts to achieve SDGs and foster a greener, healthier future for generations to come.**

Keywords: Sustainable Development Goals, drainage waste management, Internet of Things (IoT), monitoring system, solid waste management

I. INTRODUCTION

Efficient solid waste management (SWM) is crucial for achieving the Sustainable Development Goals (SDGs), as it addresses significant environmental, health, and economic challenges posed by increasing waste generation due to rapid urbanization and industrialization. Effective SWM strategies are essential for sustainable urban development and environmental protection. Over the years, the field of SWM has evolved significantly. Initially, waste management practices were rudimentary, focusing primarily on basic collection and disposal. However, with growing environmental awareness and the need for sustainability, the integration of recycling, waste diversion, and environmental protection measures became more prominent. Recent advancements now emphasize sustainable and technologically advanced waste management practices, reflecting the ongoing progress in the field.

Key developments in Solid Waste Management (SWM) include the implementation of unit pricing for municipal waste [1] and the introduction of development bands to guide waste management practices [8]. Additionally, there has been a growing focus on reducing food waste and improving waste diversion strategies to meet specific Sustainable Development Goals (SDG) targets. Technological advancements, such as waste-to-energy technologies [6] and smart waste management systems [3] , have significantly impacted the field. These innovations enhance the efficiency and effectiveness of waste management by automating processes and improving monitoring systems. Efficient SWM strategies align with several SDGs, including SDG 11: Sustainable cities and communities; SDG 12: Responsible consumption and production; SDG 13: Climate action; and SDG 7: Affordable and clean energy.

There is a need for targeted solutions to manage waste in these critical infrastructures effectively. In Iligan City, the projected generation of approximately 96,399.13 metric tons of waste in 2023 (NSWMC) exacerbates the problem of waste accumulation in drainage systems. This issue poses significant environmental and public health risks due to improper disposal, inadequate infrastructure, and insufficient maintenance [4].

Moreover, there is a notable gap in the focus on garbage monitoring within drainage systems. Existing solutions are often ineffective in preventing blockages and ensuring efficient waste management. The lack of comprehensive technological interventions to address these specific challenges represents a critical gap in current knowledge and practice. Which leads to the question, how can the Smart Drainage Waste Management and Notification System (SDWMNS) improve the efficiency and effectiveness of waste collection and maintenance in urban drainage systems to mitigate environmental and health risks associated with waste overflow.

This research is necessary to address existing gaps by developing and implementing the Smart Drainage Waste Management and Notification System (SDWMNS), which aims to improve waste monitoring and management in drainage systems. By providing insights into the practical application of technology in solid waste management (SWM), this approach can yield significant theoretical, practical, and societal benefits. These benefits include enhanced urban resilience, reduced environmental pollution, and improved public health outcomes. Moreover, the research aligns with the Sustainable Development Goals (SDGs) and can contribute to sustainable urban development.

Also, the study contributes to academic knowledge by exploring the intersection of technology and environmental management and providing empirical evidence on the effectiveness of smart waste management systems in urban drainage contexts. This research has practical applications, such as improving waste collection efficiency, reducing health risks, and enhancing compliance with waste management regulations. These findings could benefit various stakeholders, including local governments, environmental agencies, and urban planners.

The increasing use of IoT and smart technologies in environmental management is a significant trend influencing the field. This research capitalized on these trends to tackle specific solid waste management (SWM) challenges in urban drainage systems. By focusing on the often-overlooked issue of waste management in drainage systems, the study introduced a fresh perspective. It underscores the importance of technological innovation in enhancing the sustainability and resilience of urban environments.

II. LITERATURE REVIEW

A. Smart Waste Management Systems for Urban Areas

The rapid population development in the Philippines has made waste management one of the country's most pressing concerns [7]. People are depositing garbage on streets, in open drainage, and even in rivers. Waste management is one of the solutions that provides programs, mechanisms, incentives, and funding for the implementation of local government regulations and statutes. This research focuses on the development and implementation of a waste management system that separates biodegradable and non-biodegradable wastes, measures the level of waste inside the container, and helps the waste collector find the shortest path of the nearest waste container; directly to the waste land fill using the Internet of Things (IoT) and a mobile application.

The concept of Smart waste management involves the integration of technology, such as the Internet of Things (IoT), sensors, and data analytics, into traditional waste management practices. This approach enables real-time monitoring of waste levels in bins, and improving overall efficiency. Smart waste management systems can also provide insights into waste generation patterns, helping cities to plan better and implement waste reduction strategies. By leveraging technology, smart waste management not only addresses the challenges of urban waste management but also contributes to the creation of cleaner, healthier, and more sustainable cities.

