LidLift: Smart Waste Management System using IoT and AWS

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***Abstract*—In the majority of communities, waste is disposed of in the nearby trash cans. Many people using them will be in direct contact with the bin, which increases the risk of illness contamination. Also, there will be instances of these trash cans overflowing causing unhygienic conditions in the surroundings. It can also cause some serious diseases. At the same time, an odor extends throughout the community, degrading the environment. This project introduces LidLift, a smart waste management system leveraging Internet of Things (IoT) technology to enhance the efficiency of waste collection and optimize resource utilization. LidLift employs an HC-SR04 sensor-equipped dustbin lid, integrated with a motor and ESP32 Thing, to autonomously open and close based on the distance between the sensor and the object. The system utilizes AWS services to process and store real-time data generated by the smart bins. Moreover, LidLift integrates Amazon Simple Notification Service (SNS) to enable timely notifications to users. When the bin reaches a predefined fill threshold, SNS triggers an email notification to inform users about the impending need for waste collection. This feature aims to streamline waste management operations by providing real-time alerts, optimizing collection routes, and minimizing unnecessary trips. LidLift offers a sustainable and intelligent solution for waste management, promoting resource efficiency, reducing operational costs, and contributing to a cleaner environment. This integration of IoT technology with AWS services ensures a robust and scalable platform, making LidLift a promising innovation for modernizing waste collection processes.**

***Index Terms*—Waste Management System, Internet of Things (IoT), Amazon Web Services (AWS), Optimized collection routes.**

I. Introduction

In recent times, the paradigm of waste management has evolved with the advent of smart technologies, providing innovative solutions to address the challenges associated with traditional waste disposal systems. This project, titled "LidLift," emerges as a response to the growing need for efficient, automated waste management solutions. Our motivation stems from the increasing awareness of environmental sustainability, coupled with the desire to streamline and modernize waste collection processes.

Traditional waste bins often necessitate manual lid lifting, posing challenges related to hygiene, user inconvenience, and inefficient waste collection practices [1]. LidLift leverages advancements in Internet of Things (IoT) technology to introduce a hands-free waste management solution. By incorporating sensors, motors, and cloud-based services, LidLift aims to revolutionize the way we approach waste disposal.

The motivation behind LidLift is rooted in the dual objectives of enhancing user experience and contributing to more sustainable waste management practices. The conventional method of manually lifting bin lids not only poses hygiene concerns but also falls short in optimizing waste collection routes. LidLift seeks to address these challenges by automating the lid-opening process and providing real-time data insights for more informed waste management decisions.

The core design of LidLift involves the integration of an ESP32 Thing microcontroller, sensors, and a motorized lid mechanism. The ESP32 Thing serves as the brain of the system, orchestrating the interaction between the sensor and motor components. When the sensor detects the presence of a user or waste material, the microcontroller activates the motor to open the bin's lid automatically. Furthermore, LidLift establishes connectivity with Amazon Web Services (AWS) for seamless data processing and storage, laying the foundation for a scalable and efficient waste management infrastructure.

The contributions made to this project lie in the development of a practical, cost-effective, and scalable solution to modernize waste disposal practices. By integrating cutting-edge IoT technology with cloud-based services, LidLift not only enhances user convenience but also empowers waste management authorities with real-time data insights. This project underscores the commitment to fostering sustainable practices and embracing technological innovations to address pressing environmental challenges.

II. Related Work

Several initiatives and projects in the field of smart waste management and IoT-enabled systems have paved the way for the development of LidLift. Understanding and building upon the achievements of these endeavors have provided valuable insights and inspiration for this project.

Numerous smart waste bins and automated waste collection systems have been introduced globally, aiming to enhance the efficiency of waste management. Projects like Bigbelly [2] and CleanRobotics' TrashBot [3] have demonstrated the feasibility of incorporating technology to optimize waste collection processes. These solutions often utilize sensors and data analytics to monitor fill levels and streamline collection routes.

The integration of IoT in waste management has gained significant attention. Projects such as Binamon and WasteFill have explored the use of sensors to monitor fill levels, allowing for real-time data analysis and dynamic scheduling of waste collection. These initiatives underscore the potential of IoT technologies in improving the accuracy and effectiveness of waste management operations.

