Smart Garbage Management

Project Plan

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IV. List of Definitions

- Garbage: Residential waste.
- Collect/Collection: The act of picking up garbage.
- Resident: A homeowner who has garbage to collect.
- Collector: An employee of a waste management company, tasked with collecting garbage
- Admin: A user in charge of an instance of our software.
- System: The all-encompassing set of applications that controls our information.
- App: The Android mobile application component of the project, including both the Resident and the Collector functionality.
- TSP: Traveling Salesman Problem
- VRP: Vehicle Routing Problem, a more specific version of TSP

1. INTRODUCTION

1.1 Acknowledgement

Goce Trajcevski - Idea creator and IoT mastermind

1.2 Problem Statement

Problem Statement: In 2013, Americans generated approximately 254 million tons of garbage. That quantity has steadily increased over the past half-century, shown in the diagram on the right. However, garbage collection techniques have not significantly changed over the same time period, still relying on static routes and scheduling. This antiquated technique does not account for each individual's unique waste disposal habits, creating inefficiencies where one resident's garbage is picked up too often, while another's garbage is not picked up enough. Collection routes also do not take into account the rates that individual collection vehicles fill up at, creating situations where some garbage trucks have to stop their route to empty the vehicle, where others are not completely full after running their whole route.

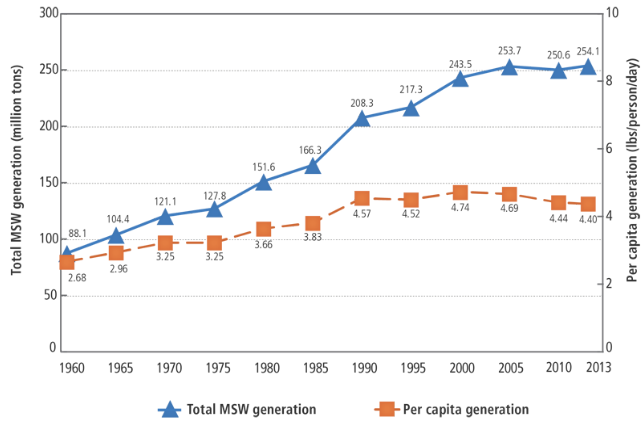


Fig 1. US garbage generation over time.

Solution Approach: Our solution is to add a small sensor package to each resident's garbage can. The sensor package routinely monitors the container's waste level, weight, and location. The sensor package then transmits the compiled information to the cloud. The information received in the cloud is stored in a database. Each night the application will take the garbage bin information to build clusters of nearby bins that need to be picked up and build fuel efficient routes to pick up the clusters. This means that the garbage will be picked up when it needs to be as opposed to being on a fixed schedule. Our application will give users a better garbage collection experience, allow waste management to better allocate their limited resources, and be better for the environment.

1.3 Project Environment

Due to the large range of environments that smart garbage containers will be exposed in, the smart garbage containers will be expected to be water, dust, and temperature resistant. The IEC standard 60529, commonly known as the IP Code, will be used to standardize the weather rating of the enclosures. Since the product will be outside for potentially long durations, the smart garbage container will be designed with an IP66 rating. Besides water and dust resistant, the container will also be designed to withstand other environmental threats like vibration, shock, and salt-water. For maximum weather protection, the possibility of potting the electronics in a non-conductive epoxy will be explored.

1.4 Intended Users and Intended Uses

- Residents using municipal garbage collection
- Municipal garbage collectors

1.5 Assumptions and Limitations

Assumptions

- The trash can be measured in a way that creates useful data
- The data that is gathered is wanted by our target audience
- Garbage companies want to minimize distances of routes and the efficiencies

Limitations

- Size - must be mounted in/around garbage can and not interfere with capacity of can or any automated pickup that may be in use.
- Power - garbage can will be battery powered so power will be limited between charges
- Range of communication - Low power wireless communications are inherently range limited and could be lost if device is too isolated
- Half duplex communication for LPWANs
- Cost - The device will be unattractive to consumers if it is too costly.
- Scale

1.6 Expected End Product and Other Deliverables

- Hardware will include a trash monitoring device that uses an ultrasonic range sensor and a load cell sensor to determine the height and weight of waste in the trash can. A GPS sensor will also be able to accurately determine the location of the trash can. Our initial sensor will serve as a proof of concept, which will influence a second iteration with streamlined components and a rugged design that is capable of withstanding the elements reliably.
- The backend of the app will perform two major functions, clustering and route building. Clustering will be performed daily, creating clusters of garbage cans that are bounded by

a minimum and maximum volume/weight and a maximum area. The idea behind this is that there is a minimum amount of trash that any less trash isn't worth sending a truck to collect it and a maximum amount of trash such that one truck would be unable to pick it all up. The maximum area would refer to the point where it is no longer fuel efficient for one truck to cover that area. The deliverable of the backend is the route, which is built from that cluster. The plan is to use a TSP Heuristic to build an efficient route to reach every point in the cluster where efficiency is defined as using less fuel than the mean of a set of current garbage routes.

