Prototype Development of IoT Based Smart Waste Management System for Smart City

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Abstract. The inefficient waste collection system has resulted in environmental pollution and large consumption of sources of energy. This is because of inefficient waste collection systems result in smell pollution, unpleasant views, breading of insects, animal scavengers and rodents which also giving rise to a range of diseases when some waste bins are left overloaded and uncollected. As one of the efforts to overcome the inefficiency of the waste collection system problem and to achieve smart cities, an IoT (Internet of Things) based smart bin prototype is proposed in this paper. Altogether, it is an automatic centralized monitoring system that provides the timely status of a bin, enables optimal route planning for collections, reduces collection times, and saves costs as well as fuel consumption.

1. Introduction
In Malaysia, around 38000 tons of waste is generated daily [1] and the number is increasing as the population growth is increasing. Improper waste management leads to an unhealthy environment and creates a threat to our lives. Therefore, a proper waste management system (WMS) is highly needed to achieve smart, green, healthier and sustainable environments and cities.

Traditionally, in Malaysia, waste bins are emptied at certain intervals by the responsible stakeholder and sometimes the waste collection processes are not well scheduled. This causes some drawbacks where some waste bins fill up much faster than the rate of emptying and they are full before the next collection. This problem has consequences where the waste is overflowing and poses an unpleasant view and odor, and hygiene as well as health risks. The impacts of the waste in our lives were described in detail in [2]. There are some special periods such as festivals when the waste bins fill up very quickly and some are not at other places. This situation is a challenge for the stakeholder to maintain a clean city [3]. This inefficient waste collection system problem does not occur only in Malaysia but also for most of the countries in the world. India has become one of the countries that are popular with the smart waste bin project due to their large population of citizens and it is obvious that the more the people, the more the waste produced.

In this paper, to solve the inefficiency of the waste collection system problem, a smart bin sensor is introduced with the amalgamation of IoT. The primary goal of this project is to develop a smart waste

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monitoring and collection system which will serve as a communication platform among the entities involved in managing the system. This automated smart bin provides its timely status by enabling optimal route planning for collections. This reduces collection times, skips additional costs as well as the fuel consumption of the stakeholders who are involved in waste collection. The cycle of the smart bin sensor system will start from the monitoring of waste in a waste bin so that the waste would be emptied before they are overloaded. The collection of waste from those waste bins that are almost full would be prioritized and that the waste collection schedule can be customized accordingly. For the collection process, the system manages on optimizing the route to the waste bins that need to be emptied which would save time and reduces fuel consumption. A wireless sensor is installed at the top of the bin for the monitoring process, under the lid and consists of Wi-Fi module which is used to send data collected from the waste bin to the next online system application using Global Positioning System (GPS) technology. The project prototype is implemented at the Faculty of Computer Science and Information Technology (FCSIT), University of Malaya (UM), Kuala Lumpur, Malaysia.

2. Related works
In recent years, many works were done in the field of WMS. A project report was submitted to propose the waste bins to be equipped with a system of transmission of information through the short message (SMS) which will provide information orders to the responsible stakeholder to collect waste bins that are already full [4]. The project targeted supermarkets or shopping complexes to implement the smart waste bins which commonly have the problem of overflowing waste bins that are not managed well due to the rapidly filled up of waste in their waste bins from the visitors. A waste bin is equipped with a sensor placed on the front of the waste bin that can detect if there is an object approaching within 3 feet from it and the lid of the waste bin will automatically open. The devices on the waste bin that are full will not work until a reset button on each waste bin is pressed after it is emptied.

In [5], the authors highlighted the problems encountered by most of the people living in Malaysia, particularly those who live in apartments, flats or condominiums with a limited number of waste bins and need to share these among all residents. The project is the development of a smart garbage monitoring system that measures waste level in the waste bin in real-time and to alert the waste collection authority via SMS. Longhi et al. [6] proposed a garbage bins monitoring process using wireless sensor networks (WSN). The data obtained from the sensors are delivered to a supervisor system which is used to make the decision to solve some WMS problems such as resource (trucks, people and other devices) optimization with cost reduction.

Another IoT based smart WMS was designed in [7]. They used NodeMCU (the web-based IoT solution) and an ultrasonic sensor to create a wireless prototype device for real-time monitoring of the waste bin level. They also provided a route optimization solution by using Dijkstra’s algorithm. For the waste collection process, a smart WMS proposed in [8]. Their system continuously monitors the status of the bin from the control station via the Graphical User Interface. This facilitates the interaction between the users and the WMS. By using WSN, a system was designed to monitor the waste bin status in real-time in [9]. In [10], a municipal solid waste monitoring system was proposed by using distributed sensor technology and geographic information system (GIS). In their system, the status of the bins (waste weight and volume) are used for route optimization of garbage trucks.
3. System Design

The system architecture of this prototype consists of the sensor nodes, the gateways, the cloud platforms, and the mobile and web applications:

3.1 Sensor nodes

The sensor nodes are the smart bins equipped with the sensors, microcontrollers, GPS modules, and Wi-Fi modules.

