

A Study On Impact Of Implementing Waste Management Systems In Bhagalpur, Bihar, Using Iot (Internet Of Things)

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Citation: Supriya Raj et al (2024), A Study On Impact Of Implementing Waste Management Systems In Bhagalpur, Bihar, Using Iot (Internet Of Things), *Educational Administration: Theory and Practice*, 30(7), 1098-1109

Doi: 10.53555/kuey.v30i7.7039

ARTICLE INFO	ABSTRACT
	Clean, healthy ecosystems need waste management. Waste collection, disposal, and resource efficiency are issues in Bhagalpur, Bihar. IoT can improve Bhagalpur's waste management, save money, and ensure sustainability. IoT waste management might green Bhagalpur. Real-time monitoring, predictive analytics, public involvement, and data-driven decision making may improve Bhagalpur's environment, resource consumption, and quality of life. IoT trash management makes Bhagalpur greener and more efficient. Real-time IoT garbage bin fill sensors manage trash. Bin fill sensors save time, reduce trips, and enhance collection routes for trash management companies. IoT-enabled trash management helps Bhagalpur disperse resources. New vehicles, sensor data, and frequency changes may help authorities find high-waste areas. Optimizing fuel, carbon, and operations saves money. Manage waste IoT allows Bhagalpur predictive analytics. The system predicts waste generation and optimizes collection routes using historical and real-time data. This proactive approach reduces manual route planning, trip distance, and trash collection time. The idea monitors public and private garbage cans using PBLMU and HBLMU end sensors. Centrally stored and analyzed PBLMU and HBLMU waste bin empty levels and locations. Garbage collectors check cans for emptiness using a sophisticated GUI. These important tests validated system architecture: Eight trash cans with LoRaWAN, eight HBLMUs and Wi-Fi. Intelligent interfaces monitored empty trashcans. PBLMUs' average current use was determined by monitoring sleep and active current contributions using an experimental device. PBLMU monitors public bin levels using sensor nodes. This architecture optimizes LoRaWAN wi-fi network and sensor node collection. Intelligence nodes monitor unit data. MSWN sensors were connected by another writer. Keywords: Waste management, Sensors, Graphical User Interface, LoRaWAN, Trash Bin

1. Introduction

The evolution of the IoT has led to various areas for expanding the city growth and development. A smart city communicating with IoT in a way to manage and support value-added services for the administration of the city and for the citizens. (Zanella, et al., 2014) In a smart city waste management is one of the prominent issue. The effective management of waste is an essential component of preserving a sanitary and healthy environment. The city of Bhagalpur in the state of Bihar faces issues with the collection and disposal of garbage, as well as the requirement to maximize the exploitation of available resources. It is possible for Bhagalpur to modernize its waste management systems by harnessing the power of the Internet of Things (IoT), which will lead to increased productivity, decreased costs of operation, and a more sustainable future. Waste management solutions in Bhagalpur that are enabled by the internet of things will allow for more efficient resource distribution. The authorities are able to identify locations with higher garbage creation by evaluating the data collected from sensors. This gives them the ability to send additional collection vehicles or change the frequency of collection as necessary. The Internet of Things enables real-time monitoring of waste collection with the use of smart trashcans detected when they are full. (Nirde, et al.,

2017) This is made possible by implementing IoT in waste management. These sensors supply accurate and immediate data on the fill levels of bins, which enables waste management authorities to optimize collection routes, limit the number of trips that are not necessary, and ensure that bins are collected on time when they are full. (Shyam, et al., 2017) The collecting data from the garbage bins and send them to a gateway using LoRa technology with the help of MQTT (Message Queue Telemetry Transport) protocol. (Bharadwaj, et al., 2016) Collection of waste adequately, for detection of fire in waste material and forecasting of the future waste generation. The IoT based device performs the controlling and monitoring the electric bins. (Ali et al., 2020). RFID and communication technologies coordinates the bin and truck database are compiled and stored for monitoring and managing. (Hannan, et al., 2011) Intelligent bins fitted with fill-level sensors are able to sends an alert of objectionable materials in the bin like recyclables, biodegradable and non-biodegradable wastes. (Paul, et al., 2019) In the end, Bhagalpur will be able to lessen the amount of waste that is dumped in landfills, preserve more of the city's resources, and help create a more sustainable future. Waste management solutions based on the internet of things produce massive volumes of data. By utilizing these data, Bhagalpur will be able to make well-informed judgments regarding the strategies for waste management, the development of infrastructure, and the implementation of policies. By analyzing the data, the authorities are able to gain insights into trends in waste generation, rates of recycling, and operational efficiency, so allowing them to continuously optimize waste management techniques.

