EE 542 - Team 1 - SmartTrashBin

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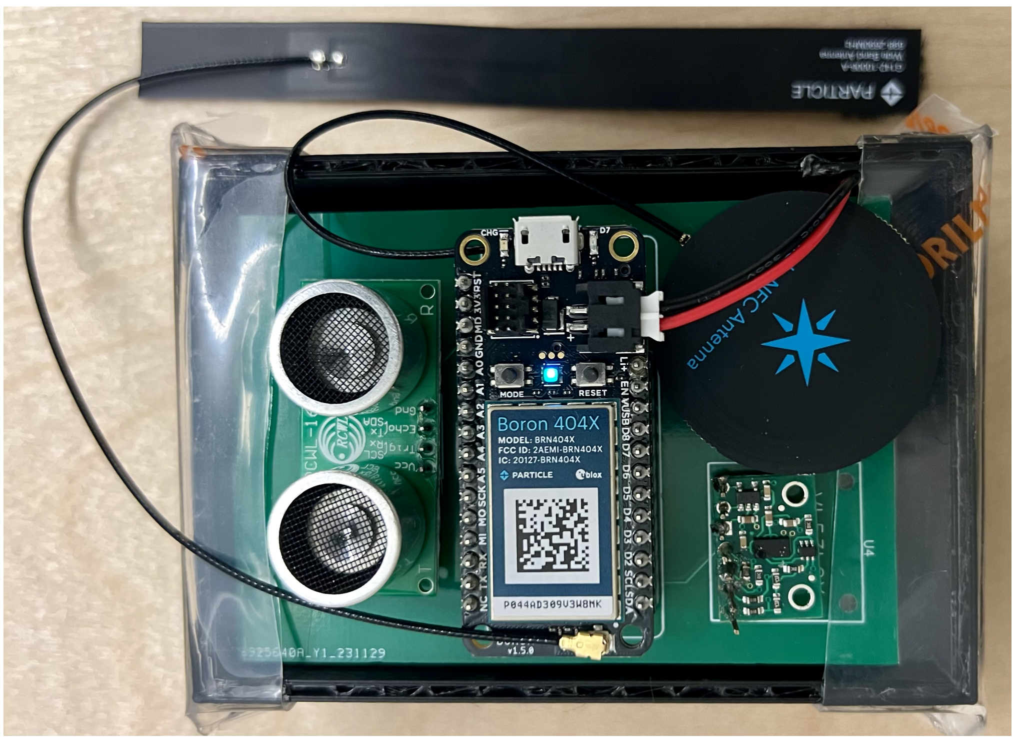

Figure 1. Prototype SmartTrashBin Device

Abstract

The Smart Trash Bin redefines waste management through integrated sensors and a Microcontroller Unit (MCU) for precise garbage bin capacity assessment. Employing an Ultra Low Power Sleep Mode, the system activates every 12 hours, optimizing data transmission to the cloud. This results in efficient collection scheduling, cost savings, and improved public sanitation for waste management companies like Republic. The device triggers alerts at 90% bin capacity, preventing overflow. A robust 3000 mAh battery underscores our commitment to environmental sustainability. NFC technology facilitates data retrieval, while ultrasonic sensors enable contactless object detection. The VL53L0X sensor module provides precise measurements up to 2 meters. Implementation results demonstrate real-time bin monitoring within 10% accuracy, facilitated by CloudSync—an interface seamlessly integrating data for immediate waste management insights.

Keywords: Smart Waste Management, Internet of Things (IoT), Cloud Data Analytics, NFC Technology in Waste Management, TOF, Ultrasonic sensing

ACM Reference Format:
Ryan Anders-McDowell, Yacob Benazouz, Judy Lu, and Deeksha Prabhu. . EE 542 - Team 1 - SmartTrashBin. In *Journal of Awesome Computer Engineering*. EE 542, Seattle, WA, USA, 6 pages

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EE 542 Team 1, Dec 2023, Seattle, WA, USA

1 Introduction

The challenge faced by garbage collection services lies in the lack of real-time information on bin capacity, leading to inefficient allocation of resources. Dispatching a garbage truck to service an empty bin represents a wasteful allocation of resources. Conversely, if a bin reaches full capacity before scheduled collection, the resulting overflow poses potential health hazards. The absence of a reliable, automated system for assessing bin fill levels in real time contributes to these inefficiencies in waste management.

