Recycle.io: An IoT-Enabled Framework for Urban Waste Management

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***Abstract*—Addressing environmentally safe management of waste is becoming increasingly a challenging task. The predicament of the rate at which waste is generated due to increasing populations is also contributing to this challenge. One possible approach for effectively handling waste can be achieved by source reduction and recycling. The problem, however, improving the collection of waste can be costly particularly during the source separation process after waste is collected. It would be desirable if there exists a mechanism that can help municipalities, local governments or waste management companies to monitor in real-time sources of violations prior to the waste collection process. In this paper, we introduce recycle.io, an Internet of Things (IoT)-enabled waste management system that is based on a serverless architecture that can identify these sources of violations. Using recycle.io, it is then possible to track the violations geographically which can help local governments, for example, to improve or enforce tighter regulations for waste disposal. Our recycle.io system uses Microsoft Azure IoT Hub for device management. Throughout the paper, we demonstrate usefulness of using our approach for urban waste management in smart cities.**

Keywords—IoT devices, IoT gateways, waste management, industrial internet of things, IIoT, garbage collection, smart bin, smart garbage, smart city

I. INTRODUCTION

Due to the rapid urbanization that has become evident in recent years, the demand for enforcing tighter regulations with respect to organic waste has become increasingly important. Recent statistics show that more than half of the world's population live in urban areas [1]. With the increasing number of megacities, urbanization, waste management, and the modernization of aging infrastructures are becoming major challenges involving social, technical and financial problems [2]. This prompted governments and industry organizations to investigate effective ways for maintaining a higher level of urban sustainability in an attempt to improve cost effectiveness and meet customers' demand [3].

In addition, preventing pollution which involves the reduction of acquired or disposed toxic and hazardous materials becomes another major challenge as a result of the impact of urbanization. Therefore, it is necessary to implement strategies for possibly reducing the acquisition of toxic materials [1]. The problem, however, is that the diversion of waste materials after it has been collected can become a very costly procedure. Furthermore, separating sources during the sorting and tracking substance diversion involve complex processes [4]. Therefore, it is essential that we need to explore effective strategies that can be cost effective at the early stages of waste collection and during resource recovery.

To address the above-mentioned challenges and issues, we introduce in this paper a smart waste management system that aims to discover waste disposal patterns at early stages prior to waste collection. Our system, which we call recycle.io, is an Internet of Things (IoT)-enabled approach that is capable of detecting items or materials at the time of disposal. This can help, for example, in discovering disposal behavior for waste management systems. Through the discovery of violations of disposed items or material in a real-time manner, it is then possible to build an advanced decision support system (DSS) for efficient smart city waste management.

In the proposed approach, we attach cameras to waste and recycle bins that capture images of disposed items or material. These cameras are connected to edge devices that are capable of processing images locally at the edge of a network and determine any violations at the time of disposal. The data is then sent via the cloud for further monitoring and analysis. Through recycle.io, it is then possible to improve the source separation process of hazardous wastes at early stages and reduce the costs associated with sorting and substance diversion.

In addition, recycle.io consists of smart bins that are equipped with sensors that detect the level of waste in real time. Determining the filling level for each bin in real-time can help waste management systems to effectively schedule and optimize the routing required for waste collection. Through the real-time analysis of violations along with the collection of contextual data (e.g. geographical location) of each bin, it is then possible to detect the rates of these violations based on city quadrants (e.g. Cartesian-coordinate-based addressing) or a grid plan.

The rest of this paper is organized as follows. Section II describes the overall architecture and implementation of our proposed system, recycle.io. Section II also discusses the usefulness of our approach in urban waste management. Finally, Section III provides the conclusion and future work.

II. RECYCLE.IO ARCHITECTURE

Traditional waste management models consist of mainly three layers: (a) a physical infrastructure, (b) a hardware layer and (3) a software analytics layer for advanced data processing as shown in Figure 1.

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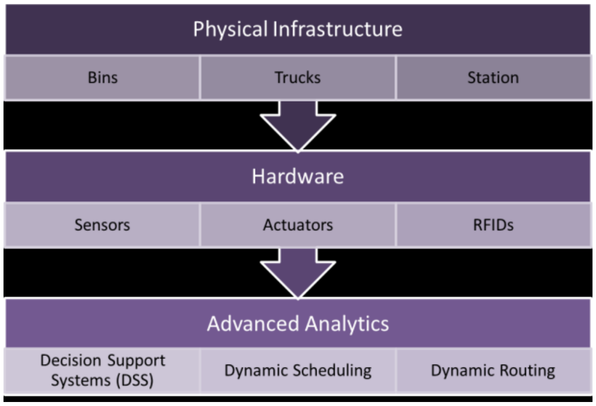

Fig. 1. Traditional Waste Management Model

The physical infrastructure consists of physical elements required for the collection of waste. This includes, for example, waste or recycle bins, delivery trucks responsible for collecting waste and a collection station. The technology platform provides the necessary hardware components that enable the physical infrastructure elements to be observed or controlled. This layer consists, for example, of sensors, actuators or RFID tags that can be attached to the physical infrastructure. It is noted that Figure 1 outlines only some of the possible elements in each layer. For example, a truck may be equipped with a GPS hardware that enables the vehicle tracking in real-time. However, the layers and examples shown in Figure 1 mainly focus on the elements that are needed or required for the implementation of our recycle.io system.