2. Related Work

- **IoT-Based Waste Management Systems in India:** Begin by discussing the general trends and initiatives in India related to IoT-based waste management systems. Highlight any successful projects or case studies from other cities or states in India. For instance, you could mention initiatives in cities like Bengaluru or Pune.
- **International IoT-Based Waste Management Projects:** Explore global IoT-based waste management projects and their outcomes. Discuss how these projects have leveraged IoT technologies to optimize waste collection, segregation, and disposal. Compare their experiences with the context of Bhagalpur.
- **IoT and Smart Cities:** Delve into the broader concept of IoT in smart city development. Explain how IoT has been integrated into urban planning and governance to improve various aspects, including waste management. Cite examples from other smart cities worldwide.
- **IoT Sensors and Data Analytics in Waste Management:** Explore the use of IoT sensors for waste bin monitoring and how data analytics can be applied to optimize waste collection routes. Discuss the potential benefits in terms of cost savings, efficiency, and environmental impact.
- **Environmental and Social Impact Studies:** Refer to studies that have examined the environmental and social impacts of improved waste management systems. Discuss how proper waste management can reduce pollution, improve public health, and create jobs in the community.
- **Challenges and Solutions in IoT-Based Waste Management:** Highlight the common challenges faced when implementing IoT-based waste management systems, such as technology adoption, infrastructure constraints, and public awareness. Discuss the solutions proposed or implemented to address these challenges.
- **Policy and Regulatory Frameworks:** Review existing policies and regulations related to waste management in Bhagalpur and Bihar. Discuss any recent changes or updates that support the implementation of IoT-based systems. Compare these with national and international waste management standards.
- **Community Engagement and Awareness Programs:** Examine initiatives aimed at engaging the local community in waste management efforts. Discuss the importance of public awareness and participation in the success of waste management systems.
- **Evaluation of IoT Technologies for Waste Management:** Explore studies that have evaluated the effectiveness and efficiency of specific IoT technologies, such as sensors, data analytics, and communication protocols, in the context of waste management.
- **Local Initiatives and Research:** If available, include any local research or initiatives related to waste management in Bhagalpur or Bihar. This could include pilot projects, academic studies, or government-led efforts.

Implementing IoT-based waste management systems in the smart city of Bhagalpur, Bihar

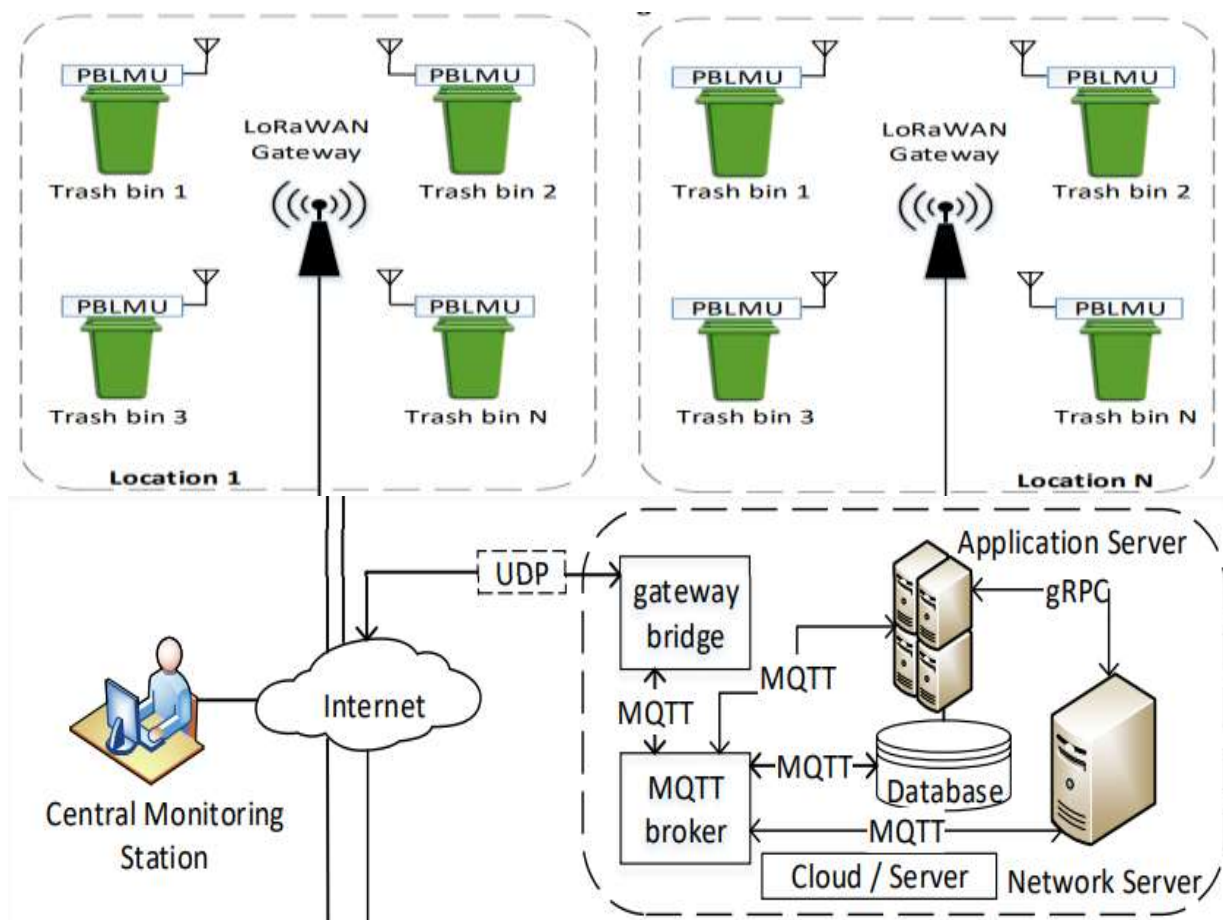
Implementing IoT-based waste management systems in the smart city of Bhagalpur, Bihar, can revolutionize waste management practices and pave the way for a more sustainable and efficient city. Here's how IoT can be leveraged in waste management systems in Bhagalpur:

