International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 12 Issue: 2
***Article Received:** 25 November 2023 **Revised:** 12 December 2023 **Accepted:** 30 January 2024*

Smart Garbage Bin Monitoring and Alert System Framework for Tourist Spots in Daet, Camarines Norte

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Abstract— Traditional waste collection methods in tourist hotspots struggle to adapt to dynamic fluctuations in tourist activity. This research proposes a smart waste management framework that leverages Internet of Things (IoT) technology to optimize waste collection and promote responsible waste disposal practices. Smart bins equipped with various sensors form the backbone of the system. Ultrasonic sensors continuously monitor fill levels, while GPS modules provide precise location data. A communication protocol, like MQTT, facilitates efficient and reliable data transmission to a central cloud platform. The cloud platform securely stores all collected data, including sensor readings, timestamps, and GPS coordinates. Data analytics tools are then applied to uncover patterns and trends in waste generation. Time-series analysis allows for a temporal understanding of waste level fluctuations. This can reveal peak generation times associated with tourist activity surges or events. Spatial analysis, visualized through user-friendly dashboards, helps identify areas with consistently high or low waste generation patterns. This empowers waste management personnel to optimize collection routes, minimizing travel distances and fuel consumption. This research proposes a novel data-driven framework for smart waste management in tourist hotspots. The framework leverages IoT technology and data analytics to optimize waste collection, promote environmental responsibility, and enhance the overall tourist experience. This approach paves the way for a more sustainable future for tourist destinations, ensuring a balance between economic growth and environmental protection.

Keywords-Data Analysis, Internet of Things (IoT), Message Queuing Telemetry Transport (MQTT), Waste Management

I. INTRODUCTION

Tourism is a double-edged sword for many destinations. While it fosters economic growth and cultural exchange, it also generates a significant amount of waste. Research published in Waste Management & Research indicates that tourist waste generation can be two to four times higher than that of local populations [1]. This waste primarily consists of single-use plastics from packaging and souvenirs, leftover food from restaurants and resorts, and construction debris associated with tourism infrastructure development [2][3]. The idyllic image of Daet can quickly deteriorate when faced with overflowing garbage bins. Inefficient waste collection not only detracts from the visual appeal of tourist spots but also poses significant environmental and health concerns. Improper waste disposal can contaminate waterways, harm wildlife, and create breeding grounds for disease-carrying vectors [4]. A study published in the Journal of Sustainable Tourism underscores the negative impact of waste mismanagement on tourist satisfaction and, consequently, tourism revenue [5].

The Philippines, a Southeast Asian archipelago nation known for its breathtaking natural beauty, also grapples with significant waste management challenges. According to a report by the World Bank, the Philippines generates over 20 million tons of waste annually, with a significant portion stemming from tourism hotspots. The lack of proper infrastructure, inefficient collection systems, and limited public awareness all contribute to the problem [1][3][4][6]. Daet, despite its efforts, is not immune to these challenges. The surge in tourist arrivals during peak seasons overwhelms existing waste collection capacities. Traditional methods, often reliant on fixed schedules and visual inspection of bins, struggle to adapt to these fluctuations [8]. Furthermore, limited resources and a lack of real-time data on waste generation hinder efforts to optimize collection routes and schedules.

Traditional waste collection methods, often reliant on fixed schedules and visual inspection of bins, struggle to keep pace with the dynamic waste generation patterns in tourist hotspots. Seasonal fluctuations in tourist arrivals further complicate the issue, leading to overflowing bins during peak seasons and under-collected bins during off-seasons [6]. Furthermore, Traditional methods are further hampered by a lack of transparency and accountability. Inefficiencies in collection routes, with trucks traversing unnecessary distances or revisiting recently emptied bins, can go unnoticed for extended periods. Missed pickups due to overflowing bins or scheduling errors often remain undetected, hindering efforts to optimize waste management processes. Additionally, the reliance on manual

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data collection through visual inspection is time-consuming and prone to human error.