The software analytics layer provides logistics, remote monitoring and autonomous intelligence based on the data collected from the hardware elements in the technology platform layer. This layer continuously communicates with the hardware layer for the harvesting and collection of data. This software analytics layer can reside locally on the hardware platform (e.g. an edge computing model) or on the cloud (e.g. on Amazon Web Services, IBM Watson IoT Platform or Microsoft Azure IoT Hub). This software analytics layer can also integrate web services for further collaboration with other applications or businesses. For example, the data collected via the hardware layer can be processed using machine learning algorithms in which the outcomes can be used for decision making through the use of web services. Figure 2 shows the overall architectural layers of our recycle.io system that has been implemented using technologies specified in Figure 1.

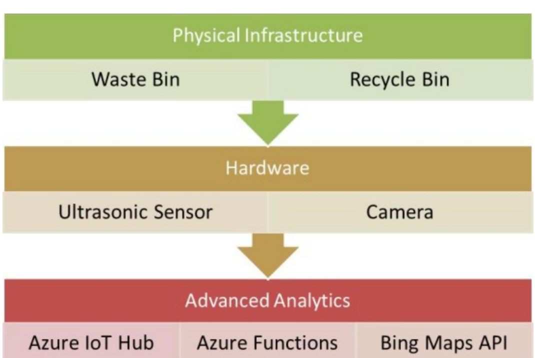

Fig. 2. Our Recycle.io System Model

Recycle.io is a smart waste management system that is composed of a physical infrastructure consisting of a number of smart recycling bins (SRB) and smart organic bins (SOB). Each of these bins is equipped with an edge computing device that connects the hardware components. For this purpose, recycle.io attaches a Raspberry Pi to each of these bins. Each edge device is equipped with an ultrasonic sensor and an infrared camera. The ultrasonic sensor is used to detect waste disposals. At the time of disposal detection, the ultrasonic sensor triggers the camera module to begin capturing images. These images are then processing locally on the edge device (i.e. Raspberry Pi) for violation detection. In case of a violation, a snapshot of the image is sent to our recycle.io IoT-based cloud platform.

Our recyle.io takes advantage of the edge computing paradigm in the sense that the computing power is distributed to the edge of the network [5]. That is, the computing device (Raspberry Pi) is placed at the network edge which is in proximity to the IoT devices (i.e. sensors and camera modules). This reduces significantly the network traffic required to transmit data. Through this technique, it is then possible to use the edge device to filter the data required for cloud transmission. This architecture helps in building a scalable IoT-based solution using serverless technologies. The edge device in this case can process the images captured by the camera module and make decisions at the edge of the network (i.e. detect violations in the case of recycle.io). When a violation is detected, the IoT edge device then sends to the Microsoft Azure IoT platform a snapshot of the violation and additional information such as the component causing the violation, the time stamp and location of the bin, among others. A deployment diagram of our recycle.io using the Microsoft Azure IoT Edge Runtime and IoT Hub is shown in Figure 3.

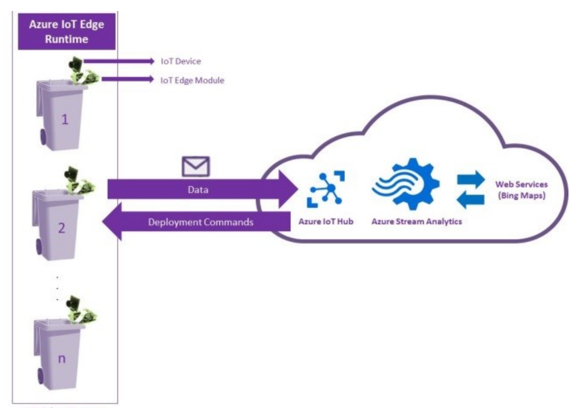

Fig. 3. Recycle.io Deployment Architecture using Microsoft Azure IoT Hub

The data collected by the smart bins' camera module and sensors is sent to an analytics unit. The analytics unit examines captured images of disposed substances and processes them to detect possible violations. For example, consider a public garbage bin in which a person disposes plastic containers. Our recycle.io is capable of detecting via the ultrasonic sensor whether an item is being disposed or not. Then, recycle.io uses the edge device to capture images and process them locally at the edge level (e.g. no cloud resources are used). Reycle.io determines whether a violation has occurred or not and then sends a summary of the results to a cloud-based application that provides a dashboard for monitoring these IoT smart bins continuously in a real-time manner.

