Recycle.io

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I. ABSTRACT

This project introduces an innovative IoT system aimed at reducing the amount of resources used by waste collection agencies in the U.S. The correct partitioning of garbage into bins at the earliest stages of the garbage disposal lifecycle can minimize man hours allocated to the separation of recyclables from non-recyclables (and organics from non-organics) at such facilities, eradicate the traditional garbage collection process and therefore optimize budgets used by relevant agencies on this matter. We specifically targeted solid waste and recycling agencies as an efficient solution to this problem would make an impact with enough magnitude to be replicated in IoT smart cities. Our system achieves this task by equipping cities' garbage bins with ultrasonic sensors, responsible for detecting garbage added to a bin in real time and a camera to take photos of items that do not belong in the recycling/organic bins, also in real time. We refer to such items as violations. In the subsequent sections, we will describe the system and provide you with a sound understanding of how our solution will yield the epitome of modern day IoT smart waste systems.

General Terms

Waste management, Violations, Internet of Things, Recycle.io.

Keywords

Garbage collection, IoT Smart City, Smart Recycling Bin, Smart Organic Bin.

II. INTRODUCTION

The Internet of Things is a computing paradigm in which objects are interconnected via the internet. With the ability to turn any object one wishes into an IoT device, virtually anything can be transformed into a smart device capable of collecting data used to derive analytics necessary to draw conclusions of a given context. With such advances in technology in most recent years, computer scientists and technology entrepreneurs around the globe have started reengineering life as we know it. This reinvention has sparked the rise of popular terms in the IoT world such as smart city, smart manufacturing, healthcare, retail, transportation and so on. The end goal, from a high level standpoint is to improve human knowledge to in turn make better business decisions, take preventive actions capable of saving lives, improve budget management and overall to make life easier, among other empowering aspects. Furthermore, the adoption of IoT technology in modern society has already proven to generate substantial revenues for relevant parties. As computer scientists with a keen interest in the IoT, we chose to provide a better solution to a sector of cities that is often overlooked. This sector is the solid waste management and recycling industry. This industry, although often oblivious to the public or unworthy of innovation, is an industry that generated 40 billion dollars in 2017, solely in the United States. Despite this impressive dollar amount, about 200 billion dollars are spent annually on waste management, also in the U.S. Part of the latter is spent by waste management agencies to acquire and maintain garbage trucks, pay staff, collect, partition and dispose of the collected garbage.

We propose a new system, Recycle.io, a smart waste collection system that enables waste management agencies to optimize their budget while providing society with a cleaner, more health friendly waste disposal mechanism. Our system comprises a set of smart recycling bins (SRB) and Smart Organic Bins (SOB) equipped with an edge device, an ultrasonic sensor and a camera. For the purpose of simplicity, we will refer to both type of bins as SRBs. Each SRB operates by being plugged in into a power source and frequently sending key statistics about its contents to an **Analytics unit**, which will be described in more details in subsequent sections of this paper. The SRBs, being edge devices, are able to choose, from the items inserted into them, which ones to send up to the **Analytics unit** for further processing. Each time an item is added to a SRB, the ultrasonic sensor detects it and a photo of it is automatically taken by a camera. The ultrasonic sensor allows Recycle.io to detect items as they are inserted into a bin, while the photos taken of the items are examined within the **Classifier unit** to determine whether or not they are fit to be labeled as cases of violations. A violation happens when a non-recyclable or a non-organic item is added to a SRB. Statistics of each respective bin are updated when a violation is detected. Those statistics include the location of the SRB, the date and time of the violation along with its photo. The optimal path to the bin is also viewable on our Recycle.io software. Upon return to the facility, the need for man hours dedicated to the partitioning of non-recyclables from recyclables (or non-organics from organics) would be minimized or deferred until further notice. This may seem like a minimal impact but the reality is that waste management agencies currently require staff to partition garbage upon arrival to their facilities. Adopting our solution would create a drastic reduction in resources spent by waste management agencies to organize garbage prior to disposal and recycling. On a long term perspective, agencies using our system would therefore see an increase in their revenues due to reduction of man-hours. In the following sections, the architecture of Recycle.io is examined, shortcomings of the system are discussed, and finally, additive features to future versions of Recycle.io are mentioned before drawing conclusions on the efficiency of our system.