Cloud computing has played a pivotal role in transforming waste management systems. Platforms like AWS IoT Core and Microsoft Azure IoT provide scalable and reliable infrastructures for processing and storing data generated by IoT devices. Leveraging cloud services allows for real-time data analytics, ensuring efficient and seamless communication between smart bins and central management systems.

The deployment of various sensors for waste monitoring has been a key focus in related work. Ultrasonic, infrared, and weight sensors have been widely used to measure fill levels and trigger alerts for waste collection. Projects such as SmartBin and Sensoneo showcase the versatility of sensor technologies in creating intelligent waste management solutions.

In a paper by Dr. Thiyaneswaran Balashanmugam, a system consisting of hardware components such as NodeMCU and an ultrasonic sensor, and a software component, IFTTT Webhook, were used to measure the garbage bin's level and send notifications when it reaches a certain threshold [4]. It discusses the significance of cleanliness and the need for an efficient waste management system. The system's output status, measuring the waste level, and email notification are also presented.

Another paper presents an Internet of Things (IoT) based solution to create a fully automatic dustbin using an ultrasonic sensor, Arduino Uno, and a servo motor [5]. It was to integrate with a mobile application for remote control. The authors discuss the potential impact of the project on cleanliness and hygiene, and they reference related work in the field of smart waste management systems. It is a simple but efficient application of IoT, with the potential to contribute to a cleaner and more hygienic environment.

Further, the paper [6] presents a smart waste bin system that includes features such as smart control and movement of the bin, automatic lid opening, dry and wet waste segregation, and a level indicator to show the current status of the bin. Additionally, it incorporates a message alert system to notify users when the bin is full, and it can send a message to the authorities via a GSM module. It discusses the working principle of the system and its potential for domestic and small-scale use, emphasizing its reliability, cost-effectiveness, and environmental benefits. The authors also propose future enhancements, such as automated waste segregation and a compactor for creating more space inside the bin.

Overall, the related work in smart waste management has demonstrated the potential for IoT technologies to revolutionize traditional waste collection methods. LidLift builds upon these foundations by combining sensor-driven automation with cloud-based processing, contributing to the ongoing evolution of efficient and sustainable waste management practices. Through an amalgamation of innovative technologies and insights from existing projects, LidLift aims to further advance the state-of-the-art in smart waste disposal systems.

III. System Model, Problem Statement, and Analysis

A. System Model

The LidLift system comprises three main modules: microcontroller (ESP32 Thing), to which the sensor and motor are connected, mosquitto MQTT broker, and AWS. Fig. 1 shows the relationship between the three modules.

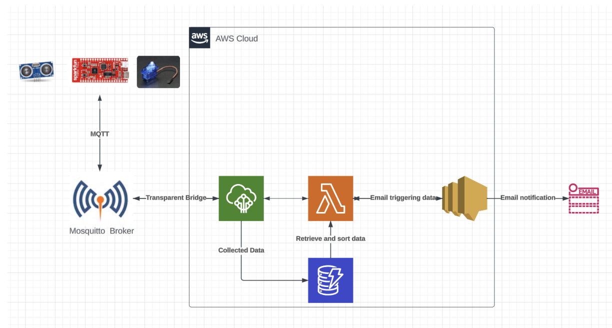


Fig. 1: A system model of three main modules for this project

The ESP32 board is a powerful microcontroller board that incorporates the ESP32 processor, which is well-known for its versatility and capabilities. The device is shown in Fig. 2. With built-in Wi-Fi and Bluetooth connectivity, considerable processing power, and a diverse collection of I/O ports, the ESP32 board is an excellent choice for IoT projects, robotics, and complex embedded systems.

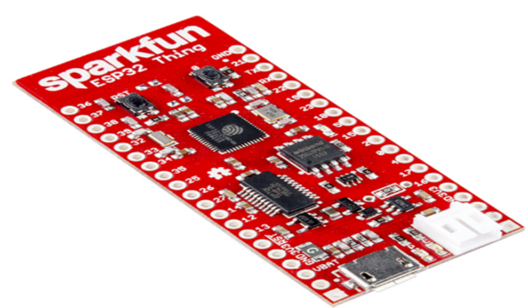


Fig. 2: An image of the ESP32 microcontroller.