1. **Smart Waste Bins:** Deploy smart waste bins equipped with fill-level sensors that utilize IoT technology. These sensors can accurately measure the fill levels of the bins and transmit the data wirelessly to a central management system.

2. **Real-time Monitoring:** Establish a central monitoring system that receives and analyzes data from the smart waste bins in real-time. This system provides waste management authorities with immediate insights into fill levels, enabling them to plan collection routes effectively and prevent overflowing bins.
3. **Optimized Collection Routes:** Utilize the real-time data collected from the smart waste bins to optimize waste collection routes. By analyzing the fill-level data and applying predictive analytics, waste collection routes can be planned efficiently, reducing travel time, fuel consumption, and greenhouse gas emissions.
4. **Efficient Resource Allocation:** IoT-enabled waste management systems facilitate efficient resource allocation. By monitoring fill levels and analyzing data, authorities can allocate resources such as collection vehicles and manpower based on demand, ensuring optimal utilization and cost-effectiveness.
5. **Sensor-based Sorting and Segregation:** Implement IoT-based sorting and segregation systems at waste processing facilities. These systems use sensors to automatically sort different types of waste, such as recyclables and non-recyclables, streamlining the recycling process and minimizing manual sorting efforts.
6. **Smart Fleet Management:** Equip waste collection vehicles with IoT devices and GPS trackers to monitor their locations, optimize routes, and track their efficiency. This ensures that collection vehicles follow the most efficient paths, reducing fuel consumption and improving overall waste management operations.
7. **Citizen Engagement and Awareness:** Involve citizens in waste management efforts through IoT-enabled platforms. Develop mobile applications or web portals that allow residents to report issues, track collection schedules, access educational resources, and receive alerts or notifications related to waste management activities. This promotes citizen engagement, encourages responsible waste disposal practices, and creates a sense of ownership among residents.
8. **Integration with Other Smart City Systems:** Integrate IoT-based waste management systems with other smart city infrastructure, such as energy management systems and traffic control systems. This integration allows for better coordination and optimization of various city services, leading to overall efficiency and sustainability.

Architecture of IoT based waste management system

Figure 1 depicts the network architecture of the developed IoT-enabled solid refuse management system. It uses a hybrid network architecture to effectively manage trash cans in public and residential locations. The architecture includes the end sensor nodes Public Bin Level Monitoring Unit (PBLMU) and Home Bin Level Monitoring Unit (HBLMU) for monitoring trash cans in public locations and residential areas, respectively.



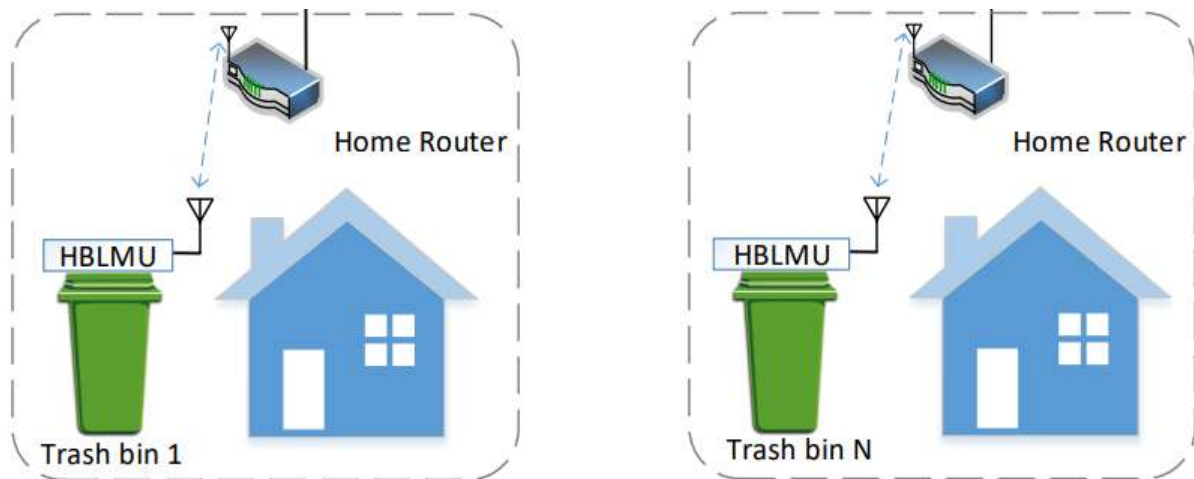


Figure 1. The network architecture of the developed system.