3.2 Gateways

Gateways are the devices used to forward the data received from the sensor nodes which in this project, are the access points, to the higher network point via a wireless network connection.

3.3 Cloud Platforms

In this project, the cloud platforms that are going to be implemented are the webserver, the database server, and the Google Maps API. The server is used for the implementation of the web and mobile applications while the database server is used for data storage of the data received from the sensor nodes. The Google API is implemented in this project for the solution for route optimization.

3.4 Mobile and Web Applications

The mobile application in this project is used by the community of UM as the users and the employees that are going to pick up the waste from the refuse receptacle chambers in the UM. Whilst, the web application is used by the community of UM but, only limited to the platform for reporting, and the building managers and the employer of the waste collection service company are the persons who are going to fully utilize the web application for monitoring and analyzing purposes.

Figure 1 shows the design of the system used as the smart bin for waste management. For the monitoring purpose, a wireless sensor is set at the top of the bin and under the lid. The sensor consists of a Wi-Fi module to send data collected from the waste bin to the next online system application using GPS technology.

Figure 2 shows the reporting steps of the system. A user can scan QR code to access the login page,
then he/she would provide his name and contact information along with the feedback/report which is then sent to the building manager and to the waste collection authority. This reporting ensures the reliability and effectiveness of smart WMS. The building manager and the authority, later on, would analyze the report and the feedback provided by the user by login to the system.

4. Implementation

We have designed the bins with several types of sensors, microcontrollers and with other circuitries. The complete hardware list is provided in Table 1. For the data collection, management and data analytics, we have used Lora Server as a cloud server, IoT server and Web Application Server with ThingsBoard.

Figure 3 shows the hardware implementation of the smart bins in the lab while figure 4 shows the implementation of the smart bins in the bin house located in FCSIT, UM. Figure 5 shows different web interfaces that are used for different purposes of waste management such as data collection, devices’ location, and status, data analytics and so on.

| Table 1. Hardware component list |
|----------------------------------|
| **Component Name** | **Purposes/functions** |
| Arduino Uno | Microcontrollers |
| Raspberry Pi 3 | Microcontrollers |
| Cytron ARM Cortex M0 | Microcontrollers |
| Ultrasonic sensor HC-SR04 | To measure the level of the waste |
| Load Cell | To measure the weight of the waste |
| Ethernet Shield: HR911105A 17/20 | As communication module |
| Transmitter: Lora Shield | For wireless communication |
| Receiver: Lora Gateway | |

Figure 2. Smart Waste Management System (Reporting)
**Figure 3.** Lab-scale or for small bin implementation

**Figure 4.** Hardware implementation in a bin house

**Figure 5.** Web interface for the list of waste level sensors and dashboard of each waste level sensor
5. Results and Discussions

Through the IoT approach, mobile assets have been monitored by embedding GPS sensors on them. Figure 5 (shown above) shows the various sensors’ information with their id, real-time status (the level and weight of waste in bins) and other information via the web interface. In WMS, waste collection is one of the main roles. Knowing the garbage trucks’ location as well as the drivers’ location is very important for the efficient WMS. Our system results with the location of the trucks, drivers’ information, current waste level, and other necessary information. Figure 6(a) displays such information. Using this information, the job can be distributed to the drivers by the system accordingly without the hassle of contacting them for a status update.

Some routes might need a larger capacity truck compared to another route while another route might need a smaller truck. Otherwise, in some routes, trucks might be overloaded and cannot collect all the waste at a time and have to redo the route, while other routes, trucks might return with wastes less than half of the truck capacity. These situations could cause wastage of fuel and time. Therefore, for the proper waste collection, optimum route selection is very much important.

We have mapped our bins with the google map (Figure 6(b)) for the optimum route selection. By combining the status and the locations of the bins, garbage truck location, and the driver information, this optimum route has been selected. This saves unnecessary fuel consumption, time and the optimized usage of all the garbage trucks (wastes are properly distributed among the trucks).

![Image](image1.png)

**Figure 6.** The user interface for (a) Job Management and Truck & Driver status (b) the location of each device with their pop-out information
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6. Conclusion and future works

A proper waste management system (WMS) is highly necessary to attain a clean and green city. IoT and other technologies can be used to upgrade the current manual WMS into the smart WMS to achieve the smart city. This paper presents an IoT based smart WMS. Bins are equipped with IoT devices and sensors to monitor their status centrally and remotely. A web-based interface has been developed for proper management. Through this interface, the authority can monitor the status of the bins, locations of the garbage trucks and the drivers and can analyze the production rate of the waste. As future works, a route optimization algorithm will be developed to reduce waste collection time and fuel consumption. A mobile application will also be developed for real-time waste monitoring, notification and for the automatic drivers’ job assigning. Besides, other currently used sensors, air quality sensors will be used to detect various types of gas and the smell of the bins. The garbage truck will also be equipped with sensors and IoT devices. Machine learning will be used for making a reliable prediction of waste production. We expect the successful commercialization of this low-cost prototype to make the smart cities in Malaysia.

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