The reliance on manual data collection through visual inspection adds another layer of inefficiency. This time-consuming approach exposes the system to the inherent limitations of human error. Imagine relying on a single observer to gauge the fill level of every bin in a vast tourist area – inconsistencies and inaccuracies are inevitable. This lack of real-time data makes it difficult to predict waste accumulation and proactively adjust collection schedules, leading to a reactive approach that fails to address the dynamic nature of waste generation in tourist hotspots.

The limitations of traditional waste collection methods necessitate a paradigm shift towards smarter and more efficient solutions. Smart technologies, such as the Internet of Things (IoT), offer immense potential for revolutionizing waste management in tourist destinations. IoT connects physical objects – like garbage bins – to the internet, enabling them to collect and transmit data wirelessly. This data can then be used to gain valuable insights into waste generation patterns and optimize collection processes. This project proposes a cutting-edge Smart Garbage Bin Monitoring and Alert System designed specifically for tourist spots in Daet. This system leverages a network of interconnected smart bins equipped with various sensors to gather real-time data on fill levels. This data can then be transmitted wirelessly to a central monitoring platform, providing crucial insights into waste generation patterns and bin occupancy levels.

The potential of IoT-based waste management systems is not just theoretical. Research studies like "Smart Waste Management System for Metropolitan Cities Using IoT" [13] showcase the effectiveness of this approach in smart city environments. The study proposes a system with functionalities remarkably similar to the one envisioned for Daet, highlighting the replicability and scalability of this technology. Furthermore, "An Integrated Intelligent Waste Management System Using IoT for Smart Cities" [14] delves deeper into the use of IoT sensors and RFID tags for waste bin monitoring, providing valuable insights into real-time data collection and analysis within smart city contexts.

However, for Daet to reap the full benefits of IoT-based waste detection, careful consideration needs to be given to a few key aspects. Firstly, seamless integration with the existing waste management infrastructure is crucial to ensure smooth operation and data flow. Secondly, fostering public awareness through targeted campaigns is essential to encourage responsible waste disposal habits among tourists and residents alike. Finally, exploring sustainable power options like solar panels for the smart bins can further elevate Daet's commitment to environmental stewardship.

By embracing IoT technology and implementing a well-designed waste detection system, Daet can position itself as a leader in sustainable tourism practices. This not only fosters a cleaner and more enjoyable experience for visitors but also demonstrates the city's commitment to responsible waste management and environmental protection.

II. MATERIALS AND METHODS

A. *Hardware Components*

The research will employ the use of low-cost IoT sensors. Ultrasonic sensors, the workhorses of this system, will be strategically placed within the bins. These sensors emit sound waves and measure the time it takes for the echo to return. By calculating the distance between the sensor and the top of the waste, the fill level of the bin can be determined with high accuracy [7]. This approach offers several advantages over alternative methods like weight sensors. Ultrasonics are more cost-effective, require less maintenance, and function reliably even in harsh weather conditions [8]. Additionally, Incorporating GPS modules into the smart bins offers a two-fold benefit. Firstly, waste collection can be significantly optimized by enabling real-time tracking of bin fullness, allowing collection crews to focus on overflowing bins. Secondly, this technology can be leveraged to create a public information system for tourists. They can easily locate nearby bins and determine fill levels through a website, promoting responsible waste disposal [9].

Furthermore, incorporating a buzzer into the smart bin adds another layer of efficiency to waste collection [15]. When the bin reaches capacity and tilts excessively, the buzzer will emit a loud, distinct sound. This serves a dual purpose. Firstly, it acts as an immediate alert for waste collectors in the vicinity, prompting them to address the overflowing bin. Secondly, for situations where no personnel are nearby, the smart bin can be programmed to transmit an alert notification to a central website. This real-time notification system ensures that overflowing bins are identified and addressed promptly, minimizing the risk of unpleasant odors and litter accumulation. Lastly, the ESP8266 will be used as the system's brain that coordinates the entire operation [16]. It continuously gathers data from a network of strategically placed sensors. The ESP8266 acts as the interpreter, seamlessly communicating with these diverse sensors using different protocols. This allows it to gather real-time data about the bin's status.