To address this problem, the primary objectives of the project were to develop a robust system capable of withstanding harsh environmental conditions, including adverse weather, grime, and potential impacts from garbage trucks. The system aimed to achieve a bin level accuracy of 10%, ensuring precise monitoring of fill levels. Additionally, the integration of a cellular connection was prioritized to facilitate seamless data transmission. Ensuring a prolonged battery life was a critical aspect of the project, aligning with the overarching goal of creating an efficient and durable solution for real-time waste management optimization.

2 Design Decisions

The selection of components for the Smart Trash Bin system was governed by a methodical approach aimed at ensuring seamless integration, operational efficiency, and robust performance. The Particle Boron 404X was chosen as the central system-on-chip due to its facile cellular connectivity, enabled by Particle APIs facilitating the uncomplicated transmission of device data to the cloud. Compatibility with essential features such as GPIO and antenna pins, notably NFC, influenced the selection of the Boron. Adhering to the Boron's 3.3V pin, we ensured sensor compatibility, leading to the adoption of the VL53L0X optical time-of-flight (TOF) sensor. This sensor met voltage requirements while offering an optimal measurement range of 6 cm to 2 m with commendable accuracy. The HC-SR04 ultrasonic sensor, chosen for its library support and compatibility with 3.3V operation, further complemented the sensor suite.

To mitigate power consumption, a 12-hour sleep cycle was chosen, awakening the system briefly to transmit cellular data. Given the substantial power allocation to data transmission, this strategy strikes a balance between energy efficiency and data reporting frequency. The 3000 mAh LiPo battery was carefully chosen for its high charge capacity, aligning with the power requirements of the system. Notably, the Particle Boron's on-chip LiPo charging capabilities obviated the need for an additional LiPo charger, simplifying the system design and contributing to its overall efficiency. NFC was identified as a passive mechanism for instantaneous device wake-up, facilitating swift access to sensor values, particularly advantageous for waste management personnel.

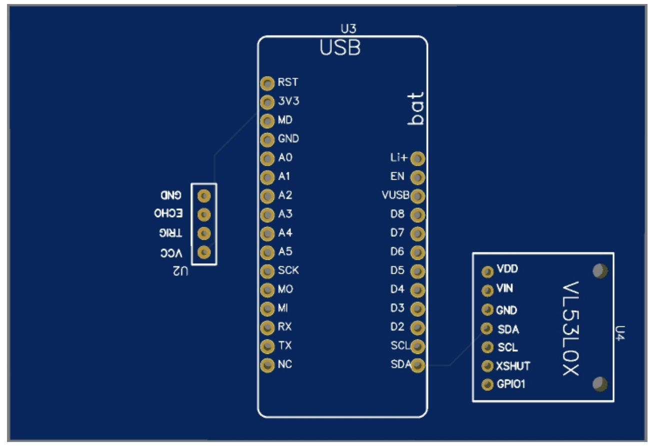

Figure 2. PCB layout: A PCB was chosen to reduce the overall form factor and enhance system stability, especially against potential accelerations experienced by the garbage bin lid

The 3D-printed box was chosen for its protective role, shielding components while enabling straightforward application onto garbage bins.

In pursuit of a compact and sturdy system, a PCB was employed to reduce the overall form factor and enhance system stability, particularly in response to potential accelerations experienced by the garbage bin lid. The selection of Google Cloud as the web server backend was predicated on its seamless integration with Particle webservers and its robust features, encompassing cloud storage for each published event and real-time messaging. These judicious design decisions, including the careful selection of a high-capacity LiPo battery with on-chip charging capabilities, collectively contribute to the efficiency, durability, and scalability of the Smart Trash Bin system. For the design of the device, we made a 3D printed box designed to securely house our device (Figure 2.). This box features two triangular layers strategically placed to prevent the device from slipping out. The internal dimensions are tailored to snugly fit our board, with a specialized compartment beneath it to accommodate the battery. To ensure maximum security and stability, we employed both Velcro and tape on either side of the box, providing a dual-layered safeguard. Additionally, rigorous stability tests were conducted to confirm the resilience and steadiness of the device within this custom-designed enclosure.