PBLMUs have a LoRaWAN networking architecture, while HBLMUs use Wi-Fi-based communication because they are placed in residential areas. The PBLMUs communicate with the LoRaWAN gateway and transmit data on the garbage cans' empty levels and locations over 915 MHz. While a LoRaWAN gateway collects and transmits data from PBLMUs to a server, where it may be stored and viewed, HBLMUs connect to home routers via a Wi-Fi module included into the devices. The PBLMUs and HBLMUs use a publish-subscribe communication strategy, therefore their data is sent to the server via a MQTT broker. The central monitoring server is the MQTT broker's subscriber, receiving data from the MQTT broker, while the PBLMUs and HBLMUs are the publishers, sending data to the designated topics of MQTT broker. With its low power consumption, fast data transfer, lightweight design, and simple implementation, the MQTT protocol is a great choice for Internet of Things-based remote monitoring systems. The empty bins and their precise locations may be tracked and analyzed by authorized users via the smart GUI, allowing for more effective garbage collection.

3.1 PBLMU Layout and Construction The PBLMU was created to collect data on how full public garbage cans are and where exactly they are placed. Figure 2 depicts the PBLMU's block diagram as it was intended. It has a GPS module to track where the garbage cans are and an ultrasonic sensor to detect when they are empty. The PBLMU has a LoRa module that communicates with the LoRaWAN gateway to set up the LoRaWAN network. Also, the PBLMU has an integrated power management unit for supplying power to its various parts at the appropriate voltages. Since PBLMUs are powered by batteries, they also have a solar panel mounted for energy gathering and self-powering. Here is a quick rundown of what makes up the PBLMU.

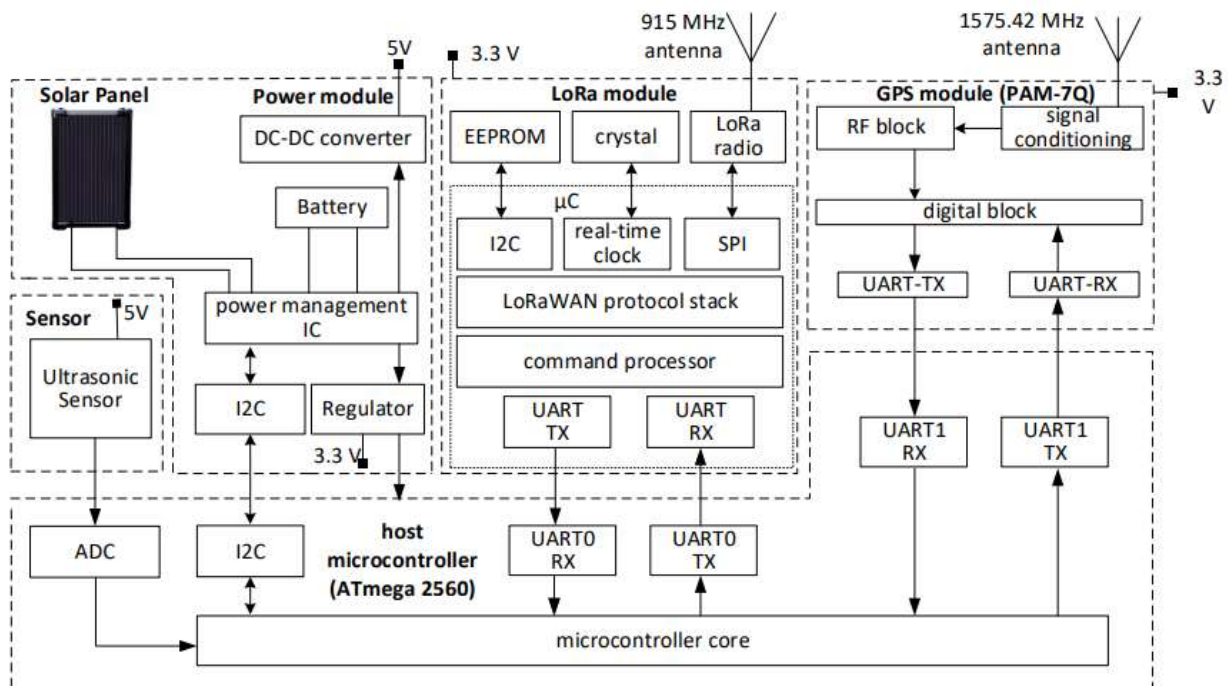


Figure 2. Block diagram of the Public Bin Level Monitoring Unit (PBLMU).