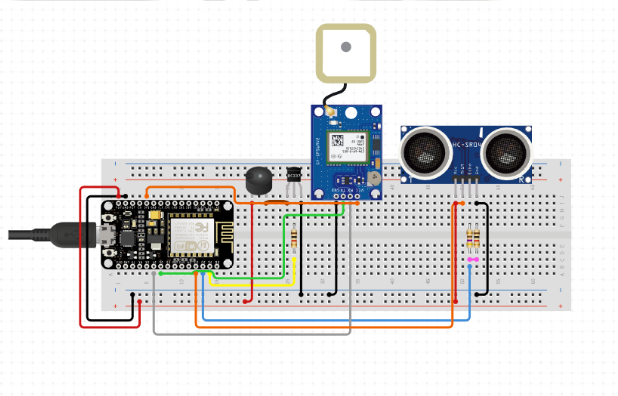

Figure 1. Circuit design of the system

The figure above shows the circuit design of the system. This circuit acts as the nervous system of the entire system, allowing for communication and data exchange between various components. Here, the ESP8266 takes center stage, functioning as the central processing unit (CPU).

B. *Data Collection*

Data collection and transmission are critical aspects of this research project, providing the vital insights needed for efficient waste management. There are two types of data collection methods that will be used, location data and status data. The system leverages GPS modules embedded within the smart bins [9]. These modules act as digital compasses, constantly tracking the precise geographical coordinates of each bin. This location data is then seamlessly transmitted along with other sensor readings, representing a comprehensive picture of the bin's placement. The second data collection method focuses on status data, providing real-time insights into the health and functionality of the smart bins. A crucial piece of status data revolves around fill level [7]. By analyzing this time difference, the sensor can calculate the remaining space and determine the fill level with impressive accuracy. This real-time data empowers proactive waste collection, ensuring bins are emptied before they overflow.

Additionally, the chosen sensors will be outfitted with low-power communication modules, acting as miniature messengers. These modules will wirelessly transmit sensor data to a central cloud platform, much like a bustling network of couriers delivering vital information to a central hub. To ensure efficient data exchange over resource-constrained networks with limited bandwidth, the system will leverage the power of MQTT (Message Queuing Telemetry Transport) [11][12]. Imagine a bustling marketplace where devices publish information on specific topics, similar to vendors presenting their wares. Other devices, acting as interested customers, subscribe to these relevant topics, receiving only the data they require. This publish/subscribe model offered by MQTT is ideal for our system, as it streamlines data exchange between battery-powered sensors and the cloud platform, minimizing energy consumption. Furthermore, MQTT utilizes a central broker, like a traffic coordinator in a busy city. This broker ensures reliable message delivery even when devices might be temporarily offline, guaranteeing data integrity despite potential network fluctuations.

C. Data Analysis

Once collected, the data will be securely stored in a central database. This data trove will encompass a wealth of information, including fill levels, precise location coordinates through GPS or other positioning systems, timestamps for each data point, and potentially additional sensor readings like temperature or bin status. Data analytics tools will be used in the system, uncovering hidden patterns and trends in waste generation.

Time-series analysis acts as a time machine, allowing us to travel back and forth in time to understand how waste levels fluctuate over different periods. Imagine analyzing hourly variations in waste generation patterns at specific locations. This granular view helps identify peak waste generation time, potentially corresponding to tourist activity surges or specific events [17][18]. Furthermore, by analyzing historical data and seasonal trends, the system can predict future waste generation patterns. This predictive power empowers waste management personnel to proactively adjust collection schedules, ensuring bins are emptied before they overflow and creating a more efficient waste collection system.

Spatial analysis acts as a powerful geographical map, revealing areas with higher or lower waste generation patterns. Imagine a user-friendly dashboard displaying a color-coded map of the tourist hotspot. Areas with overflowing bins, indicated by red markers, would be readily identifiable. Conversely, areas with consistently low fill levels, potentially green markers, would suggest the potential for reduced collection frequency in those locations [19][20][21]. This spatial analysis empowers waste management to optimize collection routes, minimizing travel distances and fuel consumption, while ensuring timely waste collection across the entire tourist hotspot.