3 Implementation Details

Our code currently works on sleep state cycles. In order to establish communication protocols within our MCU we needed to turn on NFC and BLE. The other software component would be in the RTC that we enable within our MCU. Defining a time duration for the RTC was crucial.

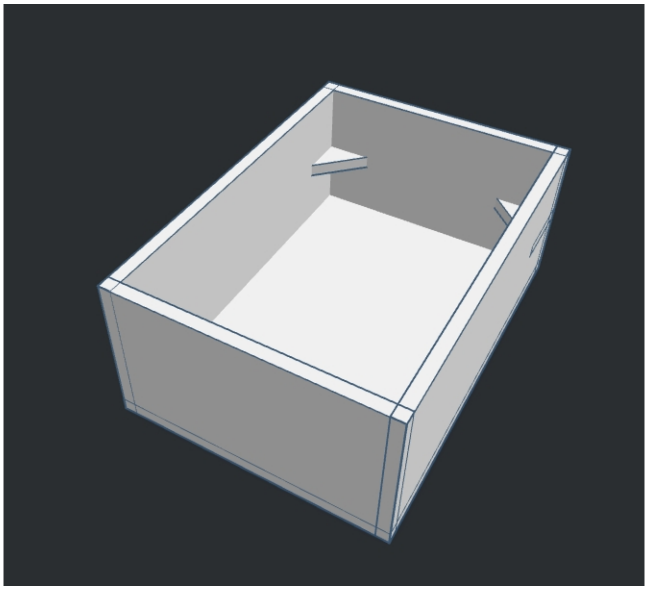

Figure 3. 3D printing

Our approach for fill level estimation employs a VL53L0X TOF sensor and HC-SR04 Ultrasonic sensor. The VL53L0X provides accurate distance measurements using laser light, while ultrasonic sensor offers a secondary distance measurement through sound waves, compensating for any anomalies in data due to the rough environment inside the garbage can.

The fill level estimation algorithm begins with data retrieval from both sensors. Upon obtaining the measurements, the algorithm proceeds to the validation and fusion stage. It first checks if both measurements are valid, i.e., whether both sensors have returned a value. If so, the algorithm calculates the average of the two measurements to determine the fill level. This averaging helps mitigate any discrepancies between the sensors due to environmental conditions or sensor anomalies. If only one sensor provides a valid reading, the algorithm defaults to using that single measurement, ensuring that the fill level estimation is still possible even if one sensor fails or provides unreliable data. This fail-safe mechanism enhances the system's robustness. Ultimately, the algorithm translates the distance measured into a fill percentage, utilizing the standard height of 750mm for garbage bins, as adopted across the University of Washington campus. The fill level percentage is a crucial metric for smart waste management systems, as it informs the scheduling of waste collection services, ensuring that garbage cans are emptied just-in-time, thereby optimizing collection routes and frequencies.

The fill level data measured periodically by our system is plotted to analyze garbage fill patterns. Figure 4 representing fill level estimation is a pivotal tool in our smart garbage collection system, offering a visual representation of bin capacity over time. By periodically measuring the fill level of