B. Smart Drainage and Sewerage Management Systems

Every living organism on Earth requires water for survival [5]. These three activities account for the majority of residential water consumption, where liquids and dry substances can coexist in the same container. Even in sophisticated societies, septic tank pumping remains challenging. The primary function of the intelligent drainage system is to collect and transport solid refuse such as plastic bottles and polythene to the proper disposal area. A common cause of clogged pipes is improper disposal of solid refuse. Regular trash collection and appropriate disposal and a system that autonomously cleans water in the drainage system and prevents clogs by collecting solid waste and depositing it in a waste bucket can prevent this issue. There is less need for and risk associated with manual labor.

In addition, there has been a dramatic rise in pollution levels since the turn of the previous decade [4]. Garbage and sludge are constantly blocking the drains, the sewers, and the manholes. Many sewer gasses, some of which are toxic or even explosive, are produced as a result. The cleaners who are exposed to these dangerous gasses run the risk of an explosion as well as their own lives. Those who live in close proximity to the affected area may also be at risk. The local government has no idea that these poisonous gasses are accumulating underground. The spread of disease could increase if cleaning is put off. The danger of an open manhole cover occurs on rare occasions. An alarm or notification system is required for situations involving hazardous sewer gas levels, the lid being left off, and slurry building up inside the manhole. They present a system that uses specialized sensor modules and the NodeMCU system on chip to continuously monitor noxious sewer gasses in addition to slurry and lid levels.

C. Power Consumption Calculation

Conveyor belts are an economical means of transporting materials, typically consisting of a rubber belt moving between two cylinders [2]. One cylinder rotates at a constant speed, creating a tension difference between the tight side and the slack side of the belt. The power transmitted from the belt to the pulley is given by the product of the belt width, the tension difference, and the belt velocity. This power facilitates useful work but also causes energy dissipation due to frictional work, particularly from slip between the belt and the pulley. Understanding the relationship between belt-pulley slip, torque, and frictional energy dissipation is crucial for improving the efficiency and durability of the conveyor system.

In addition, belt conveyor systems are extensively used for continuous transport of large volumes of bulk materials [9]. These systems involve numerous idlers. Therefore, understanding the pressure distribution exerted by the bulk material on the belt is crucial for the engineering design of the belt. However, measuring the pressure exerted by the bulk material on a moving conveyor belt is challenging. Current literature indicates a lack of effective sensors or procedures for direct pressure measurement. Previous studies have focused on measuring the forces on idler rolls using load cells or strain gauges. These methods provide indirect estimates of the pressure distribution but are limited by offering only a few measurement points, which restricts the comprehensive understanding of the pressure distribution on a loaded conveyor belt.

III. MODELS AND METHODS

This section explains the research methods used to develop a Smart Drainage Waste Management and Notification System, emphasizing its contribution to sustainable urban waste management. It details the steps involved in data collection, analysis, development, and evaluation throughout the research process.

A. PHASE 1: Planning, Data Gathering Analysis, and Design and Development

I. Requirements and Planning

The initial phases of the research focused on acquiring information and data to design and develop an Integrated Solid Waste Collection and Management System (SDWMNS) to address the infrequent waste collection issue at the Miguel Sheker Park Drainage in Barangay San Miguel, Iligan City. The researchers identified the study's issues, objectives, scope, and significance. To gather pertinent information, they conducted a literature review following PRISMA guidelines, exploring existing studies, facts, theories, legal aspects, and other designs related to waste collection and management. This comprehensive review provided valuable insights for the SDWMNS development. In essence, the researchers conducted a comprehensive review of existing literature on waste collection and management to inform the design of their SDWMNS.

II. Data Gathering

The preliminary survey aimed to collect data and insights from stakeholders in drainage waste collection to understand current practices, challenges, and the potential benefits of integrating IoT technology. The survey asked respondents about their satisfaction with the current drainage system and their views on IoT implementation to improve it. Additionally, the study used a systematic PRISMA-based literature review, starting with a keyword search to identify potential studies. These studies were screened by titles and abstracts, with non-relevant ones excluded. The remaining studies underwent a detailed review to ensure they met inclusion criteria, followed by an in-depth evaluation to synthesize current academic literature. A post-survey was conducted to gather feedback from participants about their experiences with the drainage waste collection system. This phase aimed to deepen understanding of stakeholders' perspectives on IoT integration, uncovering detailed insights into their interactions with the current system, challenges faced, and areas for improvement.