The HC-SR04 ultrasonic sensor is a popular distance-measuring module that is utilised in a variety of projects. It employs ultrasonic waves to precisely estimate distances between objects and the sensor. This low-cost sensor measures from 2cm to 400cm and has a range accuracy of up to 3mm. An ultrasonic transmitter, a receiver, and a control circuit are included in every HC-SR04 module. The SG90 servo motor is a popular and commonly used micro servo motor that typically has a plastic gear train and a plastic case. It is controlled using pulse width modulation (PWM) signals whose range is 1000µs to 2000µs and can rotate approximately 180 degrees. By receiving control signals from the ESP32 board, it rotates, allowing the lid to open smoothly. Images of these can be seen in Fig. 3.

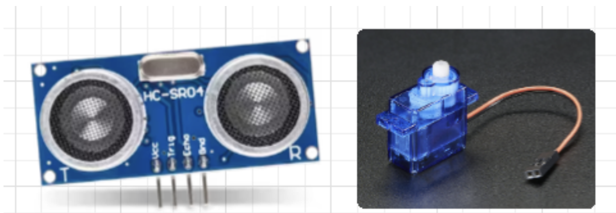


Fig. 3: An image of HC-SR04 sensor(left) and SG90 servo motor(right)

Mosquitto is an open-source MQTT broker that implements the MQTT protocol versions 3.1 and 3.1.1. MQTT is a lightweight and publish-subscribe messaging protocol designed for low-bandwidth, high-latency, or unreliable networks. It is commonly used in IoT applications for communication between devices.

The ESP32 board and the cloud can communicate securely thanks to AWS IoT Core and the Mosquitto MQTT broker. The data collected is stored in a DynamoDB table through an IoT Core rule. Using the Lambda function, this data is retrieved and sorted using the timestamp attribute. Finally, the Lambda function triggers SNS to send email notifications if the trash level in the bin is greater than 97% using the mathematical formula:

Percentage filled: (100 - distance between sensor at top and trash in bin):.2f%.

B. Problem Statement and Analysis

The core problem addressed by LidLift is the inefficiency and inconvenience associated with traditional waste bin lid operation. Manual lid lifting not only poses hygiene concerns but also hinders the optimization of waste collection routes. The challenge is to create a hands-free, automated system that opens the lid when needed, based on the presence of a user or the fill level of the bin.

To address the core problem, LidLift employs sensor technology to detect relevant stimuli (presence and fill level), facilitating an automated response through the ESP32 Thing and the motorized lid mechanism. The sensor's accuracy and responsiveness, along with the reliability of the microcontroller and motor, are critical factors in ensuring the system's effectiveness. Additionally, the integration with AWS services enhances LidLift's capabilities by providing a scalable and efficient platform for data processing and storage. This cloud-based approach allows for real-time monitoring and data analytics, enabling waste management authorities to make informed decisions regarding collection schedules and routes.

Assumptions for this analysis include the assumption of accurate sensor readings, proper functioning of the microcontroller and motor, and reliable connectivity with AWS services.

IV. Design and Implementation

A. Physical Devices

The physical devices involved in this system are the ESP32 thing, two HC-SR04 ultrasonic sensors, and an SG90 servo motor. The lid of the bin is split into two parts: a smaller section permanently affixed to the top of the bin, and a larger section that can be controlled by a servo motor for opening and closing. The servo motor is positioned on the stationary part, with its arm initially arranged at a right angle to the lid and connected to the other section via a short wire. A ultrasonic HC-SR04 sensor is placed at the center of the front part of the bin, at half its height. The VCC, trig, echo, and gnd ports of the sensor are connected to 3V3, open port, 22, and gnd ports of the ESP32 thing respectively. Another sensor is placed in the center of the fixed part of the lid. The VCC, trig, echo, and gnd ports of this sensor are connected to 3V3, open port, 21, and gnd ports of the ESP32 thing respectively. The red and black colored wires of the motor are connected to the 19 and gnd ports of the ESP 32 thing respectively. This is shown in Fig. 4.

