WasteBOT: Conceptual Design of Smart Bin and Web Service for IoT Waste Management System

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ABSTRACT

A green and clean environment has become one of the most concerning issues in our society, especially when environmental pollution cases are on the rise. Everyone wants to live in a clean environment to minimize the risk of getting any diseases because of the dirty environment. The initiative to have a better living environment for our future has to start within our community. Therefore, this paper introduces an Internet of Things (IoT) Waste Management System, WasteBOT with two easily attachable and detachable embedded sensing modules and a web service platform. The embedded sensing modules able to turn any wastebin into a smart wastebin with sensing capabilities to collect the bin status such as waste level and environmental data such as temperature. The conceptual hardware design of the embedded sensing modules is presented with a real prototype using microcontrollers and different sensors. The collected data will be upload to the server using Wi-Fi. The web service platform processes the collected data and provides monitoring and navigation services to different categories of users such as waste management companies and normal users. The WasteBOT system with the embedded sensing modules will help everyone to easily join in the effort to keep a clean environment in the society without the need to replace a conventional wastebin with a brand-new smart bin.

Keywords: internet of things, waste management, smart bin, embedded system, web service.

I INTRODUCTION

The waste management system is very important as it helps to create a healthy and clean environment. Malaysia's government implements the Reuse, Reduce, and Recycle (3R) campaign to manage waste many years ago ("Enforce Reduce, Reuse and Recycle Campaign," 2014). However, the existing system is lacking behind as the technology advanced. Common issues such as rubbish overflowing or wastebin vandalism still require manual reporting to get attention from the authorities for further action. The lack of information on the wastebin location also incurs inconveniences to the public. (Abdulla, Salleh, & Ismael, 2017; Zaipul & Ahmad, 2017). Many foreign countries have been using technologies in the Internet of Things (IoT) paradigm to improve their waste management system. Recently, some research efforts have been done in Malaysia in the interest of leveraging IoT technology in creating a better environment for sustainability. For example, Shamshiri, Gan, Baharin, & Azman (2019) introduced the electricity monitoring system using IoT-enabled devices, and Singh, Lim, & Manaf (2019) presented SAHOMASI that allow house appliances to communicate using a standardized protocol to provide a better home environment for the elderly. In terms of waste management, Kang, Kang, Ilankoon, & Chong (2020) proposed a reinvented smart e-waste collection box for household electronic waste with an Arduino board and ultrasonic sensor.

University Sains Malaysia (USM) practices sustainability policy aligns with the Sustainable Development Goals to create a healthy, clean, and green campus environment (Ilham, Zaihan, Hakimi, Ibrahim, & Shahrul, 2020). USM applies the 3R policies within the campus and promotes the idea to the neighboring communities (Norizan & Ridzlie, 2011). However, the current waste management system in the campus is lacking behind due to its inefficiency, and it is not environmentally friendly and user-friendly. The wastes on the campus are not being managed systematically whereas people on the campus face difficulties in finding available wastebin due to the lack of information on the wastebins location. Furthermore, the waste collector only collects waste at a certain schedule but some wastebin got overflows in a shorter timeframe. The motivation behind the idea to incorporate IoT into the conventional waste management system using IoT was conceived after a careful investigation of the existing systems and their problems. It is important to have a system that can manage the waste with minimal human intervention and keep track of the wastebins' status on the campus. Waste and environmental data will be collected to provide services for respective users. Thus, a sustainable campus towards a greener and cleaner environment can be created.

The paper presents an IoT waste management system, WasteBOT with easily attachable and detachable embedded sensing modules and a web service platform to create a better, green and healthy environment, not only on the campus but also applicable to the community. The outline of the paper is as the following. Section II briefly describes the existing related works applying IoT in the waste management system, while section III depicts the methodology of the WasteBOT system. The details on the hardware design of the embedded sensing modules are presented in Section IV and section V describes the software design for the sensing program and web service platform. The paper is concluded in section VI.

II RELATED WORK

A. Waste Management in Malaysia

The waste generated by Malaysians had become a great issue as it increased over the years. The deputy chief executive officer of Solid Waste Management and Public Cleansing Corporation (SWCorp), Dr. Mohd Pauze Mohamad Taha reported that the waste generated by Malaysians in 2018 was 38,142 tons per day and it had increased enormously compared to 2005 which was 19,000 tons per day. He added that 44.5% of the waste was food waste, 13.2% of it was plastic waste and the remaining were diapers made up 12.1%. According to Dr. Mohd Pauze, the recycling rate of waste was not satisfied as it was only 28%, they hope that in 2020 the rate will increase to 30% (Mei Mei, 2019). Although Malaysia practiced the 3Rs policy, the waste management system in Malaysia is still left behind compared to other modern countries. Malaysia does not have enough facilities and technologies to manage waste systematically. As a result, there was a lot of decomposed and non-decomposed waste such as plastic, glass, and aluminum were not managed properly and overloaded. These non-decomposed wastes can be harmful to the public and the environment without proper management as they are hazardous.