III. Design and Development

1. System Development

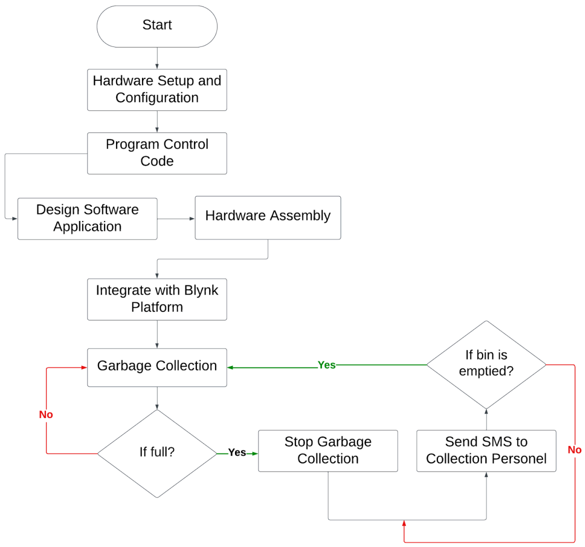

Figure 1: System Circuit Diagram

Figure 1 shows the development phase of the Smart Waste Collector and Notification System begins with creating the hardware design, followed by testing the circuit to ensure functionality. Once the circuit is successfully tested, the focus shifts to programming the code that controls the hardware, managing sensor data, triggering actions, and facilitating communication with the software application. Simultaneously, researchers design the software application, which is crucial for user interaction, data visualization, and system configuration, allowing users to monitor the waste collector's status, receive notifications, and adjust settings.

After the hardware and software components are ready, the hardware is assembled by integrating sensors, a microcontroller, and other elements into a cohesive unit. The system is then integrated with the Blynk Platform, connecting the software application with the hardware for seamless communication. The Blynk Platform provides a user-friendly interface for monitoring the smart waste collector and receiving real-time notifications about the waste level and system status.

Overall, the Smart Waste Collector and Notification System is designed to make waste collection in drainage systems easier and more efficient. The system includes a trash bin, waste collector, and sensors, all working together to provide an automated way to collect waste, simplifying the process and improving waste management.

2. System Block Diagram

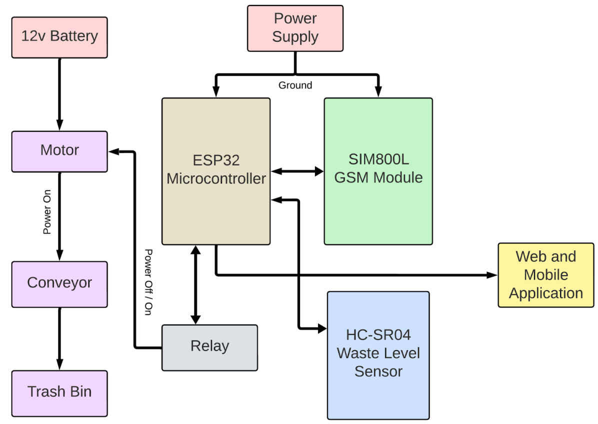

Figure 2: System Circuit Diagram

Figure 2 shows the system block diagram outlines the operational flow of an efficient waste management system. Powered by a 12V battery, a gear motor connected to a conveyor moves the waste collector. An ESP32 microcontroller and a GSM module, both powered by a separate power supply, manage data transmission and control. An ultrasonic sensor detects waste levels, triggering a relay module to shut off the gear motor when a certain level is reached and transmit data to the GSM module. The ESP32 processes this data and sends it to web and mobile applications for monitoring and management. When waste levels drop below the threshold, the ultrasonic sensor reactivates the gear motor to resume collection. This system automates the waste collection process and enables real-time monitoring and control, ensuring efficient waste management.