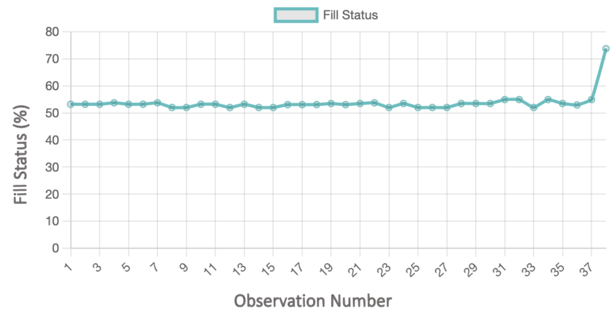

Figure 4. Fill Status

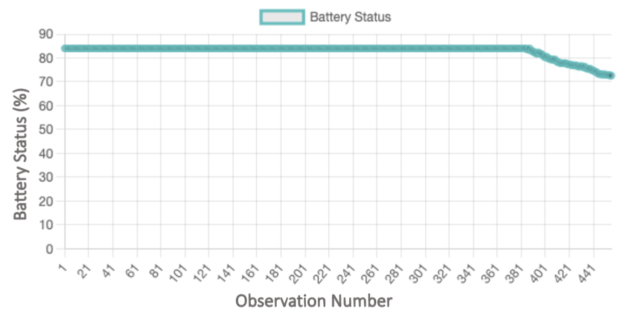

Figure 5. Battery Status

bins, we gain valuable insights into usage patterns, which is critical for optimizing collection schedules. The uptick observed in the chart indicates a surge in waste accumulation, signaling the need for prompt collection to avoid overflow. Such data enables waste management companies to predict when bins will reach capacity and proactively schedule maintenance, leading to more efficient operations and enhanced urban cleanliness.

The battery status of our system is measured at regular intervals to monitor and analyze energy consumption patterns. In Figure 5, the chart illustrates the results of our system's periodic battery status checks. This offers insightful visual analytics, delineating the trend in battery consumption across the deployed sensor network. This data is invaluable for corporations, enabling proactive planning for timely battery replacements or recharging schedules, thereby ensuring uninterrupted service and operational efficiency. Through this predictive analysis, organizations can optimize their maintenance operations and extend the lifespan of their assets, leading to a more sustainable and cost-effective management of the smart garbage collection infrastructure.

4 Test and Evaluation

The evaluation of the system involved practical tests to assess its functionality, robustness, and specific components.

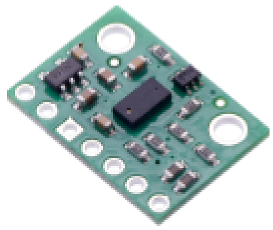

Figure 6. Pololu VL53L0X Optical Time-of-Flight Sensor

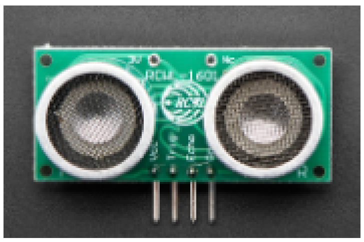

Figure 7. HC-SR04 Ultrasonic Sensor

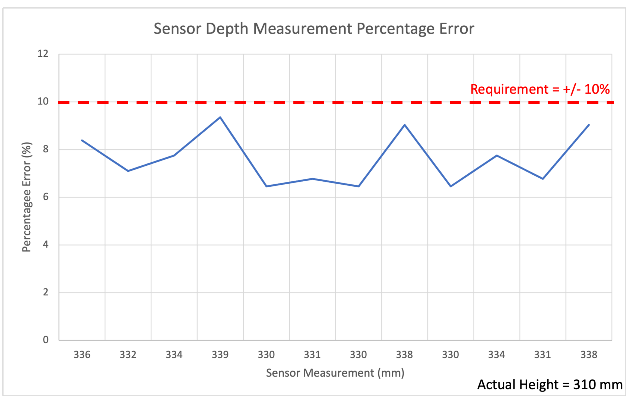

Figure 8. Depth Measurement Accuracy

To gauge the overall integrity of the system, it was affixed to a wooden board mimicking a garbage bin lid using velcro. The board, with the attached system, underwent controlled shaking to simulate potential environmental stresses. The test was considered successful if the system remained securely attached to the board, demonstrating its resilience to external forces.

The state machine embedded in the system's firmware, responsible for orchestrating the 12-hour ultra low-power sleep cycle, underwent testing using a 15-minute sleep cycle as a demonstration version. This test involved resetting the device, starting a stopwatch when the LED indicated the initiation of the sleep cycle, and stopping the stopwatch when the LED signaled the device's reactivation after 15 minutes. The successful completion of this test confirmed the proper functioning of the device's internal real-time clock (RTC) and its ability to autonomously awaken after a programmable duration.