- The mobile application will provide an interface for our system. It will allow Residents to communicate with our System about their garbage collection needs. It will also enable Collectors to complete more effective collections.

2. PROPOSED APPROACH AND STATEMENT OF WORK

2.1 Objective of the Task

A complete system for facilitating the tracking and collection of garbage.

2.2 Functional Requirements

- Must determine approximate trash level in can
- Must communicate without error
- Must create efficient routes that fill trucks to certain fullness level without overfilling

2.3 Constraints Considerations

- Trash can power usage - The device must be able to run without charging or battery changes for long periods of time (years?) (Could also use timeline of weeks with inductive or solar charging)
- Cost - The price of the final prototype should not exceed 50% of the cost of the Trash Bin
- Standards to be used
    - MQTT - ISO/IEC PRF 20922
        - ISO/IEC 20922:2016 is a Client Server publish/subscribe messaging transport protocol.
        - We will use MQTT to facilitate communication between our bins and the Amazon MQTT broker.

- IEC standard 60529 Ingress Protection. The device enclosure will conform to IP rating 66.
  - Must be dust proof
  - Must not be damaged by spraying water from a 12.5mm nozzle from any direction

2.4 Previous Work and Literature

"'Hey #311, come clean my street!' A Spatio-temporal Sentiment Analysis of Twitter Data and 311 Civil Complaints"

This paper examines usage of geo-tagged tweets in order to find locational sentimental patterns. Tweets mentioning 311 civil garbage pickup service are scraped and analyzed using pre-existing sentiment analysis techniques. The tweets are classified by positive and negative connotations and mapped to the geographic position of where the tweet was posted. Analysis is performed to find "Locational Sentiment" and related patterns.

"The Optimal Sequenced Route Query"

This paper explores an algorithm for solving optimal sequenced route queries. OSR queries are a specific version of the nearest neighbor problem in which you find the minimum length route to visit a sequence of typed locations. The paper proposes a lightweight, iterative algorithm, R-LORD that which uses thresholds to prune routes that are obviously not part of the minimum length routes. This gives it a large performance boost over Dijkstra's algorithm for this type of query

"Minimum Spanning Tree Based Clustering Algorithms"

This paper explains the design and usage of the k-spanning tree graph clustering algorithm. The k-spanning tree algorithm is largely beneficial to our project because if you use proper scoring it should be possible to use the generated spanning trees as the routes, effectively clustering and routing in one step. The downside to the k-spanning tree algorithm is that it it builds clusters by removing low scoring edges, and it is likely for our project that low scoring edges will be clustered together, so we need to make modifications in order to handle long stretches of unnecessary pickups.

"IoT Based Smart Garbage and Waste Collection Bin"

The idea of designing a smart garbage container that can sense the weight and height of garbage has already been specified by several papers and companies. For example, in this paper researchers outlined a smart garbage bin that detects approximate level of trash in container in addition to height. The garbage bin described in the paper is for a public garbage can, where ours will be for residential garbage containers. This gives our sensor more flexibility where we can expect a lid to be closed most of the time. This allows us to use an ultrasonic sensor instead of infrared sensors for increased granularity of height measurements. We also propose moving to a LPWAN connection instead of WiFi for added security and less networking issues on our end. Using a WiFi connection would create an issue where each garbage bin would need to be inside of a network. Using the resident's WiFi network could create network vulnerabilities for both the resident and garbage sensor. Moving the garbage sensor to it's own private network or cellular network would decrease the number of vulnerable areas in the network and also not create an issue if a resident does not have a WiFi network.

2.5 Proposed Design

2.5.1 Hardware Design

The garbage sensor will be designed to be a retrofittable package that can be attached to a standard 90 gallon wheeled garbage container currently in use by waste management companies. The goal is to design the device to be installed in a short period of time to allow a small team to travel along the route, installing the devices. There will be an additional component, which is the load cell sensor. This will be mounted on the bottom of the container to approximate the weight of the trash in the container.