3. Hardware Development

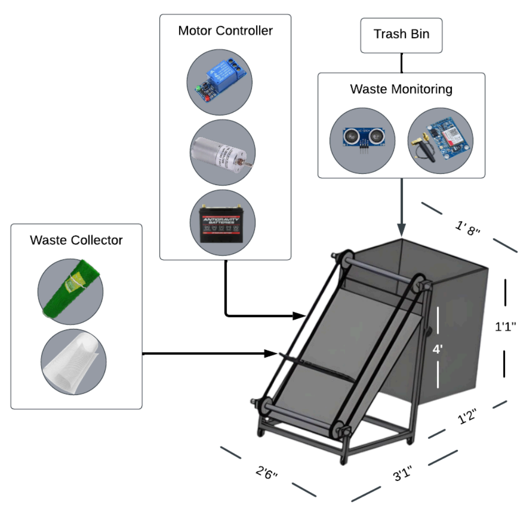

Figure 3 Hardware Block Diagram

Figure 3 shows the researchers identified suitable materials and components for building the system, which includes a window mesh and metal screen for the waste collector, an ultrasonic sensor and GSM module for waste monitoring, and a 12V DC power supply, gear motor, and relay for the motor controller. The waste collector operates like a Ferris wheel, collecting and carrying trash to drop it into the trash bin, which serves as the storage for collected waste. When the trash bin reaches its capacity and triggers the sensor, the system notifies communication personnel that the bin is full and ready for collection.

4. Collecting Garbage

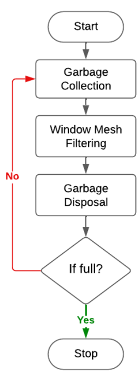

Figure 4: Garbage Collecting Flow Chart

Figure 4 shows the Smart Waste Collector and Notification System simplifies the process of collecting garbage in the drainage. As trash flows through the waste collector system, it makes its way towards the window mesh. This mesh acts as a filter, allowing only the garbage to pass through. Once the garbage reaches the top of the waste collector system, it is automatically dropped into a designated trash bin. The system stops if the bin is full; otherwise, it continues collecting garbage.

5. Trash Bin Monitoring

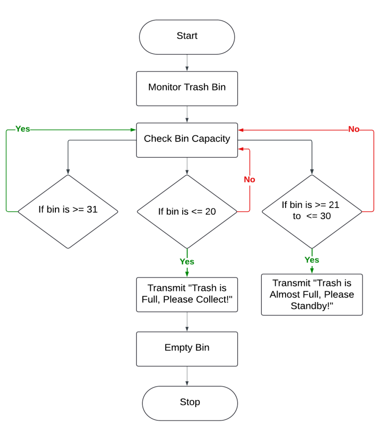

Figure 5: Trash Bin Flowchart

Figure 5 shows the Smart Waste Collector and Notification System enhances waste management efficiency by monitoring the trash bin's capacity. If the bin is less than 20% full, the system continues monitoring. When the bin is 21-30% full, it triggers a notification that the bin is almost full. If the bin exceeds 31% capacity, indicating active garbage collection, the system transmits a "Trash is Almost Full, Please Standby!" message. If the bin is full, a "Trash is Full, Please Collect!" message is sent to waste management personnel, who then notify the collection personnel via SMS.

6. Software Development

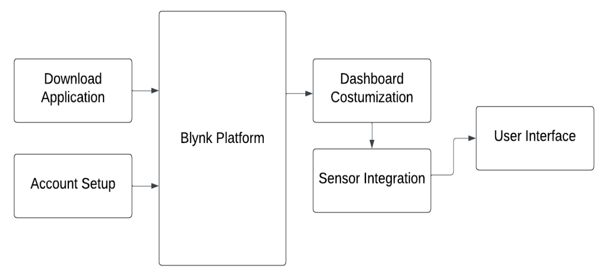

Figure 6: Software Development Block Diagram

Figure 6 shows the software development for the Smart Waste Collector and Notification System utilizes the Blynk platform to create an intuitive, user-centric dashboard. This customizable dashboard, featuring widgets designed to monitor and manage waste levels, incorporates a GSM module for real-time notifications and an ultrasonic sensor to measure waste levels, ensuring continuous monitoring. The software components must be robust, reliable, and scalable, supporting real-time data processing and compatibility with existing waste management infrastructure. This integration aims to improve the operational efficiency of waste collection services and enhance the sustainability of drainage systems.