B. Waste Management and IoT

There is plenty of research on waste management in the literature. Most of them were focusing on manual waste collection, distribution, and recycling. Recently, people started to use technology in waste monitoring and collection. Table 1 shows some of the existing systems or research that incorporate IoT into waste management systems. The table focuses on the sensors and microcontrollers used in their system, and also the strengths and weakness of each existing system.

III METHODOLOGY

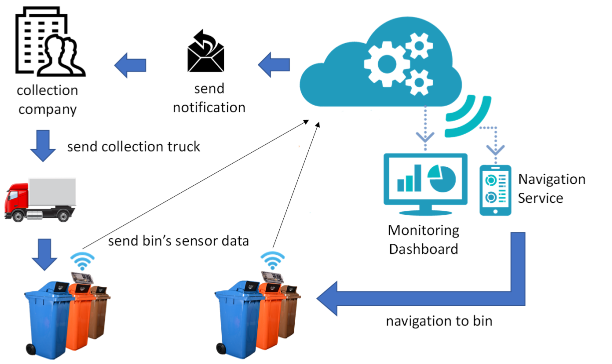


Figure 1. System Architecture of WasteBOT.

Table 1. Comparison of Existing Solutions.

Reference	Microcontroller/Sensor	Strength	Weakness
(Rupa, Kumari, Bhagchandani, & Mathur, 2018)	**ATMega 16/Ultrasonic sensor/SIM800 (GPRS/GSM) module** The ATMega 16 obtains the waste level and processes it before updating to the website via GPRS. It also uses GSM to send collection notification when the bin is full.	It helps improve the quality of the environment and is a step towards fulfilling the goal of a government initiative for environmental cleanliness.	Other users cannot use the system as it is built for the employees of Municipal Corporation (higher authority) but can be implemented for other users.
(Gutierrez, Jensen, Henius, & Riaz, 2015)	**Arduino Uno/ Ultrasonic sensor/CC3000 WiFi module** The microcontroller collects the waste level using an ultrasonic sensor and sends it to the server via the CC3000 WiFi module. Its future work is to forecast future waste levels for efficient collection using an intelligent solution.	The author presented the concept of using location intelligence to manage waste with simulation experiments.	It lacks actual implementation of the forecasting capability and the server only serves as a data sink from the bin.

(Amritkar, 2017)	**PIC controller/ Ultrasonic sensor/Radio Frequency Identification (RFID)/GSM and GPS** The controller scans the RFID tag attached to the waste and sends an instruction to the user via GSM to throw the rubbish into the correct wastebin. The ultrasound sensor measures the waste level and GPS retrieve the bin location.	This system intends to help the user to recognize the type of waste and throw them into the correct wastebin.	It is not feasible to associate each waste with an RFID tag. The implementation leads back to the design and the manufacturing of a product.

The WasteBOT system is mainly comprised of the conceptual design of embedded sensing modules in the wastebin and the web service that make use of the collected sensor data to generate useful output. Figure 1 shows the system architecture of the WasteBOT system. The wastebins equipped with WasteBOT hardware modules collect the status (e.g., the level and weight of waste) and environmental condition (e.g., temperature and humidity). The collected data are sent to the server over the air through WiFi. The authorities will be able to monitor the status of wastebin in real-time through the monitoring dashboard provided by the web service and trigger necessary action to notify the waste collection company to send collection trucks for waste collection. Furthermore, the web service enables mobile application users to locate the available wastebin nearby and navigate to the designated destination. The details of hardware design on the embedded sensing modules and software design on the web service are presented in sections IV and V respectively.

IV HARDWARE DESIGN

Figure 2. Design of Embedded Sensing Modules.

The conceptual hardware design of the WasteBOT system is comprised of two embedded sensing modules as shown in Figure 2. Each module is a hardware bundle embedded with a microcontroller and a few different sensors so that they can be installed easily on the top and bottom of the bin.

A. Embedded Sensing Modules (Top)

The first module is to be placed at the top of the bin facing down (e.g., underneath the lid) with the following sensors and their respective functionalities:

Ultrasonic sensor. The ultrasonic sensors are to detect the presence of waste by measuring the distance using ultrasonic waves. The distance between the ultrasonic sensor and the waste surface is measured to determine the availability of the bin (Fadel, 2017; Zhmud, Kondratiev, Kuznetsov, Trubin, & Dimitrov, 2018). The status of the bin will be marked as full in the web service when the measured distance is below a certain threshold such as 3 cm.