There are four main sensors for the hardware; the height sensor, the weight sensor, the lid detection sensor, and the location sensor. The weight sensor was previously stated above and will be connected to the microcontroller via an analog signal that will be converted to a digital value using the microcontroller's built-in ADC. Initial testing shows that the output from the load cell is very noisy, so some testing may be conducted to determine if a low pass filter will lower the noise of the cell to get a better read value. The height sensor will consist of an ultrasonic range finder. Testing showed that the range value returned by the ultrasonic sensor measured a much wider area than an infrared proximity sensor. This will be good since the surface of the garbage will not be uniform and the maximum height will be the most important to measure. Our initial testing was conducted with a cheap hobbyist rangefinder that would return a high digital value equal to the time it took for the ultrasonic pulse to travel from and back to the module. More durable ultrasonic sensors that would be considered for use in our final prototype tend to use an SPI or I2C communication protocol, which our microcontroller will need to support. The lid detection will consist of an accelerometer contained in the sensor package. We considered using some type of switch or a reed sensor with a magnet on the other side of the lid for a mechanical means of lid movement detection, but we decided that it would be hard to easily retrofit a garbage can with one of these technologies. Instead we found that there are accelerometers on the market that have a “wake on shake” feature that consumes little current while the device is at rest. If the accelerometer detects acceleration beyond a set value, a pin is set to high, which would be used to wake the entire sensor package. The accelerometer could also be used to determine the angle that the lid is at, determining if the lid is opened or closed. Finally the location sensor will be a GPS modem to track the location of the garbage container. This will mainly be to ensure that the garbage container is located at its intended position and for tracking if the module is stolen. Another possible feature would be to ensure if the garbage container is left on the curb the night before it is supposed to be emptied by the waste management service. Failure to leave the garbage container on the curb could be used to send a push notification to the resident reminding them to move their garbage container. Communication between the GPS module and microcontroller will most likely be via serial AT commands based on the products currently on the market.

As mentioned above, a microcontroller will be used to interface with each of the sensors. We currently are developing with the Pycom FiPy, but plan to switch to a much simpler and cheaper development board as we move forward. At the time of ordering the FiPy we were unsure of what wireless technology we wanted to use. Mesh networking was considered using a LPWAN technology, but because we felt that dense clustering may not be guaranteed, we should use a cellular connection, which will be discussed below. The microcontroller we decide to end up using must have one ADC and support SPI, I2C, & Serial communications for each of the sensors mentioned above. Also, since we plan to use end-to-end encryption between the garbage sensors and the cloud, cryptographic hardware acceleration would be a plus, which is why we initially went with the FiPy which uses an ESP32 chipset which supports hardware acceleration.

The microcontroller will connect to the cloud using an LTE Cat M1 modem. We chose this technology because of the half-duplex narrow band protocol is low power with long range and high building penetration. This will ensure that the devices are always able to connect to the cloud and also will not drain their battery while communicating. Mesh networking would cause issues where devices would always need to be somewhat active to act as repeaters in the network. With an LTE Cat M1 connection the device will only need to be powered on when garbage is placed in the can to remeasure the height, weight, and location of the garbage.

Finally we will need to design power circuitry that will be capable of keeping the device on for an extended period of time. Since garbage cans are typically unpowered, residents will not be used to charging their garbage cans. For this reason we want to design a non-invasive means of charging the device. We are currently split between two different ways of charging, induction and solar. Inductive charging would be performed by a mat that is connected to an electrical socket. This mat would sit in the garage where the garbage bin normally sits. One extra benefit we considered is that the load cell could be set in this charging mat, eliminating the need for the sensor to be attached to the bottom of the garbage container. The mat would then communicate with the device via bluetooth or some other wireless technology. The only downside is that additional wireless communication could potentially decrease the security of the system, increasing the need to fully protect the sensor. The second option would be for the garbage container to use a solar cell on the top of the sensor package to recharge the batteries in the sensor package. This would be the most simple for the resident, where very little to no interaction is needed to charge the container. If we decided to use a solar panel, we would need to do extensive testing to ensure that our solar panel and battery would be able to keep the device always powered on. We assume that the garbage bin will be left out during the day after it is collected in the early morning. The sensor could charge during this time until the resident returns home and places the garbage bin inside. This means that the garbage container could get less than a day's worth of solar charging every week, which could be prolonged even longer if the sun is blocked by unsatisfactory weather. For this reason we would want our sensor package to be able to stay powered on for a month with only 4 hours of peak solar output. One other potential solution would be to send a push notification to the user asking them to place the garbage can outside if the sensor's batteries are low and the weather is ideal for charging.