7. System Schematic Diagram

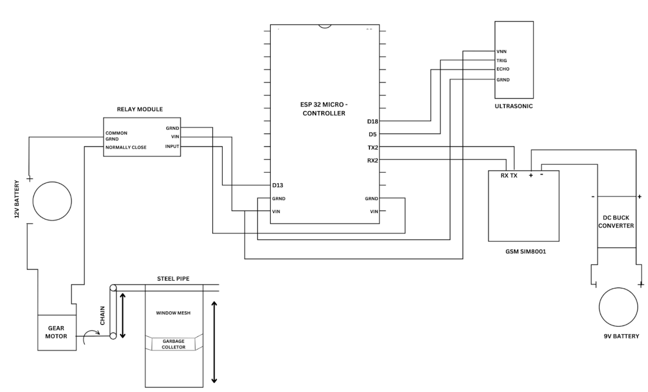

Figure 7: System Schematic Diagram

Figure 7 shows The schematic diagram of the Smart Waste Collector and Notification System showcases its layout and components, centered around an ESP32 microcontroller. The ESP32 controls a gear motor via a relay connected to a 12V battery, enabling operations requiring physical movement. An ultrasonic sensor connected to the ESP32 measures distances or detects objects. For communication, a GSM SIM800L module, powered by a 9V battery and connected to the ESP32 via serial communication, allows the system to send SMS and perform GSM network-related activities. A DC buck converter steps down the voltage from the battery to power components like the GSM module. This configuration creates a versatile system for automated tasks and remote monitoring in waste management.

8. Circuit Development

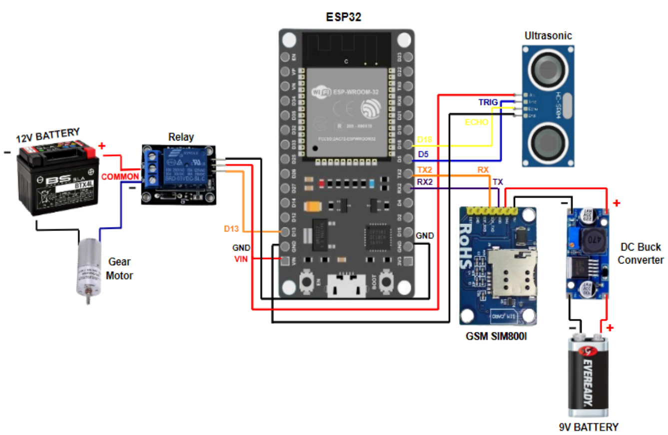

Figure 8: System Circuit Diagram

Figure 8 shows the circuit diagram illustrates a waste collection system powered by a 12V DC source, which drives a gear motor crucial for waste collection. The motor is connected to a relay and an ESP32 microcontroller for automation. An ultrasonic sensor, powered by the microcontroller's VIN and GND pins, monitors the system, with its trigger and echo pins connected to the D5 and D18 pins of the ESP32, respectively. Notifications are sent via a GSM SIM800l module, which communicates with the ESP32 through its Rx and Tx pins connected to the TX2 and RX2 pins of the microcontroller. This module, powered by a 9V battery, requires a DC Buck Converter to reduce the voltage to 5V for safe operation. The system sends SMS notifications like "Trash is almost full!" and "Trash is Full" to waste collectors, ensuring timely alerts and enhanced functionality.

B. PHASE II: Implementation and Testing

In the system testing process, researchers examined the system's performance to ensure it functions as expected. This began with individual testing of sensors using a serial monitor for precise monitoring and calibration. They then integrated the feedback control system for optimal responsiveness and stability, tested the WiFi module for wireless communication, and assessed the real-time monitoring system to track performance and detect anomalies. During the system deployment phase, researchers integrated the prototype with the existing framework, followed by testing in a controlled setting to gather feedback from waste management personnel. This stage included testing and validation of sensors and actuators, addressing any discovered issues. The deployment concluded with comprehensive documentation of all actions, findings, and outcomes for future reference and analysis.

A. Waste Level Monitoring: HC-SR04 Ultrasonic Sensor

The HC-SR04 Ultrasonic Sensor was tested for its ability to detect waste levels in a trash bin. The sensor measures the distance from the sensor to the surface of the waste, and this distance is used to determine the status of the trash bin. In the tests, the known distance represents the actual distance from the sensor to the trash surface, while the measured distances are the readings obtained by the sensor. The average of the measured distances is taken to minimize errors and provide a more accurate representation of the actual distance.