The processed data will be transformed into user-friendly dashboards, similar to interactive maps and charts. These dashboards will empower waste management personnel with real-time insights into bin fill levels across various locations. With a single glance, they can identify areas requiring immediate attention, optimizing waste collection routes and minimizing unnecessary trips. This comprehensive data visualization will serve as a cornerstone for informed decision-making, transforming waste management from a reactive to a proactive endeavor, driven by the power of data. [9][10].

D. Data Interpretation

The process of IoT data collection in this research isn't a singular act, but rather includes a several layers working together. Each layer plays a crucial role in transforming raw sensor data into actionable insights that empower informed decision-making for waste management. Data provided by the GPS module and the ultrasonic sensors forms the initial layer, the very foundation upon which the data collection process is built. The raw sensor data then undergoes a transformation within the smart bin or a connected device. This layer involves data preprocessing, a crucial step that ensures the data's accuracy and usability. Basic calculations might be performed to convert sensor readings into meaningful units such as voltage readings from an ultrasonic sensor translated into a percentage fill level. Once preprocessed, the data is then packaged into a format suitable for transmission. This packaged data is then transmitted wirelessly using MQTT and other protocols for transferring sensor data from IoT devices acting as the information pipelines within the system.

The data packets containing the preprocessed sensor readings travel through the chosen communication protocol and reach the cloud platform. This platform acts as a central repository, diligently receiving and storing all the incoming data. Here, powerful data analytics tools can be used such as time series and spatial analysis [17][18][19][20]. This data analysis transforms the raw materials into valuable knowledge, building a comprehensive picture of waste generation patterns across the entire waste management network. Lastly, the final layer focuses on data visualization that can be seen by user through a dedicated website provided by the system. These visualizations empower waste management personnel and tourists with real-time insights into bin fill levels, allowing for targeted waste collection efforts and proactive resource allocation.

III. PROPOSED FRAMEWORK

The architectural design shown in Fig. 2 depicts the data collection and transmission for the system focusing on efficiency and reliability. These bins, equipped with various sensors, act as the system's eyes and ears, constantly monitoring their fill levels and other relevant parameters. The collected sensor data then travels through this digital network, seamlessly transmitted to secure cloud storage. This centralized storage ensures easy access and retrieval of data, empowering informed decision-making.

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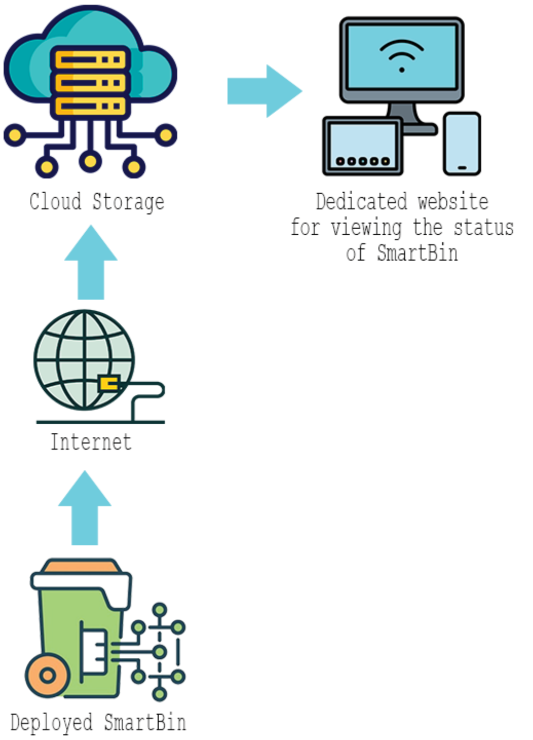

Figure 2. Architectural Design of the system

Furthermore, users equipped with a PC, laptop, or mobile device, can access a dedicated website. This website acts as a window into the system, providing real-time insights into the status of each bin. Imagine a virtual map displaying the location of every bin, accompanied by color-coded icons reflecting its current fill level (e.g., green for low, red for full). This intuitive interface empowers users to monitor waste generation patterns across various locations, allowing for proactive waste collection and resource optimization.