With all of these technologies described, we think we can build a sensor package that would support the data needs of the cloud while minimizing interaction with the resident and also minimizing installation requirements for waste management companies. A figure showing the components connected together is shown on the next page. Also included is a state diagram showing the intended behavior of our garbage bin sensor.

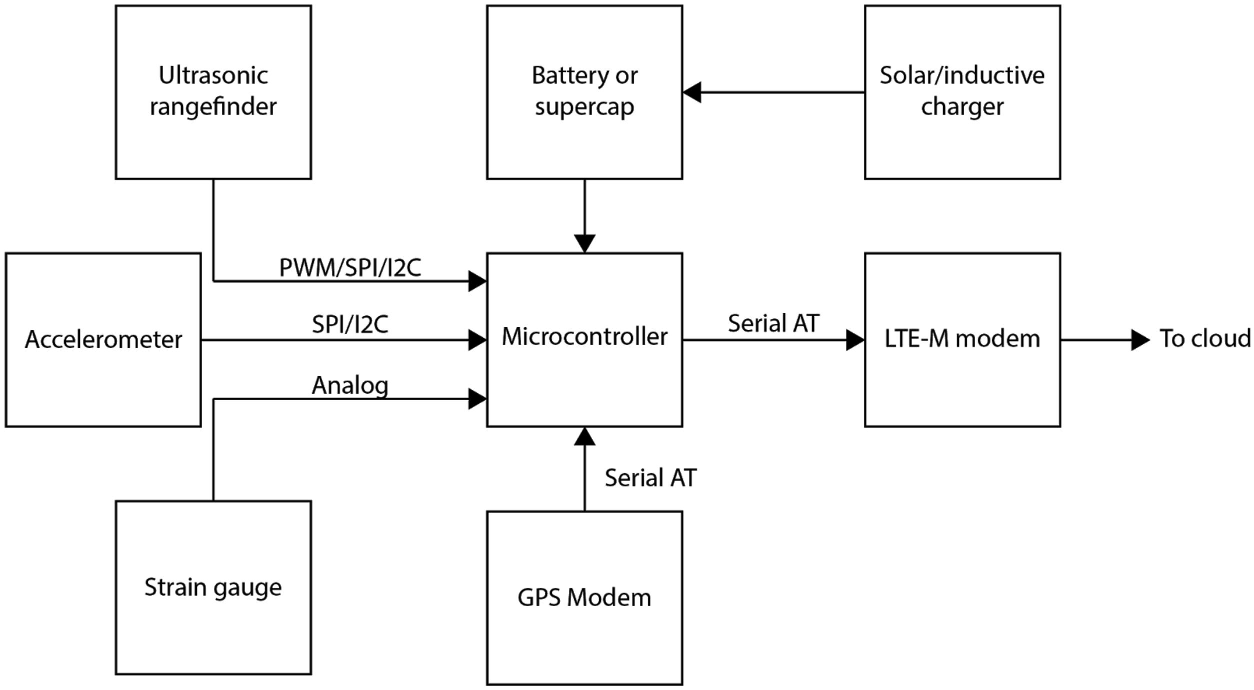


Figure 3: Hardware diagram

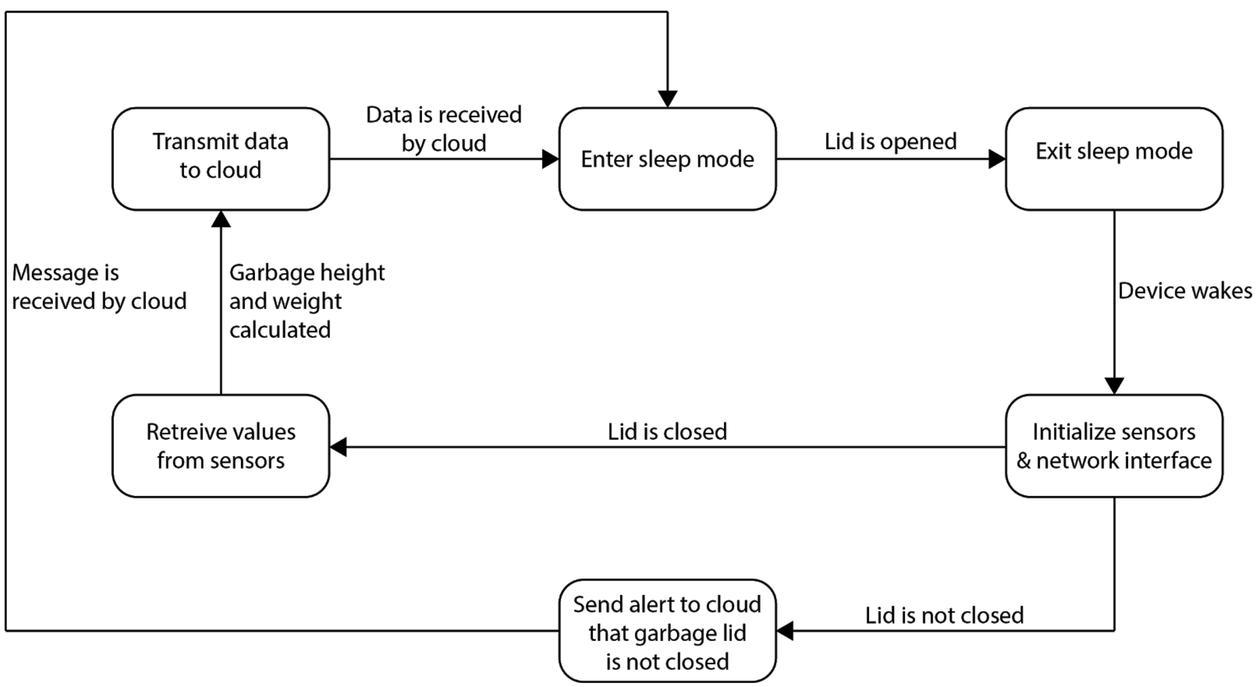


Figure 4: Hardware state diagram

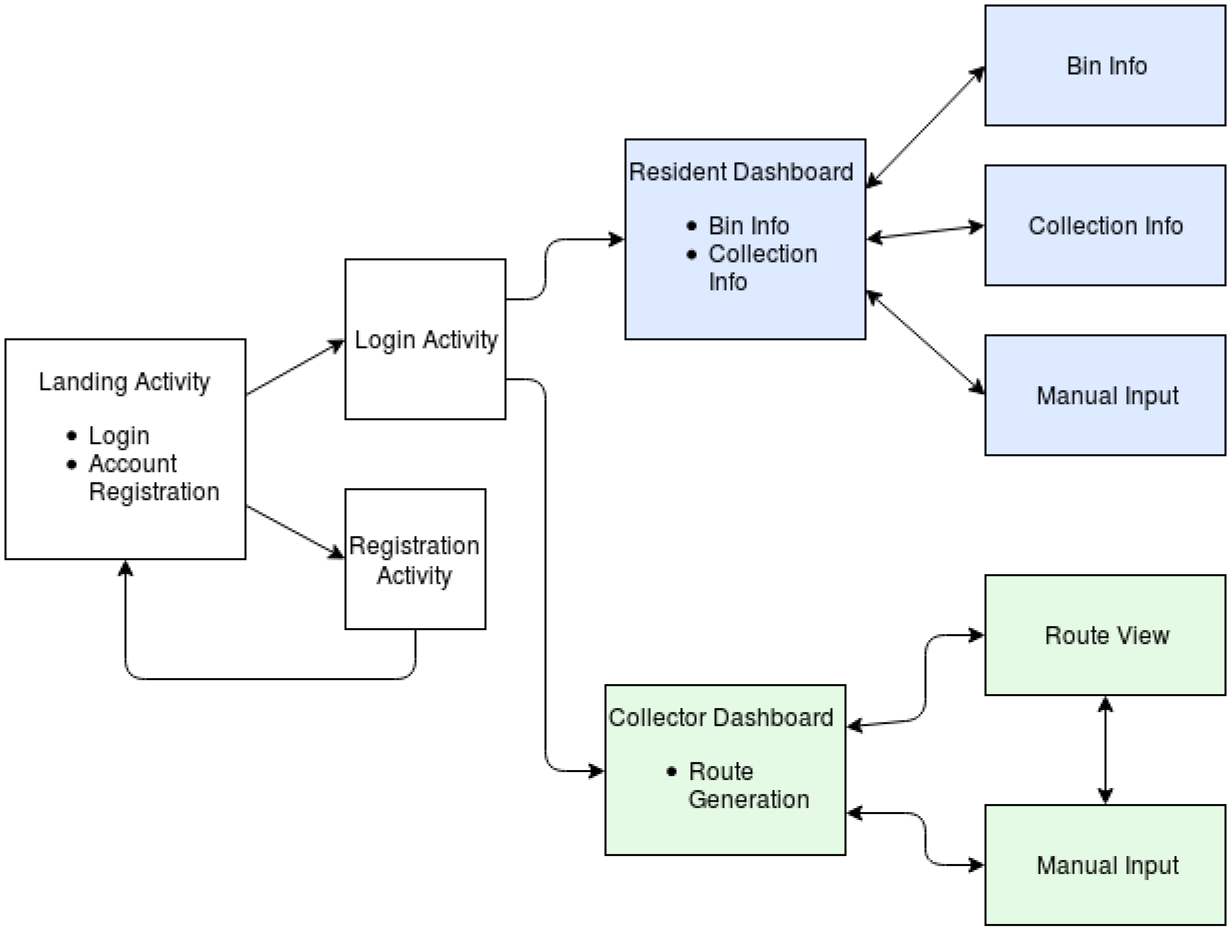


Fig 2. Activity Navigation of the mobile app.

2.6 Technology Considerations

- LP WANs
- Microcontroller
- MQTT - ISO/IEC PRF 20922
- IR Proximity Sensing
    - Easy to use analog sensor that uses reflected Infrared Light to determine distance
    - Sensitive to differing reflectivity of garbage
- Ultrasonic Distance Sensing
    - Sensor that transmits an ultrasonic pulse and measures the time it takes to reflect off of an object and return.
    - Sensitivity

- Pressure Plate Sensing
    - Uses a load cell sensor to measure weight based on the deflection on the plate.
    - Sensitive to placement and
- Android Operating System Support
    - The features and technological restrictions available to our mobile app are dependent upon the lowest version of Android we choose to support. We will be developing for Android 4.0.3, which will allow us to support 100% of our target devices.

2.7 Safety Considerations

- Data privacy - Resident information should only be accessible by Residents and Admins