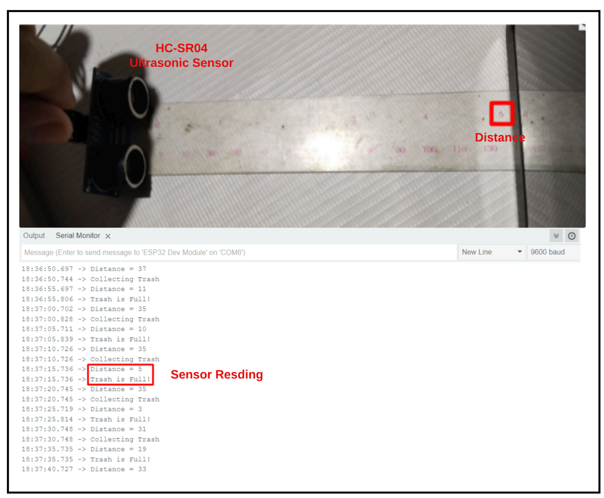

Figure 10: Ultrasonic Distance Detection Testing

Figure 10 shows the ultrasonic sensor HC-SR04 is used to measure the fullness of the trash bin by sending out sound waves that bounce off the trash and return to the sensor. By timing the return of the sound waves, the sensor calculates the distance to the trash, indicating how much space is left in the bin. If the bin is almost full, the system sends a message to the waste management team to empty the bin, ensuring cleanliness and efficient trash collection. The ultrasonic sensor provides accurate, real-time data on the trash level. To test its accuracy, a ruler was placed on a flat surface with the sensor at one end, and an object was used to measure distances. This process was repeated at various distances to compare the sensor's readings with the ruler's measurements. Additionally, messages were implemented in the serial monitor to indicate if the trash bin is full (≤ 20 cm), almost full (21-30 cm), or collecting trash (≥ 31 cm), facilitating easier testing.

Table 1: HC-SR04 Ultrasonic Sensor Result

Number of Testing	Known Distance (cm)	Measured Distance (cm)			Average Distance (cm)	Status Indication	Correct Status
		Distance 1	Distance 2	Distance 3			
Test 1	>= 31	41	38	35	38.00	Collecting Trash	Yes
Test 2	>= 31	39	36	35	36.67	Collecting Trash	Yes
Test 3	>= 21 <= 30	29	26	24	26.33	Trash Bin is Almost Full!	Yes
Test 4	<= 20	19	17	16	17.33	Trash Bin is Full!	Yes
Test 5	>= 31	42	40	39	40.33	Collecting Trash	Yes
Test 6	>= 31	38	37	35	36.67	Collecting Trash	Yes
Test 7	>= 21 <= 30	25	25	23	24.33	Trash Bin is Almost Full!	Yes
Test 8	<= 20	12	10	9	10.33	Trash Bin is Full!	Yes
Test 9	<= 20	16	13	12	13.67	Trash Bin	Yes

Table 1 shows that the tests can be grouped into three categories based on the known distance. The first one is the Known Distance of >= 31 cm that is tested in 1, 2, 5, 6. In these tests, the trash bin is relatively empty and still collecting trash, and the sensor accurately detected this by indicating the status as "Collecting Trash." The average measured distances were close to or within the expected range, confirming the sensor's accuracy in detecting an empty or nearly empty bin. Next is the Known Distance of >= 21 cm and <= 30 cm that is tested in 3, 7. These tests represent a trash bin that is almost full. The sensor successfully detected this condition, with the average measured distances falling within the expected range. The status indicated as "Trash Bin is Almost Full" was correct in both cases. Lastly the Known Distance of <= 20 cm that is tested in Tests 4, 8, 9, 10. In these tests, the trash bin is full. The sensor accurately detected this condition, with the average measured distances being close to the known distances.