The ultrasonic sensor enables recycle.io to detect items as they are being inserted into the bins. As images are being captured, a classifier unit attempts to determine whether or not the disposed item is considered to be a violation or not. A violation takes place when a non-recyclable item is added to a SRB. The edge device then updates the cloud-based application with a snapshot of the item being disposed as a proof of the violation. The recycle.io dashboard contains a map laying out all connected smart bins while it displays the data in real-time as shown in Figures 4, 5 and 6.

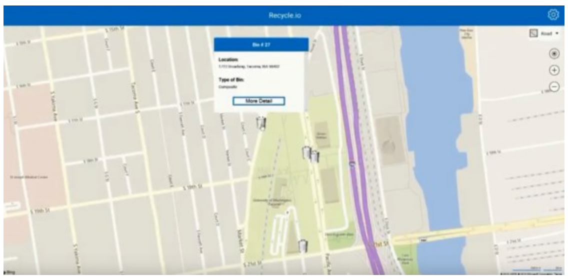

Fig. 4. Recycle.io Dashboard Displaying Map of Distributed IoT Edge Bins

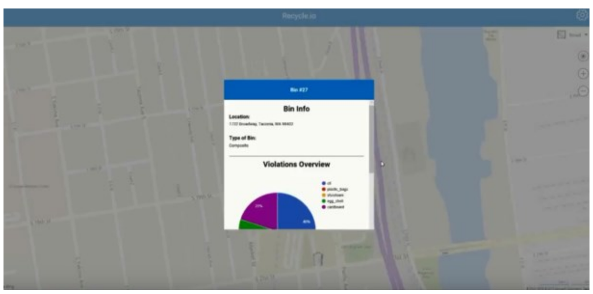

Fig. 5. Recycle.io Dashboard Displaying Violation Overview for Bin #27

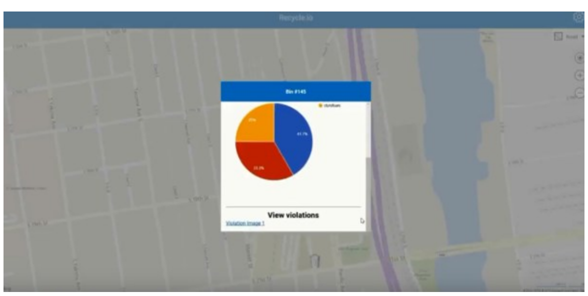

Fig. 6. Recycle.io: Violation Summary for Bin #145 with links to violation images captured on Microsoft Azure IoT Platform

Recycle.io uses Azure IoT Hub for controlling and maintaining our SRBs. Through Azure IoT Hub, it is possible to upgrade and deploy new modules on the IoT edge devices. Furthermore, we use this platform to facilitate the interactions between edge devices and the cloud particularly during the times of transmitting the summaries of the violations. The identification of images is achieved via the classifier unit in which a captured image is compared against a trained model deployed at the edge device. The machine learning model, for example, 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 recycle.io system, we integrated Microsoft's Custom Vision, an artificial intelligence tool that can label images based on a given trained set. Our recycle.io system replicates data and stores it into a SQL database via Azure Functions. The Blob storage is used to store captures of violations on the cloud. The first stage of the analytics unit is the processing of data by Azure Functions. This gives recycle.io a serverless aspect which improves the efficiency of our recycle.io system and provides a higher level of scalability [6]. Recycle.io was implemented and deployed in a real-time environment (at the University of Washington Tacoma campus).

Through this edge computing paradigm, nearly all of the processing is done on the edge device without any use of the cloud. Having these tools deployed at the edge of the network has a number of advantages including (a) reducing the network traffic since less data is being transmitted to the cloud, (b) enhance the real-time processing of the data being analyzed at the local device level (rather than sending it to the cloud which can be time consuming), (c) improve the performance of the recycle.io application (e.g. reduced latency), and (d) reduce costs associated with the operations of smart IoT edge devices.

III. Conclusion

In this paper, we presented an edge computing architecture for our recycle.io that is capable of detecting waste disposal violations in real-time. Recycle.io is a serverless IoT-enabled framework that can effectively be used to reduce costs associated with the diversion of waste materials. Throughout the paper, we presented the overall architecture of the recycyle.io and the edge computing capabilities. We believe that integrating edge computing capabilities into waste management strategies can help overcome the existing challenges associated with rapid urbanization and organic waste. Throughout the paper, we discussed the advantages of recycle.io and presented an overview of our recycle.io system. As future work, we plan to extend the edge computing capabilities of recycle.io to a wider network of distributed IoT edge devices and enhance the recycle.io's data analytics unit.

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