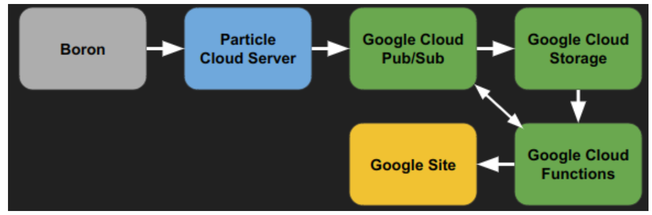

Figure 9. Cloud Network Connectivity Block Diagram

The NFC functionality was evaluated by resetting the device and allowing it to enter sleep mode. Subsequently, a smartphone equipped with the NFC Tools app was tapped onto the NFC antenna. The test considered NFC successful if the device's LED turned on, verifying that the NFC technology effectively awakened the device from its sleep mode.

To assess the accuracy and reliability of the sensors, a systematic test was conducted by holding the board at specific distances from the sensors. Log files were generated, indicating the estimated distances recorded by the sensors. This meticulous examination confirmed that the sensors met the specified accuracy criteria, operating within the 10% margin of error outlined in the system's specifications. The chart titled "Sensor Depth Measurement Percentage Error," presented in Figure 8, portrays the sensor's accuracy compared to a known benchmark bin height of 310 mm. The results indicate that all sensor measurements were within the acceptable error threshold, denoted by the red dashed lines at 10%.

5 Schematics and Block Diagrams

The backend architecture of the system is structured to enable efficient data transmission, storage, and retrieval. The Particle Boron, equipped with cellular connectivity, broadcasts data to Particle webservers, initiating the first layer of communication. The Particle webservers utilize a Google Cloud Pub/Sub interface to seamlessly relay data to the Google Cloud platform. As illustrated in Figure 9, Google Cloud Functions play a pivotal role in interfacing with Google Cloud Storage, ensuring systematic logging of each transmitted message. This approach facilitates the secure and organized storage of data, contributing to the creation of a comprehensive dataset. To provide real-time access to this dataset, a Google Site incorporating HTML/Javascript code is employed. This web-based interface dynamically retrieves and displays values from Google Cloud Storage, allowing users to access the most recent waste management information promptly. This intricate backend infrastructure ensures the smooth flow of data from the Particle Boron sensors to a user-friendly interface, establishing a robust foundation for data management and analysis.

6 Societal/Ethical Considerations

The implementation of our system addresses societal and ethical concerns by promoting a more equitable distribution of garbage collection resources. Traditional periodic schedules for garbage collection may lead to inefficient resource allocation, especially in high-use bin communities where fill levels vary unpredictably. Our system, with its real-time monitoring and alert capabilities, enables garbage collection services to respond dynamically to the actual needs of each bin. This ensures that high-use communities are serviced according to demand, reducing unnecessary pickups of empty bins and preventing potential health hazards associated with overflowing bins. This approach aligns with a more equitable and resource-efficient waste management strategy, optimizing the allocation of resources based on real-time data rather than rigid schedules.

7 Discussion of Results

The implementation of our waste management optimization system yielded promising results in addressing the challenges faced by garbage collection services. The real-time monitoring system proved effective in providing accurate and timely information on bin capacities, thereby significantly improving resource allocation and overall operational efficiency.

Another aspect to our results was achieving a bin level accuracy of 10 percent was a key milestone for the project. Through rigorous testing and calibration, our system consistently demonstrated a high level of precision in monitoring fill levels. This accuracy ensures that resources are deployed optimally, eliminating the unnecessary dispatch of garbage trucks to service empty bins and mitigating the risk of health hazards associated with overflowing bins.

One of the critical aspects of our project was developing a system that could withstand harsh environmental conditions. Rigorous testing under adverse weather conditions, exposure to grime, and simulated impacts from garbage trucks confirmed the robustness of our solution. This resilience ensures the system's functionality and longevity, even in challenging operational environments.