- Hardware Protection - Garbage can is protected against tampering of electronics
- Network privacy - Communication is protected against eavesdropping

2.8 Task Approach

- Hardware Roadmap
- Hardware
    - Sensor testing
    - Sensor integration and software development
    - Circuit design
    - PCB design and printing
    - Final prototype testing

2.9 Possible Risks and Risk Management

- Data leak
- Trash can sensors broken
- Power loss on dead battery or
- Missed garbage pick-ups

2.10 Project Proposed Milestones and Evaluation Criteria

Hardware

- Successful Individual sensor tests
- Successful Integrated sensor test
- Successful communication test

Software

- Communication between app and database
- Functioning Homeowner app
- Successful Clustering tests
- Functioning waste management app
- Full stack integration test

2.11 Project Tracking Procedures

- Using GitLab Issues will provide the team with an exceptional
- Weekly meetings

2.12 Expected Results and Variation

Our desired outcome is a garbage-monitoring app that keeps track of trash levels and builds routes for pickups. We will also create robust, production ready hardware that can be integrated into an existing trash receptacle. We will ensure our full system solution works by developing robust tests simulating a wide range of use cases.

2.13 Test Plan

Hardware Testing

The hardware will consist of a device mounted to the lid of a standard residential style garbage can that will be able to detect the distance to the bottom of the can by some sensing means that will be determined after testing a few candidate sensors. A weight sensor may also be attached to the bottom of the can such that the weight of the trash can be used in decision making. These sensors will be connected to a microprocessor with radio peripherals that will be able to transmit the state of the weight and height of garbage to our server side infrastructure.

Our hardware testing plan is as follows:

The sensor elements will be individually tested using calibrated laboratory equipment available in our labs to very their function, calibration and suitability. This tentatively includes tests for:

- Distance sensing using a LDPE and paper targets every 15 centimeters from 0 to 2 meters and measuring the sensor output using a multimeter.
- Weight sensing using known weights from every 5kg from 0 to 100 kg and measuring the sensor output using a multimeter

- Switch testing using an oscilloscope to verify

The energy harvesting and storage system will be tested using a dummy resistive load that will simulate approximate load of our actual system. This will generate storage capacity rating and approximate usable lifetime figures. The test will pass if it can retain more energy than required by our worst use case.

The remaining piece of the hardware to be tested is the microcontroller which in this case has numerous radio interfaces. LoRa, LTE-M, SigFox and WiFi. Not all of the capabilities of the radios may be tested individually due to lack of receivers to test them with and with the large expense in both time and equipment it would require to test them in a controlled manner. However these radios will be covered by integration testing and WiFi in particular will be exercised extensively during development.