B. Notification System: SIM800L GSM Module

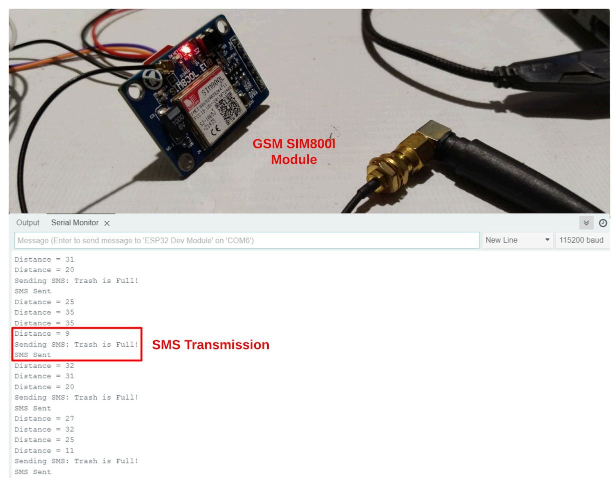

Figure 11: SIM800L GSM Module Transmission Test

Figure 11 shows the test for the SIM800L GSM Module that can be seen on figure 4.6, the researchers implemented a message that can be seen in the serial monitor so that it will send a message if the trash bin is full (cm ≤ 20). This test involves programming the GSM Module to respond to the ultrasonic sensor's readings. When the sensor detects that the trash level in the bin has reached or fallen below 20 centimeters, it triggers the GSM Module to send a predefined message. This message is displayed on the serial monitor as part of the test, serving as a simulation of the actual alert that would be sent to the waste management personnel.

Table 2: SIM800L GSM Module Result

Number of Testing	Message Type	Total Transmission (Serial Monitor)	Successful Transmission (SMS Message)	Accuracy (%)
Test 1	Trash Bin is Almost Full, Please Standby!	10	8	80%
Test 2	Trash Bin is Almost Full, Please Standby!	13	11	84%
Test 3	Trash Bin is Full, Please Collect!	5	5	100%
Test 4	Trash Bin is Full, Please Collect!	10	9	90%
Test 5	Trash Bin is Almost Full, Please Standby!	9	8	89%
Test 6	Trash Bin is Almost Full, Please Standby!	12	12	100%
Test 7	Trash Bin is Full, Please Collect!	7	6	86%
Test 8	Trash Bin is Full, Please Collect!	8	7	88%
Test 9	Trash Bin is Almost Full, Please Standby!	9	9	100%
Test 10	Trash Bin is Full, Please Collect!	8	8	100%

Table 2 shows the test results for the HC-SR04 Ultrasonic Sensor's communication module showed variability in transmission attempts and success rates. Test 1 had an 80% success rate with 10 attempts, which is acceptable given the non-critical nature of the notifications, despite a 20% error rate due to factors like network instability and hardware limitations. While Tests 3, 6, 9, and 10 achieved perfect success rates, Tests 1 and 7 had the lowest accuracies at 80% and 86%, respectively. Tests 2, 4, 5, and 8 showed moderate success rates, ranging from 84% to 90%. Specifically, Test 2 had an 84% success rate with 13 attempts, Test 4 had 90% with 10 attempts, Test 5 had 89% with 9 attempts, and Test 8 had 88% with 8 attempts. Overall, these results highlight the module's potential for high performance, despite occasional inconsistencies.

Table 3: Waste Collection Test Result

Number of Testing	Waste Collection Capability			
	Able to Collect Waste (Yes/No)	Initial Waste Load 1	Trash Bin Waste Collection Load 2	Percentage (%)
Test 1	Yes	2.1 kg	2 kg	95%
Test 2	Yes	2 kg	1.9 kg	95%
Test 3	Yes	2.25 kg	2.05 kg	91%

Table 3 shows the results of three different tests. In each test, the system was able to collect waste, as denoted by a "Yes" in the "Able to Collect Waste" column. The initial waste load varied slightly across tests, ranging from 2.00 kg to 2.25 kg. The corresponding waste collected, or "Trash Bin Waste Collection," was slightly less than the initial load for each test, resulting in collection percentages ranging from 91% to 95%. The highest efficiency was observed in Tests 1 and 2, both with a 95% collection rate, while Test 3 saw a slight decrease in efficiency, collecting 91% of the waste. The waste collection system has demonstrated a high level of efficiency in all tests, with a minimum of 91% of the initial waste load successfully collected. Despite slight variations in the initial waste load, the system-maintained a near-consistent collection percentage, which underscores its reliability in waste collection applications. Further optimization might be focused on maintaining or improving the efficiency noted in the first two tests.