The integration of a cellular connection proved instrumental in achieving seamless data transmission. Real-time updates on bin fill levels were consistently and reliably transmitted, providing waste management authorities with instantaneous and actionable insights. This feature enhances the responsiveness of garbage collection services, allowing for proactive decision-making and resource allocation.

Maintaining a prolonged battery life was a critical consideration for our project. Extensive testing confirmed that our system achieves a balance between energy efficiency and performance. This ensures prolonged operational periods without compromising the accuracy and reliability of the data collected. The extended battery life aligns with our goal of creating a sustainable and efficient solution for waste management optimization.

8 Future Work and Areas for Improvement

Despite the achieved functionalities, several aspects for future work and improvement have been identified.

Firstly, the 3D-printed box housing the components lacks weatherproofing, leaving circuits exposed to environmental elements, potentially affecting sensor performance. Future efforts should focus on enhancing the box's design, considering options such as incorporating weather-resistant materials like glass for the VL53L0X or relocating the ultrasonic sensor outside the box.

Although the Boron supports over-the-air (OTA) updates and cloud event subscriptions, these features were not implemented in our current iteration. Enabling these capabilities would provide the flexibility to remotely update the system and send data while connected to cellular networks. Additionally, incorporating the external RTC into the Boron to enable HIBERNATE mode could further enhance power efficiency.

Moreover, the Bluetooth connection, initially employed for debugging purposes, holds untapped potential. Future work could involve developing a dedicated app for the Boron, enabling efficient data exchange and enhancing the device's overall functionality.

Presently, our system employs LiPo batteries for energy requirements. Moving forward, we aim to evolve the system towards a battery-less operation by harnessing energy harvesting technologies. Potential avenues include solar energy harvesting from photovoltaic panels integrated into the bins, and RF (Radio Frequency) energy harvesting from ambient telecommunications. These methods promise to significantly reduce maintenance demands, enhance the system's sustainability, and contribute to the overall goal of creating self-sufficient smart garbage collection system.

9 Related Research (EE 542 Requirement)

The first study [1] discusses the design and development of a waste management system tailored for municipal areas, emphasizing the challenges posed by public habits and the absence of an efficient waste management infrastructure. The proposed prototype integrates sensors into trash bins to enable real-time monitoring and control of garbage collection schedules, addressing critical phases of segregation and garbage collection with subsystems for hardware, data management, and data visualization. The system demonstrates effective detection of various types of garbage, providing valuable insights for urban waste management solutions.

The second research [2] introduces a trash detection and classification system for a social-education trash bin robot, targeting public facilities with high waste generation potential. Utilizing the Haar-Cascade method, Gray-Level Co-Occurrence Matrix (GLCM), Histogram of Oriented Gradient (HOG), and Support Vector Machines (SVM), the system achieves an offline testing accuracy of 82.7%. The robot aims to instill proper waste disposal habits by autonomously detecting and classifying organic and non-organic waste. While online testing yields a 63.5% accuracy, the research underscores the potential impact of robotic systems in promoting responsible waste disposal habits.

The third study [3] focuses on a cost-effective design of an intelligent waste container for small-scale applications. Leveraging Arduino Nano, ultrasonic sensors, GSM modules, and solar panels, the system monitors container fullness levels, sends SMS alerts, and supports charging of external devices. PIR sensors record usage events, and a memory card stores data for further analysis. The design, powered by a lithium battery power bank and solar energy, successfully implements an economical solution with satisfactory performance.

Considering future directions, advancements in sensor technologies, machine learning algorithms, and energy-efficient solutions could enhance the capabilities of existing systems. Integration with emerging technologies such as edge computing and the Internet of Things (IoT) could further improve real-time monitoring and decision-making. Additionally, exploring social and behavioral aspects, including public awareness campaigns and community engagement, could contribute to more effective waste management strategies. Collaboration with urban planners, environmental scientists, and policymakers may provide holistic solutions that address broader societal and environmental challenges associated with waste management.

10 Conclusion

The successful implementation of our waste management optimization system presents a significant advancement in addressing the inefficiencies plaguing current garbage collection services. The improvements in resource allocation, environmental resilience, data transmission, and battery life contribute to a more streamlined and effective waste management process.

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