We currently do not have any intention to do accelerated lifetime testing or combined environmental testing due to the proof of concept nature of this project. However we would advise that prior to a product being commercialized that these types of tests be performed

Software Testing

Backend: The backend testing will be focused on clustering and routing. Our clustering will be tested by comparisons to a yet to be set value representing the ratio of perimeter to the square root of the area. In an ideal situation our clusters would be perfect squares so the ratio of perimeter to square root of area would be 4, so we will likely be looking for a ratio of about 3 to determine a good clustering. Clusters will also be constrained by a maximum and minimum area and a maximum and minimum volume/weight. Routing will be tested by checking fuel consumption. The goal is to consume less fuel than current garbage routes so we will be testing our routes against a mean value for distance traveled and fuel consumption from a set of garbage routes. The routes will also be constrained by ensuring each point is hit, so we can use a graph traversal algorithm to guarantee that each node is hit.

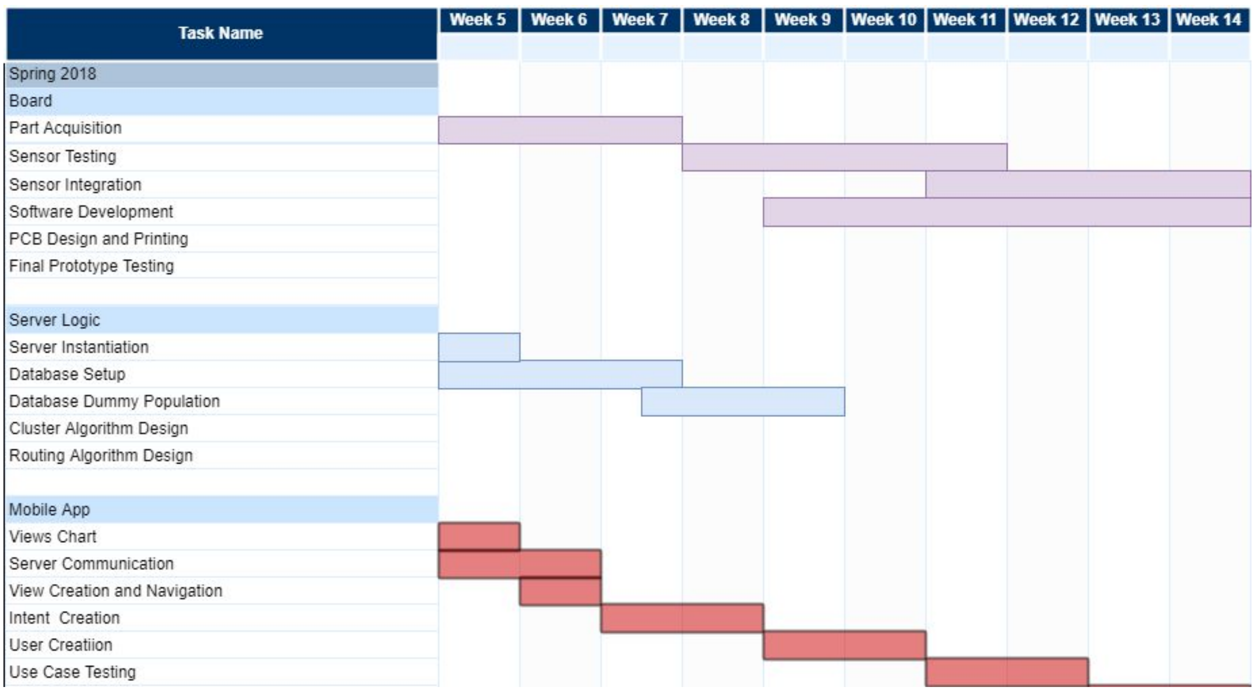
Frontend: The frontend testing will be focused on navigation standards, GUI being fluid on multiple devices, for both resident and collector, and meeting customer standards. Our navigation will be tested by showing that the navigation system is showing the correct points for the collector to follow and updating accordingly when the collector follows the given path. For the GUI tests we want to make sure that the specific user has to correct modal on their android devices. We also want to make sure that both a collector and resident can have the app open and have their specific views without interfering with one another. Finally, to test the customer standards we want to make sure that the GUI is up to their liking by possibly surveying and seeing that they do not want anything added to the app.