Temperature and humidity sensor. This sensor is to detect the environmental condition inside the wastebin and trigger an emergency notification if the temperature is higher than a certain threshold or the humidity is lower than a certain threshold. For example, a burning cigarette butt might cause a fire inside the bin and remedial can be taken in the shortest possible time frame.

PIR sensor. The PIR sensor is to detect the usage of wastebin whenever the wastebin's flip-door or lid is opened. The usage information is also useful for the authorities to assess the usability of the wastebin and perform bin relocation if necessary.

OV2640 camera. The camera module is to capture the image of the most recent waste and upload it to the server. Further processing can be done on the image such as waste object identification and trash classification, but it is not in the scope of the paper.

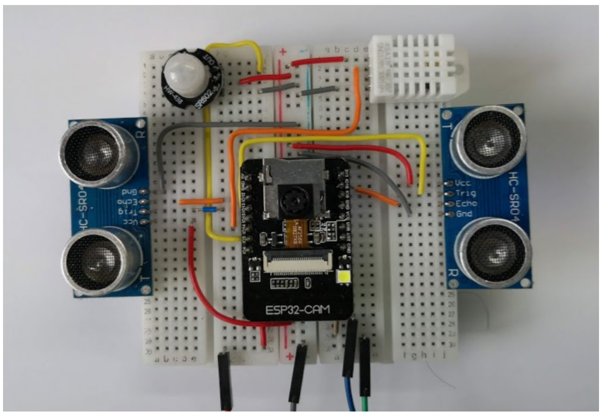


Figure 3. Embedded Sensing Module (Top).

The hardware prototype of the top embedded sensing module is shown in Figure 3 and Figure 4 illustrate the operation and workflow of the top module. The microcontroller is configured to enter deep sleep mode after all required actions upon every rubbish throwing event to conserve energy because the module is expected to be battery operated and long-lasting. Whenever the flip-door or lid cover is opened, the sensor detects the motion and sends a wake-up signal to the microcontroller. The microcontroller starts to measure trash level, temperature, and humidity, followed by camera module activation to capture the most recent trash in the wastebin. Next, the microcontroller connects to Wi-Fi and upload the data and image captured to the server for further action in the web service platform. The microcontroller will enter deep sleep mode again after completing the necessary action and wait for another occurrence of rubbish throwing event.

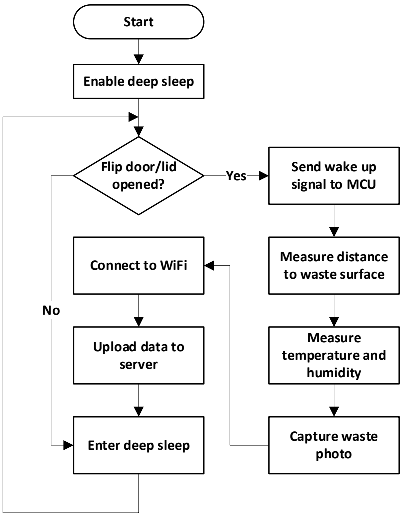


Figure 4. The Workflow of Embedded Sensing Module (Top).

B. Embedded Sensing Modules (Bottom)

The second module is placed at the bottom of the bin facing up with the following sensors and their respective functionalities:

Load cell. The load cell with HX711 analog-to-digital converter (ADC) is to measure the weight of waste that currently residing in the bin. It is important to monitor the weight of trash inside the bin especially the recycling bin for metal and glass because overweight wastebin might cause injury to waste collectors when they are clearing the bin.

GPS Module. The GPS module is to obtain the current latitude and longitude coordinates of the bin and keep track of the wastebin location.

Tilt Sensor. The tilt sensor is to detect if the wastebin remains upright. For example, a fallen wastebin required immediate attention to avoid wild animals searching for food and mess up the surrounding.

Vibration Sensor. The vibration sensor is to detect wastebin usage through vibration when the user opens the flip-door or lid cover. Besides that, continuous vibration could indicate that the bin is under vandalism when the bin is not upright as detected by the tilt sensor.