Figure 3 illustrates a granular view of the system's internal workings, presented as a block diagram. Each block represents a critical component, and the interconnections between them illustrate the seamless flow of data. Several key components form the sensory network within the bin. The GPS module acts as a digital compass, precisely pinpointing the bin's location. This location data is crucial for visualizing bin placement and optimizing waste collection routes. Additionally, ultrasonic sensors function like virtual tape measures, meticulously gauging the fill level of trash within the bin. Imagine these sensors sending out sound waves that bounce back from the trash, allowing the system to calculate the remaining space and predict when collection is necessary. The system might also include a buzzer, acting as an audible alert. This buzzer could be triggered when the bin reaches a critical fill level, notifying sanitation workers or nearby residents of the need for collection.

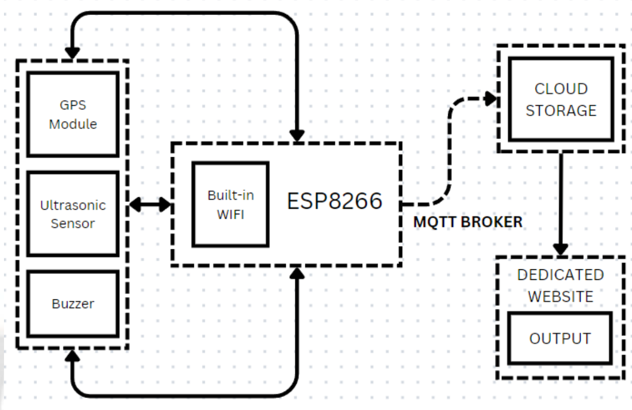

Figure 3. Block Diagram of the system

Furthermore, the collected data from these sensors doesn't operate in isolation. The MQTT broker acts as a central communication hub, facilitating the exchange of data between the sensors and the cloud. Imagine the broker as a conductor in an orchestra, ensuring each instrument (sensor) contributes its data at the right time and in the correct format. Utilizing the MQTT protocol, the sensors publish their data to specific topics (e.g., "Bin_1_Fill_Level"), and the broker efficiently routes this data to the cloud platform.

The cloud platform serves as a secure data repository. This digital vault stores all the collected information, including GPS coordinates, fill level readings, and any additional sensor data. This centralized storage ensures easy access and retrieval for further analysis. The data was then transmitted to a dedicated website. Users, equipped with a PC, laptop, or mobile device, can access this website to view the collected data in a user-friendly format. A dashboard displaying real-time information on bin locations and fill levels, empowering informed decision-making for waste management personnel.

IV. Conclusion

This research has introduced a novel framework that leverages the power of Internet of Things (IoT) devices to tackle the growing challenge of waste management in tourist hotspots. Specifically focusing on Daet, Camarines Norte, Philippines, the framework proposes a data-driven approach to optimize waste collection and promote responsible waste disposal practices. The core of the system lies in the integration of various sensors within smart bins. Ultrasonic sensors, acting as the system's eyes, meticulously gauge fill levels, ensuring timely collection before bins overflow. GPS modules, functioning as digital compasses, precisely pinpoint the location of each bin, empowering efficient route planning for waste collection vehicles. Additionally, a buzzer could be incorporated to serve as an audible alert, notifying sanitation workers or nearby residents of critically full bins.

The framework goes beyond mere data collection. A dedicated website acts as a window into the system, offering real-time data visualization for users. This transparency empowers not only waste management personnel but also the local community. Residents and tourists can access information on proper waste disposal practices, fostering a sense of environmental responsibility and encouraging collaborative efforts towards a cleaner Daet. By ensuring timely waste collection and preventing overflowing bins, the system fosters a more aesthetically pleasing environment for tourists, enhancing the overall visitor experience. Furthermore, the data collected is analyzed by the system which provides valuable insights into tourist activity patterns, potentially informing infrastructure development and waste management strategies for the long term. This data-driven approach paves the way for a more sustainable future for tourist destinations like Daet, ensuring a balance between economic growth and environmental responsibility.

ACKNOWLEDGMENT

The researchers gratefully acknowledge the support of their home institution, the University of the Cordilleras. They also extend their sincere appreciation to the CHEDRO5-SIKAP Grants program for their financial assistance, which proved invaluable to this research project.

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