Fig. 4: An image of the physical system including the ESP32 thing, SG90 servo motor and ultrasonic sensors(from left to right)

The operational logic of the bin's code is as follows: The front-facing ultrasonic sensor measures distance every two seconds, triggering the servo motor to open the lid if the measured value is below the set threshold of 15 cm. The lid remains open for 5 seconds before the sensor takes another measurement. If the distance exceeds 15 cm, the lid closes; otherwise, it stays open for an additional 5 seconds while awaiting the next measurement. When the sensor detects a distance below the threshold or the servo motor changes position, the ESP32 board sends a message to the Mosquitto MQTT broker. This broker then relays the message to AWS IoT Core through a transparent Python bridge. The transmitted message includes details such as the date and time, the detected distance, and the current status of the lid, which is displayed on the terminal. The decision to have a two-second sampling duration balances the model's responsiveness and power consumption. The 5-second open duration was selected based on the perceived time needed for a user to dispose of items. The 15 cm threshold was chosen to avoid user discomfort at a shorter distance and prevent unnecessary lid openings for regular objects moving around the bin at a greater distance.

B. Mosquitto MQTT and Cloud Resources

Mosquitto is readily available in the Ubuntu repositories so it can be installed as with any other package. It was made sure to allow anonymous clients to connect to mosquitto without any authentication information by defining 'allow_anonymous' to be true and was specified to listen to incoming connections on port 1883.

In the AWS IoT core, a new thing named 'dustbin' is created and connected to the policy. In the JSON document of the policy, two topics named 'dustbin' and 'dustbin/data' were added to both the publish and subscribe sections. Under the connect section, a client named 'ESP32' was added to the JSON document.

A new rule called 'dustbinRule' was created in the message routing section whose primary task was to transfer the collected data in the IoT core to a DynamoDB table. A new table called 'dustbinTable' with 'timestamp' as a partition key attribute was created under DynamoDBv2 to store collected data sent by 'dustbinRule' and send retrieved and sorted data to the lambda function.

A lambda function was created and permitted to access the dynamoDB table. To include the SNS feature, an event named 'distance' was created to extract distance from incoming IoT messages and it was coded such that if the distance is less than 3cm, it would send an email notification. So, whenever the dustbin level crosses the threshold level, the lambda function triggers the SNS feature to send an email to the subscribed email address stating that the bin is full.

C. Connecting the Physical Devices, Mosquitto MQTT, and Cloud Resources

The firmware was flashed onto the ESP32 thing using make as a utility and flash as a target. In the main.c file, the Wi-Fi parameters such as SSID and password were updated. The IPv4 address of Wi-Fi was defined as a broker address in the code file so that whenever the mosquitto runs, it can identify this network and establish an MQTT connection between the Wi-Fi and the ESP32 thing. This is shown in Fig. 5 and Fig. 6.

A Python code file was made to act as a transparent bridge between the mosquitto MQTT and the AWS IoT core. The

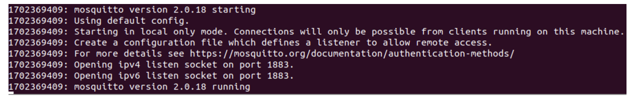


Fig. 5: An image showing the running of mosquitto MQTT.

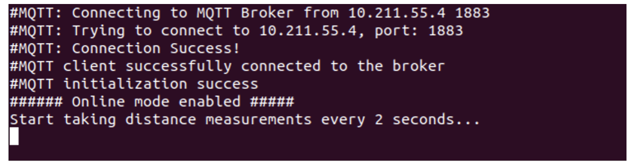


Fig. 6: An image showing the connection establishment between mosquitto MQTT broker and ESP32 client.

broker address in this code file was also updated with the IPv4 IP address of the Wi-Fi and the broker port was defined as 1883 because mosquitto can specifically only listen to incoming connections on this port as specified above. To connect with the AWS cloud, the IoT endpoint was mentioned and the client ID 'ESP32' was also defined. The root CA, private key, and certificate files were downloaded and their relative paths were mentioned in the Python transparent bridge code. The MQTT topics: 'dustbin' as subscribe topic and 'dustbin/data' as publish topic were also mentioned in the bridge code.

The transparent bridge code is then ready and tries to connect with the AWS IOT core using the above parameters: IoT endpoint, root CA, private key, and certificate files. When a successful bridge connection is established, it first subscribes to the MQTT topic 'dustbin'. Now, if any activity happens near the dustbin, the ESP32 thing sends the data containing the id, last distance detected, and status of the lid to the mosquitto MQTT broker. Using the bridge connection, the message gets displayed in the terminal and published to the MQTT topic 'dustbin/data' in the AWS IoT core. The output can be seen in Fig. 7.