C. Waste Level Real-Time Data Monitoring in Web and Mobile Application

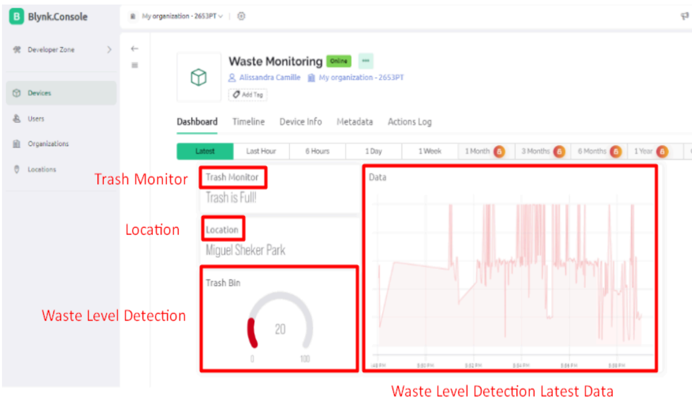

Figure 12: Web Interface using Blynk Platform

Figure 12.1: Mobile Interface using Blynk Platform

Table 4: Waste Level Real-Time Data Monitoring in Web and Mobile Application

Number of Testing	Ultrasonic Reading (cm)	Blynk Dashboard Reading (cm)	Status Indicated	Correct Status	Accuracy Percentage (%)
Test 1	34	34	Collecting Trash	Yes	100%
Test 2	32	32	Collecting Trash	Yes	100%
Test 3	26	26	Trash Bin is Almost Full!	Yes	100%
Test 4	24	24	Trash Bin is Almost Full!	Yes	100%
Test 5	23	23	Trash Bin is Almost Full!	Yes	100%
Test 6	17	17	Trash Bin is Full!	Yes	100%
Test 7	9	9	Trash Bin is Full!	Yes	100%
Test 8	37	37	Collecting Trash	Yes	100%
Test 9	25	25	Trash Bin is Almost Full!	Yes	100%
Test 10	15	15	Trash Bin is Full!	Yes	100%

The table 4 shows the test results for the waste level monitoring system using an ultrasonic sensor connected to a web and mobile application via the Blynk platform show high accuracy in measuring the trash bin waste levels. Across ten tests, the ultrasonic sensor readings, which represent the distance from the sensor to the waste level, match exactly with the readings displayed on the Blynk dashboard. This consistency results in a 100% accuracy percentage for all tests. The system also provides appropriate remarks based on the measured waste levels, indicating whether the trash bin is "Almost Full" or "Full." These results demonstrate the reliability and effectiveness of the monitoring system in providing real-time waste level information and facilitating efficient waste management.

C. PHASE III: System Evaluation

In the course of assessing the system, the researchers implemented a comprehensive evaluation strategy that included a post-survey and an interview. During the survey phase, participants were shown a video that demonstrated the system's functionality. Their feedback and responses to various questions were then collected, providing valuable insights into the system's performance and user experience. Additionally, the researchers conducted an interview with an individual who had firsthand experience with the system's deployment process.

1. User Evaluation of the System

User evaluation of the Blynk Application for waste management involves a detailed analysis of user interactions to understand its usability, functionality, and overall user experience. This process is crucial for gaining insights into user perceptions and identifying areas for improvement. Feedback is collected through both qualitative and quantitative methods. Qualitative data is gathered via direct observations, interviews, and open-ended questions, providing valuable insights into usability issues and user perspectives. Quantitative data is collected through surveys or questionnaires, measuring user satisfaction, perceived system performance, and likelihood of continued use. Metrics such as ease of use, efficiency, and effectiveness are evaluated to quantify the user experience. Incorporating Nielsen's Heuristic Evaluation adds another layer of analysis by comparing the application's user interface against ten established usability principles, such as visibility of system status, user control, consistency, and error prevention. This helps identify usability problems and suggests practical solutions. By integrating user feedback, quantitative metrics, and heuristic evaluation, a comprehensive understanding of the Blynk Application's usability and user experience is achieved. This holistic approach enables the identification of specific areas for enhancement, leading to a more user-friendly and effective waste management system.

D. Conclusion

This study addresses the critical issue of garbage accumulation in drainage systems, driven by improper waste disposal, inadequate infrastructure, poor maintenance, and limited public awareness. It explores the potential of IoT technology to improve drainage waste management efficiency. By analyzing existing technologies, frameworks, laws, and policies in the Philippines, the research identifies significant gaps and misalignments with local and international standards, highlighting the need for innovative solutions. The study details the development of the Smart Drainage Waste Collector Notification and Management System (SDWMNS), which uses IoT technology to enhance waste collection efficiency and reduce environmental pollution. Through extensive testing, the system's user-friendly interface and functionality were validated, demonstrating its potential for broad implementation. This research provides empirical data supporting the integration of IoT in urban waste management, emphasizing the need for updated policies and regulatory frameworks. It also addresses technical and societal challenges, offering practical solutions to enhance the effectiveness and user acceptance of such technologies, ultimately contributing to sustainable development goals and improving urban life quality.

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