III. SYSTEM ARCHITECTURE

The Recycle.io system comprises two main units: the Analytics and Classifier units. In the following subsections, we will provide you with a thorough description of the components of each unit, along with the relationship they have with each other. Figure 1 illustrates the architectural diagram of the system.

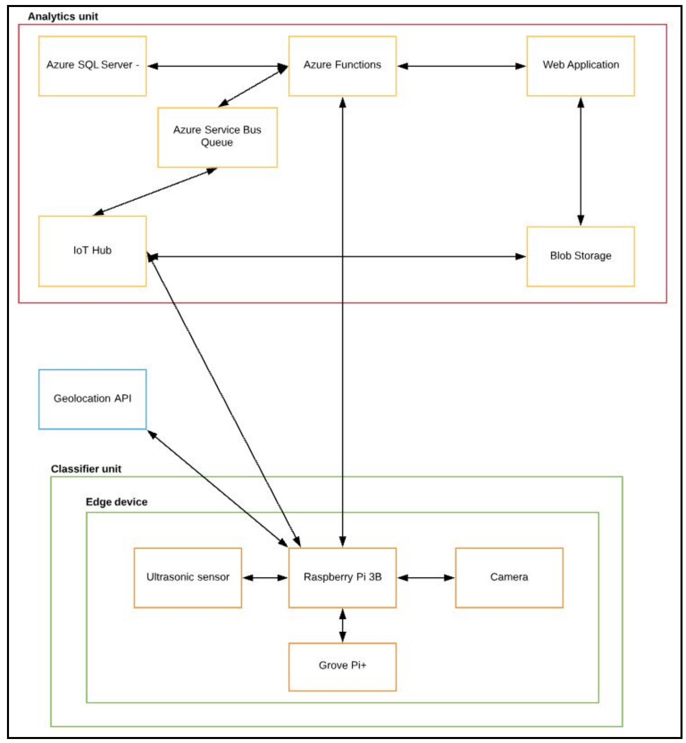

Figure 1. Recycle.io architectural diagram

A. Classifier unit

The Classifier unit is made of technology equipment required for the system to operate. That equipment consists of a Raspberry Pi 3B (the Edge unit), a Grove Pi+, an ultrasonic sensor and a camera. For the purpose of this project, imagine this set of equipment as the Smart Recycling Bin. They were in fact the source of the smart data processing made by our SRBs. Each time a SRB is newly installed, the bin's MAC address, location and type are stored in a database. We set up the system by placing the Edge unit at the inside top edge of a SRB in such a way that everything inserted in a bin would be scanned. The purpose of the ultrasonic sensor is to detect objects as they are inserted into a bin. Upon such detection, the camera automatically takes a photo of the item inserted for processing at the Edge. What that processing entails is simple but yet the most important feature of Recycle.io. The item's image is compared against a trained model deployed on the Edge device. We identify images of that model as violations. The Machine Learning model is trained on cardboard, CFL, egg shell, plastic bags, styrofoam as the classifiers. For the purpose of image classification which is the core of our system, we used Microsoft Custom Vision, an artificial intelligence tool which labels images according to a trained set. These were then used to classify violations in the actual test images. If no match is made, the photo is discarded and the system resumes its idle stage until the next time an item is inserted into a SRB. If a match is made, informative data (image url, timestamp, bin id, type of violation) about the item are passed to the Analytics unit for cloud computation. With fault tolerance in consideration as we developed our system, we chose to replicate that informative data and store it into a SQL database via Azure Functions. The Blob Storage is used to store violation images into the cloud. From there, the image's URL is stored into the previously stated SQL database.

B. Analytics unit

The Analytics unit consists of cloud technology including Azure Functions, Azure SQL Server, Azure IoT Hub and a web application, which is the main user interface of the system.