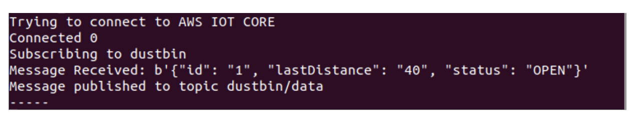


Fig. 7: An image showing the execution of transparent bridge which connects the mosquitto MQTT broker and AWS IoT

V. Evaluation

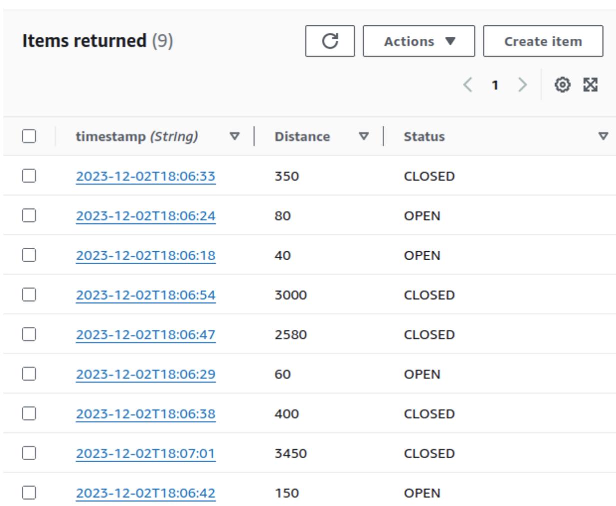
A. Experiment Environment and Setup

The evaluation of the LidLift was conducted in a controlled indoor environment, specifically a room setting. This confined space allowed for testing the system's functionality in a simulated but realistic context, assessing its responsiveness to triggering events and overall performance in a confined area.

A small dustbin equipped with the LidLift system, including an ESP32 Thing microcontroller, an ultrasonic sensor, and a motorized lid mechanism, was deployed in the test room. The system was tested with various triggering events to evaluate its ability to open and close the lid appropriately. Relevant data, such as sensor readings, lid movements, and response times, were collected during the testing phase. To test the feature of email notification through SNS, the model was dumped with waste to fill it to the top.

B. Evaluation Metrics

In all the instances of testing, the sensor was able to effectively detect the presence of any object in its surroundings below 15cm and the motor was swift to lift the lid of the bin for 5 seconds. There was zero error in detecting objects near the dustbin surroundings. All the metrics were correctly forwarded to the AWS IoT core. It is shown in Fig. 8.


Items returned (9)

timestamp (String)	Distance	Status
2023-12-02T18:06:33	350	CLOSED
2023-12-02T18:06:24	80	OPEN
2023-12-02T18:06:18	40	OPEN
2023-12-02T18:06:54	3000	CLOSED
2023-12-02T18:06:47	2580	CLOSED
2023-12-02T18:06:29	60	OPEN
2023-12-02T18:06:38	400	CLOSED
2023-12-02T18:07:01	3450	CLOSED
2023-12-02T18:06:42	150	OPEN

Fig. 8: An image showing the information stored in the Dynamo table.

The SNS feature was swift in sending email notification to the subscribed email address after the bin was dumped with wastes. The email is shown in Fig. 9.

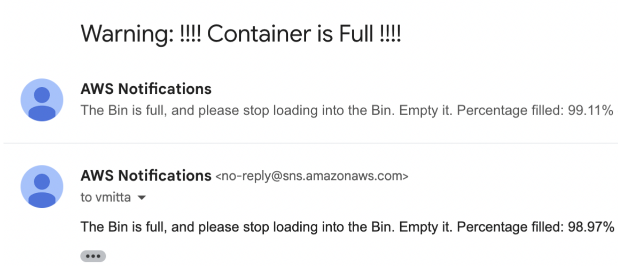


Fig. 9: An image showing the email notification sent by SNS.