The hardware prototype of the bottom embedded sensing module is shown in Figure 5 and Figure 6 illustrates the operation and workflow of the bottom module. The microcontroller with deep sleep mode enabled will be wakened up once vibration is detected by the vibration sensor upon a rubbish throwing event. The module first detects if there is any continuous vibration that could result from on-going vandalism and triggers to send a notification to the authorities. When no continuous vibration is detected, it further checks if the wastebin is upright and sends a notification when the bin is fallen. When everything is normal, it will start weight measurement and retrieves GPS coordinate in latitude and longitude pairs. All the data will be uploaded to the server for further action in the web service platform.

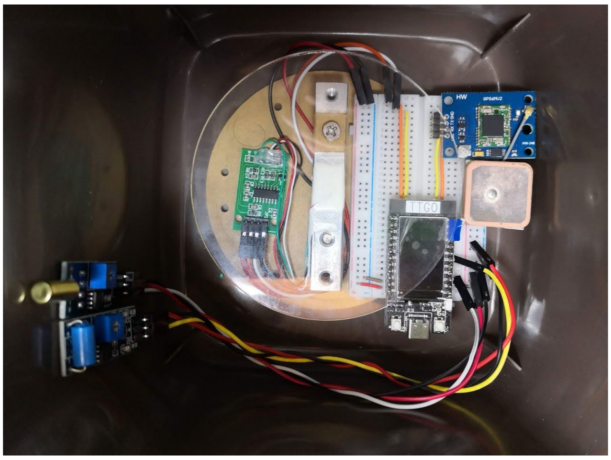


Figure 5. Embedded Sensing Module (Bottom).

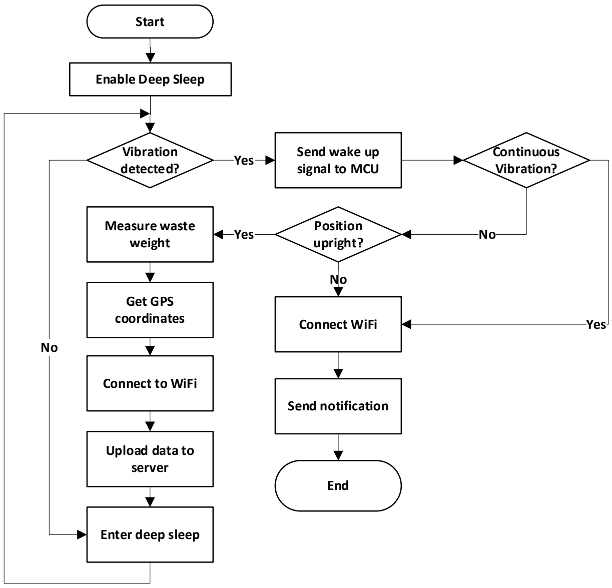


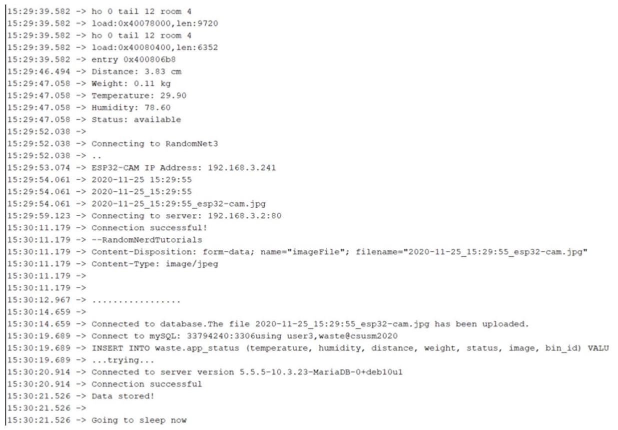
Figure 6. The workflow of Embedded Sensing Module (Bottom).

V SOFTWARE DESIGN

The conceptual software design for the WasteBOT system consists of the program to run the sensing modules and the web services for monitoring and navigation.