Each time a violation is detected at the Edge, descriptive information about the violation is sent to the Analytics unit for computation intended at drawing visual representations of the contents of a bin. The first stage of the Analytics unit is data processing by Azure Functions. This is the serverless aspect of our project. The logic chosen at this stage mainly depends on the state of the SRB. It is the stage where violation data is routed to its next destination in the cloud. At that stage, key attributes of that violation (SRB id, location, type, url, etc.) are stored via Azure SQL Server. new SRBs may be configured and the web application may retrieve most recent updates about the states of SRBs. Which of the previously stated actions is taken depends on the state and statistics generated about each SRB. The most common event at this stage is the processing of violations freshly sent from the Classifier unit. The Recycle.io interface, which is a web application displays a city map with SRB icons where they are located, in real time. The location of each SRB is acquired not by a gps but by passing the MAC address of the Edge device to the Geolocation API. The Recycle.io web application is therefore the main tool used by the authorities of waste management agencies to view details about a SRB such as its content, images of violations and the bin's address/type. Lastly, we use Azure IoT hub for two purposes. The first is to control and maintain our SRBs, depending on the tasks at hand, it is efficient to upgrade and deploy new modules onto a SRB (Edge device). The second purpose of our use of Azure IoT hub is to facilitate interactions between Edge devices and the outside, referring to any tool of the system that may need to interact with the device. The following screenshots illustrate the main interface of Recycle.io as seen by authorities of waste management agencies. Figure 2 displays the system upon boot in the Seattle area. Icons representing the SRBs in that location are automatically shown. Hovering over a SRB icon will provide users with its status. That status comprises the bin's address along with its type (Figure 3). Advanced details of a SRB can be seen by clicking on the More Details button. Doing so will yield a pie chart representing the amount and type of violations present in a SRB.

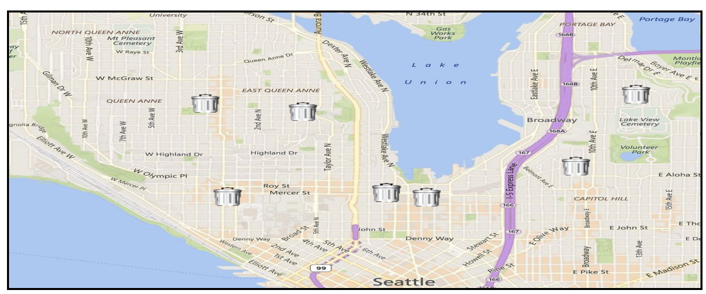

Figure 2. Web application interface.

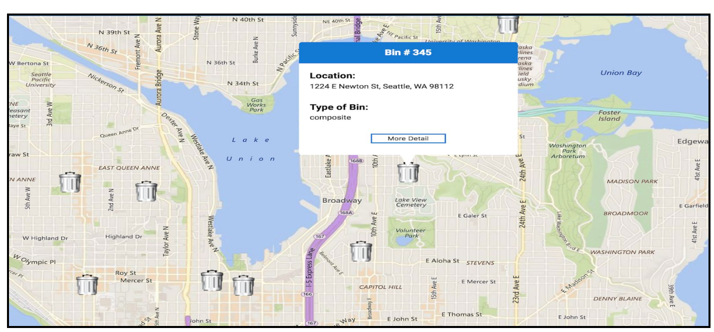

Figure 3. Status of a bin

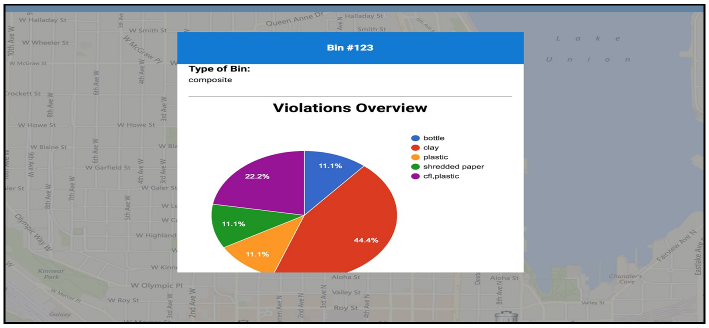

Figure 4. Advanced status of a bin

IV. RELATED WORKS

As we researched ideas for our project, we came across many valuable projects related to IoT waste management systems. They each aimed at lowering investment costs while maximizing revenues for smart cities. Some of those projects were intended at optimizing costs on a local, home to home standpoint, while others focused on the larger infrastructure aspect of waste management. Below are two of the projects that sparked our choice for Recycle.io. Access to their respective white papers is available in the REFERENCES section.