3. System Components

3.1.1 Ultrasonic Detector

The PBLMU uses a commercially accessible, lightweight, and compact ultrasonic sensor called the MB1010 LV-MaxSonar-EZ. This sensor has great precision, consistent range sensing, and a high-quality beam, all at a reasonable price. This sensor generates high-frequency (42 kHz) sound waves and analyzes the reflected echo. This sensor is able to detect solid waste from extremely close up to a great distance, from 0 to 6.45 meters. The sensing range of this sensor is so precise that there is no room for error. The sensor may simultaneously output RS232 serial data, analog voltage data, and pulse width data. The sensor can work in temperatures from -40 degrees Celsius to 65 degrees Celsius, however it performs best in temperatures between 0 degrees Celsius and 60 degrees Celsius. When the sensor is set to its triggered mode of operation, it provides the required measuring range for gauging the empty volume of a garbage can. But a sensor in free-run mode can continuously report the range data because it is gathering it in real time.

3.1.2 GPS Module

Waste management in a big area calls for the installation of numerous trash cans. The geographical coordinates of each trash can are required for rubbish collection. Keeping track of the precise locations of many trash cans by hand is an onerous undertaking. Garbage cans that have been relocated or stolen can be found with the help of geolocation data, and the most efficient path for garbage collection can be planned. The PBLMU has a PAM-7Q GPS antenna module for pinpointing the precise location of each trash can. The PAM-7Q's outstanding performance is guaranteed even in challenging circumstances thanks to its embedded antenna, low power consumption, clear interface, high sensitivity of 161 dBm, and effective interference suppression. The PAM-7Q's standout quality is the fact that it can perform RHCP with a much more compact patch antenna. With its straightforward construction and straightforward interface, an 18 mm 18 mm patch antenna helps keep installation expenses to a minimum. The GPS module is set up in a power-saving mode termed ON/OFF service in order to reduce the average current consumption of the PBLMU.

3.1.3 LoRa Module

Each PBLMU has a built-in RN2903 transceiver module for low-power, long-range data transmission. Spread spectrum modulation allows the RN2903 module to gain excellent immunity to interference. To improve the system's resilience to interference, the US902-928 MHz ISM band is used for each transmission in a pseudo-random method. Using a 3.3 V DC supply, the RN2903 module talks to the host microcontroller using a UART. The RN2903 may be tuned to transmit at a maximum of 18.5 dBm with a sensitivity of 146 dBm. It may also be maintained and programmed with ASCII commands sent over a UART interface. When transmitting at full power, the RN2903 uses 124 mA of current, while receiving only uses 13.5 mA.

3.1.4 Microcontroller on Board Host System

The host microcontroller is the brains of the PBLMU and manages everything the unit does. The PBLMU uses an Atmel ATmega 2560 microcontroller, an 8-bit device with a sophisticated RISC architecture, low power consumption, and high performance. Four 8-bit PWM channels, a 16-channel ADC, four USARTs, a master/slave SPI serial port, and an I2C interface are only some of the peripheral functions offered by the host microcontroller. In the PBLMU architecture, the host microcontroller communicates with the RN2903 LoRa transceiver module through UART1, the PAM-7Q GPS module over UART0, and the MB1010 sensor over the ADC channel. It operates at a clock speed of 8 MHz and a voltage of 3.3 V. It also operates within the same temperature range as the GPS module, which is -40 to 85 degrees Celsius.

3.1.5 Power Supply Control Board

While the controller and other components can run on 3.3 V, the sensor needs 5 V to function. A power management unit is built into the design of the node to supply the necessary 5 V and 3.3 V. A solar panel, a battery with a capacity of 2500 mAh, and a charging circuit make up the power management unit. To draw electricity from the solar panel and charge the batteries, a low-power charger chip (BQ25505) is used. As little as 100 mV of voltage from a solar panel is enough to power it. The BQ25505 has a battery health indicator, monitors the solar array's maximum power point, and has an ultralow quotient current usage of 325 nA. The chip contains protections against under- and over-charging in the form of a 3 V under-voltage threshold and a 4.2 V over-voltage threshold. Due to its need for a 5 V supply voltage, the ultrasonic sensor is powered by a boost DC-DC converter (MCP16252T). It runs automatically in PFM/PWM mode, with typical efficiencies of 96%. The MCP1825S LDO regulator maintains 3.3 V to supply the LoRa module, host microcontroller, and GPS module with the juice they need to function.

3.1.6 LoRaWAN Access Point

The proposed Internet of Things-enabled solid waste management system requires central monitoring of all PBLMUs. Each area needs a gateway to connect the PBLMUs in that region to the internet and the server because the PBLMUs in that region form the Wide Area Network utilizing non-IP based communication protocols like the LoRa protocol. A commercially available microchip LoRa gateway is chosen for use as the gateway in the proposed system. The LoRa gateway sets the required values for the system's network address,

IP address, default subnet mask, server IP, server up port, and server down port. The two main parts of a LoRa gateway are the LoRa radio board and the LoRa core board. The RFSW1012-SPDT switch takes data from the PBLMUs coming in over the SMA radio connector on the radio board and splits it between two separate RF outputs. The RF outputs are filtered at two different frequencies before demodulation. Gathering data sent by the radio board, the microcontroller on the LoRa gateway's core board formats it as JSON before sending it on to the Ethernet controller. Additionally, a UDP header is appended to the packets by the Ethernet controller before they are transmitted to the server via a network switch.