Small scale integration testing

3. PROJECT TIMELINE, ESTIMATED RESOURCES, AND CHALLENGES

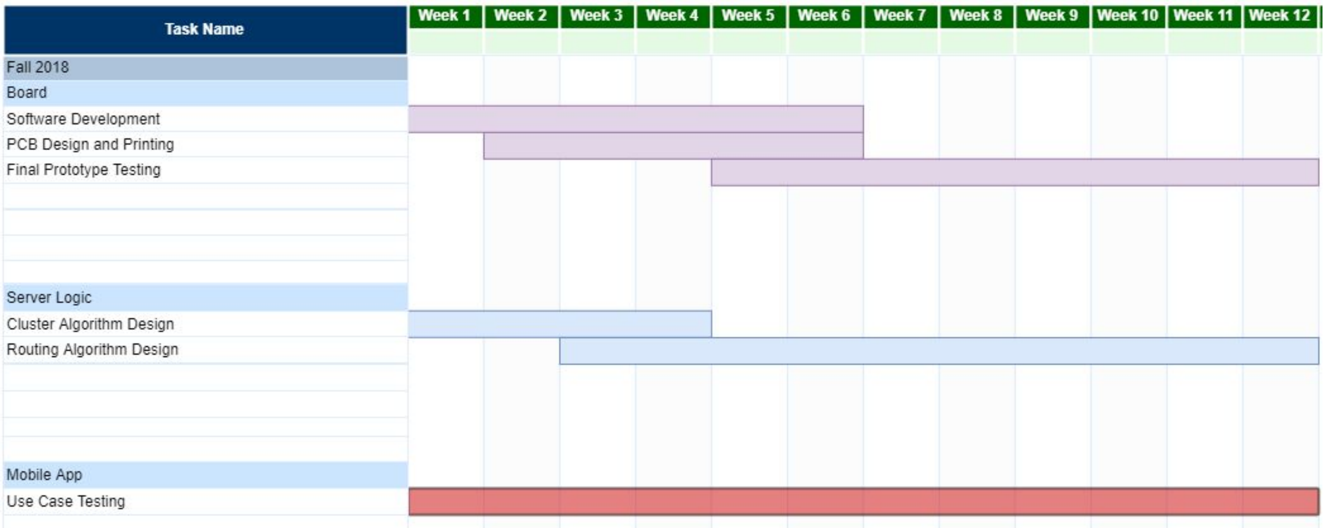
3.1 Project Timeline

Semester 1:



For this first semester we wanted to focus on preparing a solid prototype for the end of the semester. The hardware team focused on acquiring the sensors needed and testing those sensors to see if they would be adoquent for our design. After testing the sensors they went on to doing sensor integration with the trash can and integration with the AWS server. The software team focused on initializing the server, setting up the Database, and starting on the mobile app. The mobile app development included making the needed views, setting up server communication, and setting up the different users views within the app.

Semester 2:



Second semester will be finishing up our project in each area. For hardware we will be finishing up the developing the embedded code to have all of the parts work together. Then we will design our board and print it out. The last few weeks will be spent testing the prototype. The backend team will be finishing the development of the clustering and routing algorithms and then implementing them using OpenStreetMaps graphs. The mobile team will be spending most of the semester use case testing and expanding features as time allows. Finally all groups will come together for integration testing towards the end of the semester.

3.2 Feasibility Assessment

Cost and power constraints are the two main considerations to consider when determining if the garbage sensor package is feasible.

Due to the fact that LPWAN technology is still in its infancy, the cost of modems is still very high.

Because of the nature of our project being used by municipalities, its feasibility hinges on its ability for it to scale. Our clustering algorithm will need to be able to run efficiently on tens to hundreds of thousands of nodes for each municipality and still make high quality, efficient routes. This means that we will need to keep the complexity of our algorithm to a minimum. Our plan to handle that is to do clustering based on a minimum spanning tree, which we can use Kruskal's algorithm to complete in E log(E) time. That way, we can transfer computation cost to the municipalities themselves and know that our clustering and routing will remain efficient.

Consumer adoption is not within the scope of this project

3.3 Other Resource Requirements

AWS services, LTE-M network

3.4 Financial Requirements

Sensors & components, development board, PCB development, LTE-M subscription, AWS costs, Garbage Bins. See the Bill of Materials in the section 4.3.

4. CLOSURE MATERIALS

4.1 Conclusion

In an effort to reduce carbon emissions on the environment and create an efficient route for garbage clean up, this project will meet the criteria. Once the new optimized route is given by data collection from the residential areas trash cans, an algorithm will construct an efficient route for garbage collectors that will reduce their usual travel time. Through this optimization, the garbage trucks will be traveling less overall which will reduce the carbon emissions produced by these heavy vehicles and also save resources by not needing to burn excess fuel on inefficient routes.

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AWS IoT services

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4.3 Appendices

Bill of Materials