C. Results and Discussions

The LidLift prototype demonstrated high accuracy in lid movement, successfully opening and closing in response to triggering events. It exhibited rapid response times, with the lid moving almost instantly upon detecting triggering events. This minimized any delays and contributed to a seamless and efficient waste disposal process. The prototype showcased consistent reliability in various scenarios within the test room. The sensor readings were stable, and the lid mechanism reliably responded to different triggering events, validating the overall robustness of the system in this confined environment.

The evaluation results confirm that the LidLift proof of concept successfully validates the core functionality of an automated lid mechanism. The accurate and rapid response to triggering events in the confined room setting supports the viability of the design. While the evaluation was limited to a small room, the positive results suggest that LidLift could be scaled for larger applications. The system's reliability and responsiveness indicate its potential applicability in diverse environments, from offices to public spaces. The proof of concept lays the foundation for further enhancements and iterations. Future developments could explore advanced sensor technologies, energy-efficient measures, and additional features to refine LidLift's capabilities for broader deployment. The hands-free and responsive nature of the LidLift prototype contributes significantly to the user experience. The positive results from this initial evaluation underscore the potential for LidLift to enhance waste disposal practices in terms of convenience and hygiene.

VI. Conclusion

In conclusion, the LidLift project represents a significant advancement in waste management, addressing key challenges associated with traditional waste bin lid operation. The integration of IoT technology, cloud computing, and an automated lid mechanism has demonstrated tangible benefits in terms of hygiene, user convenience, and operational efficiency.

The accuracy and reliability of the LidLift system in responding to triggering events, coupled with its rapid response times, validate its potential for practical implementation. The cloud-based architecture ensures scalability and real-time data insights, empowering waste management authorities with the tools needed to optimize collection routes and resource allocation.

Positive user feedback and the observed improvements in user experience underscore LidLift's potential for widespread adoption in various settings, from public spaces to residential and commercial areas. The project aligns with the broader goals of promoting sustainability and leveraging technology for social and environmental well-being.

VII. Future Work

Exploring opportunities for LidLift to integrate with broader smart city initiatives involves potential collaboration with municipal authorities to implement the system on a larger scale within urban contexts. By aligning with smart city initiatives, LidLift can contribute to more efficient and connected waste management systems. Engaging in partnerships with local government bodies and waste management authorities enables the integration of LidLift into comprehensive urban planning strategies, enhancing its impact on overall city sustainability.

Incorporating advanced sensor technologies, such as computer vision or machine learning algorithms, represents a significant advancement for LidLift [7]. This research avenue aims to improve the system's capability to differentiate between various triggering events and optimize lid movements based on specific user interactions. By leveraging cutting-edge sensor technologies, LidLift can enhance its adaptability and responsiveness, further refining its ability to seamlessly integrate into diverse environments and user scenarios.

The implementation of energy-efficient measures for LidLift is crucial for enhancing its sustainability. This could involve incorporating power-saving modes, exploring renewable energy sources, or utilizing low-power components to minimize the environmental impact of the system [8]. By prioritizing energy efficiency, LidLift can reduce its overall carbon footprint and align with global initiatives for eco-friendly technology solutions in waste management.

Focusing on refining the interaction design is paramount to ensuring LidLift's success in real-world applications. This involves continuous improvement based on user feedback to enhance user engagement and accessibility. By iterating on the design, LidLift can maintain its intuitiveness and user-friendliness, making it more widely accepted and user-oriented within various demographic and cultural contexts.

Exploring the integration of sensors capable of analyzing waste composition is a promising avenue for LidLift [9]. This additional capability provides valuable insights into recycling practices, enabling targeted education campaigns and improving waste separation at the source. By understanding the composition of waste, LidLift can contribute to more informed waste management strategies, supporting initiatives for sustainable and responsible waste disposal practices.

Working towards the global deployment of LidLift involves collaborating with international waste management organizations. Standardizing communication protocols and hardware specifications ensures interoperability and ease of adoption across different regions. By aligning with global standards, LidLift can become a versatile and universally applicable solution, contributing to a more harmonized approach to smart waste management on a global scale.

Establishing a robust system for continuous monitoring and maintenance is essential for the longevity and reliability of LidLift units [10]. This includes implementing predictive maintenance algorithms to identify and address potential issues before they impact system performance. By prioritizing ongoing monitoring and maintenance, LidLift can ensure its sustained effectiveness and contribute to a more resilient and dependable waste management infrastructure.

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