3.2 The HBLMU's Layout

The HBLMU is meant to gather data on where garbage cans have been placed and how full they are when emptied. Figure 3 is a block schematic of the finalized HBLMU. It has a GPS module to track the location of trash cans and an ultrasonic sensor to determine how much trash remains in each can. To connect to a cloud server, the HBLMU uses a Wi-Fi module to create a wireless connection with a user's home router. Additionally, the HBLMU incorporates a power management unit to give the necessary voltages to the various other units. Since HBLMUs rely on batteries for power, they also include a solar panel linked to their PMU for energy collecting and autonomous operation. The ultrasonic sensor, GPS module, and power management unit of the HBLMU are all similar to their counterparts in the PBLMU, and their respective functions and specifications are outlined below.

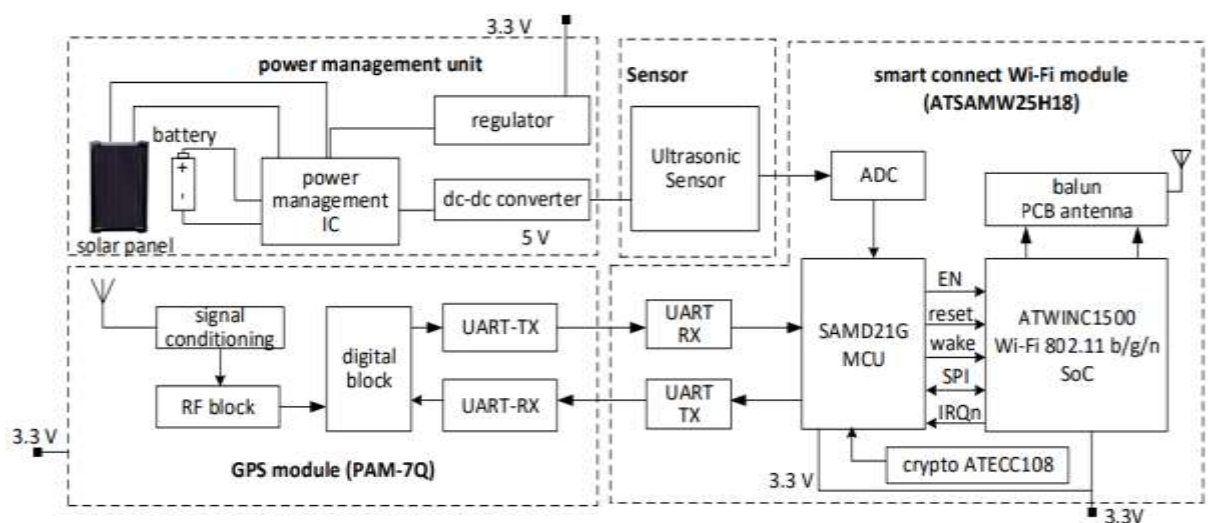


Figure 3. Block diagram of the HBLMU.

Wi-Fi Adapter Module 3.2.1 The HBLMU utilizes a Microchip Smart Connect ATSAMW25H18 SOC for its Wi-Fi module. It's compatible with the 802.11 IP stack and has received certification for it. The ATWINC1500 wireless network processor is paired with an ARM cortex MO+ microcontroller (host computer). There is a 48 MHz clock frequency in use on the host machine. It has a memory management engine built right into the chip, so it can work with less CPU power. It has an on-board flash memory of 8 MB allowing over-the-air firmware upgrades. TLS and SSL protocols are used to create a safe connection to the network. Moreover, it works with common network protocols like DHCP, DNS, UDP, HTTP, and HTTPS. Typically, 3.7 V is used as the controller's operating voltage. It has a ten-bit DAC and a twelve-channel analog-to-digital converter. Due to its ultra-low power consumption, over-the-air software update capability, and integrated security features, the ATSAMW25H18 is the optimum choice for the HBLMU design.

3.2.1 In-House Router

As a result of the HBLMUs being used to monitor the empty cans and their geographical locations, the home router plays a key role in facilitating communication between the command and control hub and the sensing nodes. The TP-Link TL-MR6400 wireless router was used for this study. It's compatible with wireless technologies up to 300 Mbps and is IEEE 802.11/n/a and IEEE 802.11b/g/n compliant.