The first project is a RFID based smart garbage collection system for the Republic of Korea. The system is composed of a number of smart garbage bins (SGB), routers, and servers. Each Smart Garbage Bin, which plays a role in collecting food waste, is battery operated for mobility and depending on configurations set by residents, performs various techniques through wireless communication. Their model allows individual billing of citizens based on the weight of the materials they add to SGBs. Their SGBs would ideally replace all garbage bins of a town such that residents of that particular town would only be able to dispose of their garbage by scanning their personal RFID card to open the bin. This system removes the standard billing for waste collection in Korea. That standard billing causes businesses and homeowners to pay the same rate for their garbage disposal, a problem this team found to be unfair.

The second project we examined was an IoT garbage monitoring system. This system measures garbage level in real time and alerts the municipality whenever and wherever a bin is full, based on the types of garbage.

The system lets users being alerted of the level of garbage on four types of garbage: domestic waste, paper, glass and plastic. It also predicts when a bin will be filled based on its known rate of use. Their model focused more on keeping Smart Cities clean than creating a larger source of revenue.

V. FUTURE WORKS

In the future, we plan to enhance the usability of our system by adding the following features: weight, fill level, RFID access and dispatch. The weight feature will be straightforward as it will function in two formats. The first format would be to keep track of the overall weight of a SRB at any given time while the second format will exist in conjunction with the RFID access chip, which users of SRBs will be required to have in order to discard their trash. In a Smart City setting, advantages could be drawn from the use of such SRBs with RFID access chip given relevant proposals by our engineering team were approved by city councils. Such proposals could vary depending on certain factors but as examples, we may propose a pay-as-you-go model in which city SRB users only pay for the amount of trash they discard. This billing would be enforced by weight each time users' RFID chips are scanned to discard their garbage. Another example could be an incentive system in which users (homeowners, businesses) who discard their trash by taking it themselves to the Waste Management agency benefit of a discount on what they pay monthly after a set threshold is reached. Lastly, the dispatch feature would improve cleanliness of cities particularly at locations where major events are held. A dispatch alert would ideally be sent to waste management agencies as maximum fill level of a SRB nears. A garbage truck would therefore be dispatched to the said location for replacement of the public SRB. In such public settings, we may or may not use the RFID access feature previously mentioned. More research would need to be done by our engineers to determine the appropriate set of actions to take in this instance. This dispatch feature may prove to be an ideal solution to reduce liabilities currently faced by waste management agencies. The current dispatch system follows a standard route that is taken periodically. One of our arguments in this case would be that garbage bins along that route may not always be ready to be emptied each time a garbage truck is sent out. Adding fuel costs, driver wages and maintenance costs of garbage trucks to this equation may help us solidify our case. Overall, the future of Recycle.io would be to increase billing fairness for homeowners while reducing liabilities for all parties involved, in a Smart City context.

VI. CONCLUSION

In this paper, we introduced a new system, Recyle.io, capable of optimizing the staff headcount and maximizing revenues of waste management agencies by keeping track of the type of trash inserted into their garbage bins. Our system focused on detecting violations, which happen when a non-organic item is added to a Smart Organic Bin, or when a non-recyclable item is added to a Smart Recyclable Bin. Doing so defers or removes the need for such agencies to have a fixed number of employees to sort through garbage prior to disposal at their factory. We believe this approach is efficient in speeding up the garbage disposal lifecycle as authorities would know exactly what their bins contain and therefore take appropriate measures accordingly. Some of the limitations of our system were the size of the trained set and the system's likelihood to create false positives or false negatives. We only trained five types of violations (cardboard, CFL, egg shell, plastic bags and styrofoam). False positives could be detected in either case. A set of organic items disposed of in a plastic bag would cause a violation in Smart Organic bins while a small light bulb among organic items would not be detected when inserted into the same bin. The tests we ran showed our system's ability to correctly distinguish the types of violations inserted into our Smart Bins. It is therefore the responsibility of relevant authorities to take action by deciding when to partition garbage upon arrival to their facilities. With the scalability potential of Recycle.io, we believe it could be replicated across smart cities as the development of IoT Smart Cities progresses.

ACKNOWLEDGMENT

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