3.2.2 Interface and Server Components

The server has a 16 GB RAM Intel Core i7-8700T processor, 500 GB hard drive, and Ubuntu 20.04 LTS operating system. Redis, PostgreSQL, the ChirpStack gateway bridge, Eclipse Mosquitto, the ChirpStack network server, the ChirpStack application server, and a smart graphical user interface are only some of the open-source components included in this software suite. The MQTT protocol, which employs a publish/subscribe architecture to convey data, is implemented with the help of the Eclipse Mosquitto message broker. Temporary data can be stored in Redis, an in-memory database, while permanent data can be stored in PostgreSQL. C Sharp, a programming language built for Microsoft's .NET framework, was used

in the creation of the smart GUI. To facilitate real-time message push without polling, .NET Core 3.0 incorporates the gRPC framework, a lightweight and highly performant RPC framework. After the bin level data has been decoded and organized, the PBLMU and HBLMU measurements are graphically mapped to the created graphical representation of the main window, all area icons, and all garbage bin icons. There is a color code for each garbage can level for easy reference.

4. Result & Discussion

Figures 4 and 5 depict the HBLMU and PBLMU that were manufactured. The designed IoT-enabled solid waste management system was put through extensive testing to prove its viability. The newly created IoT system was first tested by keeping track of the percentages of trash that had not been collected using a smart user interface. The average current consumption of a PBLMU was then calculated by measuring its sleep current and active current contributions in an experimental configuration. Finally, a hypothetical PBLMU's expected lifespan was calculated.

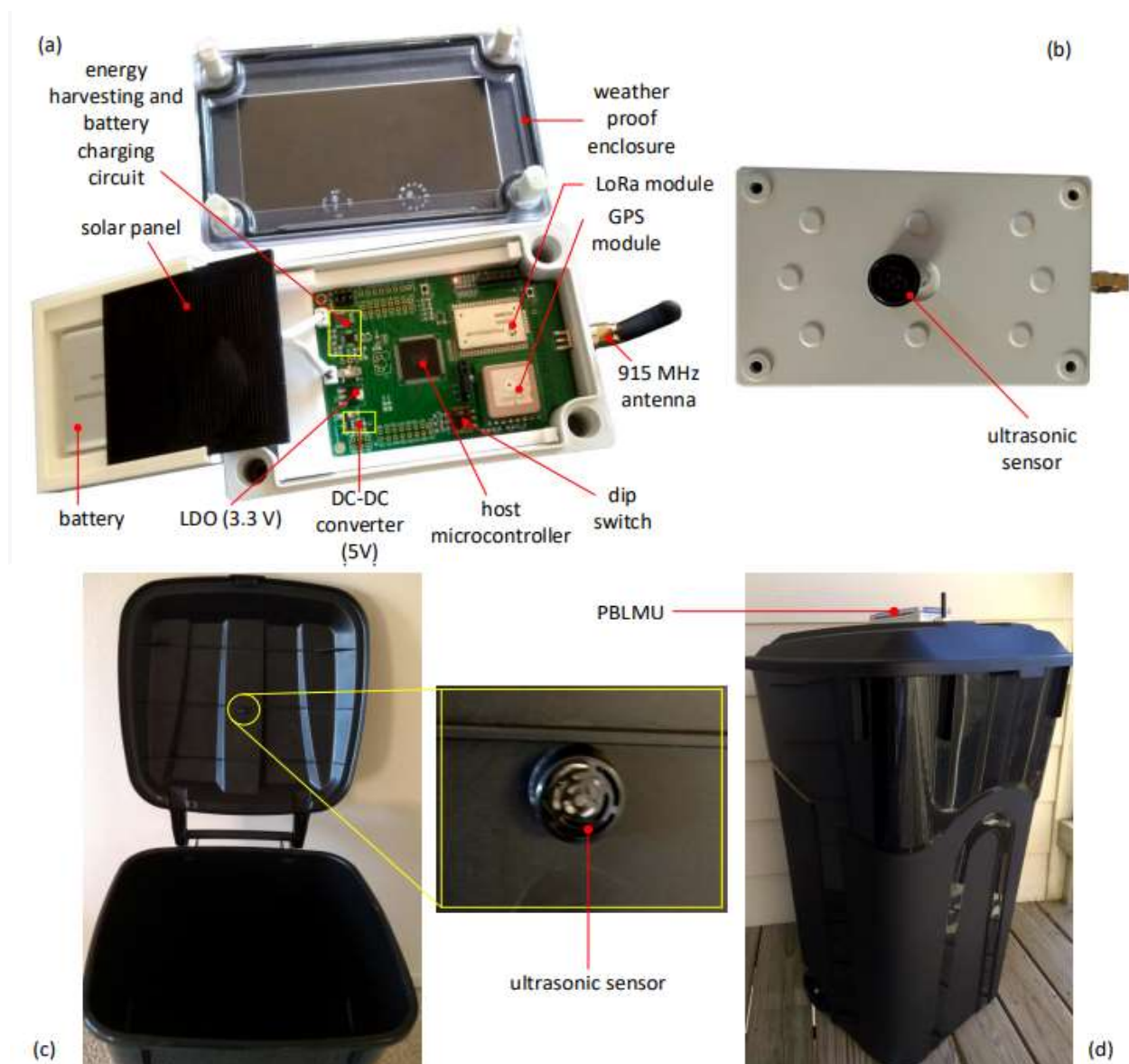


Figure 4. (a) Various components of the fabricated PBLMU. (b) Rear view of the fabricated PBLMU. (c) Installation of PBLMU on a trash bin. (d) Front view of the PBLMU equipped trash bin.

4.1 Verification of the Finished Product

Our research garbage cans feature a top opening of 40 cm 40 cm, a bottom opening of 30 cm 30 cm, and a total height of 82.5 cm. Eight bins were outfitted with PBLMUs and connected to a LoRaWAN, while eight more were outfitted with HBLMUs and connected to a Wi-Fi network as part of an experiment designed to evaluate the established IoT system in both indoor and outdoor settings. Both the PBLMU and the HBLMU's firmware were set to automatically transmit blank data at 5-minute intervals. Using the Intelligent GUI, we

tracked how full each garbage can was as we added various amounts of paper, cardboard boxes, bottles, and clothing. The intelligent GUI gives each garbage can a unique color based on information gathered from the PBLMU, HBLMU, and the can's maximum unfilled level. Trash cans of different colors are assigned different thresholds for when they should be emptied.

Table 1. Mapping table for the threshold unfilled levels and color code.

Unfilled Bin Level in cm	Color Code	Status
Equal to 82.5	Green	Empty
Greater than 70	Green	Lightly filled
Between 55 and 70	Orange	Partially filled
Equal to 50	Orange	Half filled
Less than 30	Red	Almost full

Figure 4. illustrates a screenshot of the developed intelligent GUI, which depicts the global level (home icon), levels of different regions, and Region 1's trash bin levels.

The intelligent GUI was created in a tree-like structure so that the fullness and placement of the garbage can could be tracked in real time. For example, in an IoT-enabled solid waste management system, the major icon (at the top level) of the intelligent GUI is a progressing bar that is in sync with all PBLMUs and HBLMUs. The major icon's hue represents the percentage of trash that has not yet been collected. Intelligent user interfaces typically have regional symbols pop up when the user clicks on the "home" button. The number of available PBLMUs and HBLMUs in a given region is also displayed as a progress bar within the region icon. The number of empty garbage cans in a given area is represented by the color of the corresponding region icon. When a user selects a certain area symbol, the smart GUI brings up a list of all waste receptacles in that area. The PBLMU or HBLMU sensor value is what determines the bin icons' progression across a progressive bar. The illustration's primary symbol is colored red because trash can 1's remaining capacity is less than 30 centimeters (the threshold value). This serves as an immediate warning that some of the garbage cans in the Internet of Things-enabled waste management system are getting full. The unfilled value of Trash Bin 1 is 11.2 cm, hence that region's icon is colored red. The orange regions 2 and 3 indicate that the unfilled level of the trash cans is between 30 and 70 cm. Region 4 is green because its uncollected waste reaches 70 centimeters.

4.2. Average Current Consumption of a PBLMU

We used an INA233 evaluation module to assess the active and sleep mode current contributions of a PBLMU while operating the LoRa module at a spreading factor of 7, power level of 10 dBm, bandwidth of 125 KHz, and a coding rate of 4/5. Table 2 shows the nomenclature of the mathematical symbols used in the equations.

Average current consumption of a PBLMU:

$$I_{PBLMU} = \frac{Q_{PBLMU_a} + Q_{PBLMU_s}}{T} = 1.5 \text{ mA}$$

4.3. Life Expectancy of a PBLMU

The PBLMU's life expectancy was determined under the hypothetical scenario under which the battery's voltage is optimal before its power is depleted. Assume a standard battery has a capacity of 2500 mAh and the following calculation is used to determine the life expectancy of the sensing nodes.

$$PBLMU_{\text{days}} = \frac{Q_{\text{Battery}}}{I_{PBLMU}} \approx 70 \text{ days}$$

Once the battery is fully charged it can power a PBLMU for approximately 70 days without any interruption.

5. Conclusions & Future Work

The development and validation of a hybrid network architecture approach to efficiently manage trash bins in public places and residential areas of cities were discussed in this paper. All facets of an IoT system have been developed, including the design of end nodes, i.e., PBLMU and HBLMU; long-range data transmission with LoRa network for public places and Wi-Fi connectivity for homes; long-term data storage; and hierarchical visualization of trash bin level with the intelligent GUI. Experiments were conducted to validate the developed IoT system, as well as to estimate current consumption and maximum life expectancy of the end node. First, the trash bins had been filled with waste, and the corresponding unfilled levels on the

Intelligent GUI were monitored. Second, based on the measured active and sleep current contributions, the PBLMU's average current consumption is calculated as 1.5 mA. Finally, the life expectancy of a PBLMU was estimated as approximately 70 days under hypothetical conditions. According to the obtained results, the proposed IoT-enabled solid waste management system is well suited for monitoring real-time trash bin information in smart cities. Future work in this area, trash bin information (unfilled level and geolocation coordinates) obtained through the proposed IoT system can be used for framing geographic information system (GIS). Furthermore, optimum routes can be obtained through machine learning algorithms for waste collection trucks.

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