A. Programming Sensing Modules

The microcontrollers are programmed using Arduino programming with a wide variety of ready-to-use libraries. The program for the sensing modules, namely Arduino sketch is uploaded to the microcontrollers to perform their respective sensing functions. The microcontrollers collect the sensor data and pre-process them to become the input for the web service. For example, the ultrasonic sensor measures the distance to the trash surface and outputs analog signals to the analog input of the microcontroller. The microcontrollers have to convert the raw value into human understandable numbers such as centimeters. However, the actual distance is not critical to the web service since the user only needs to know which waste bin is available. Therefore, only one of the states (i.e., full or available) is sent to the server to determine the respective wastebin availability. Figure 7 shows an example of the debugging output of the Arduino sketch when running on the top embedded sensing module.



```
15:29:39.582 -> ho 0 tail 12 room 4
15:29:39.582 -> load:0x40078000,len:9720
15:29:39.582 -> ho 0 tail 12 room 4
15:29:39.582 -> load:0x40080400,len:6352
15:29:39.582 -> entry 0x400806b8
15:29:46.494 -> Distance: 3.83 cm
15:29:47.058 -> Weight: 0.11 kg
15:29:47.058 -> Temperature: 29.90
15:29:47.058 -> Humidity: 78.60
15:29:47.058 -> Status: available
15:29:52.038 ->
15:29:52.038 -> Connecting to RandomNet3
15:29:52.038 -> ..
15:29:53.074 -> ESP32-CAM IP Address: 192.168.3.241
15:29:54.061 -> 2020-11-25 15:29:55
15:29:54.061 -> 2020-11-25_15:29:55
15:29:54.061 -> 2020-11-25_15:29:55_esp32-cam.jpg
15:29:59.123 -> Connecting to server: 192.168.3.2:80
15:30:11.179 -> Connection successful!
15:30:11.179 -> --RandomNerdTutorials
15:30:11.179 -> Content-Disposition: form-data; name="imageFile"; filename="2020-11-25_15:29:55_esp32-cam.jpg"
15:30:11.179 -> Content-Type: image/jpeg
15:30:11.179 ->
15:30:11.179 ->
15:30:12.967 -> .................
15:30:14.659 ->
15:30:14.659 -> Connected to database.The file 2020-11-25_15:29:55_esp32-cam.jpg has been uploaded.
15:30:19.689 -> Connect to mySQL: 33794240:3306using user3,waste@csusm2020
15:30:19.689 -> INSERT INTO waste.app_status (temperature, humidity, distance, weight, status, image, bin_id) VALU
15:30:19.689 -> ...trying...
15:30:20.914 -> Connected to server version 5.5.5-10.3.23-MariaDB-0+deb10u1
15:30:20.914 -> Connection successful
15:30:21.526 -> Data stored!
15:30:21.526 ->
15:30:21.526 -> Going to sleep now
```

Figure 7. Debugging Output of Arduino Sketch.

B. Web Service

The WasteBOT system also provides different web services such as wastebin monitoring and navigation. The provided services are accessible by different categories of the user such as waste collection company employees and normal users according to their privilege level.

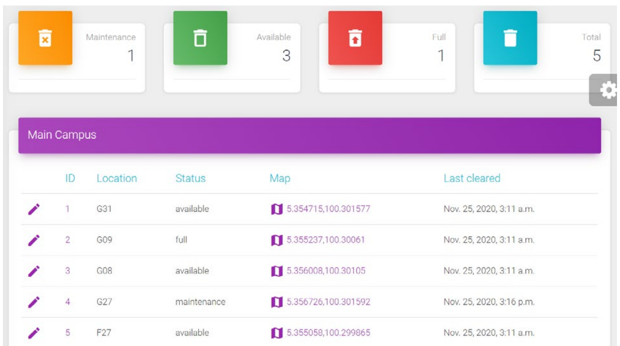


Figure 8. Monitoring Dashboard for WasteBOT.

Figure 8 shows the monitoring dashboard of the WasteBOT system. The authorities can monitor the status of wastebins deployed over a certain map area and check their condition in real-time with the dashboard. Based on the data and information collected from the wastebins, the waste collection company can schedule an optimized route to send out a collection truck and make wastebin reallocation decisions when a wastebin is not fully utilized.

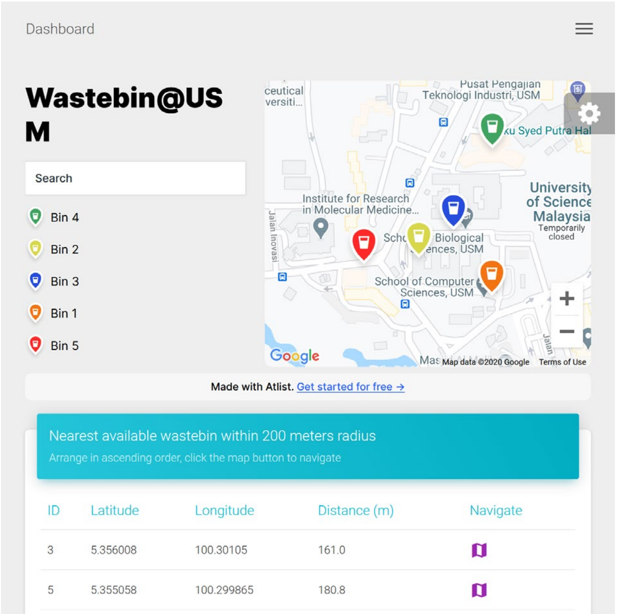


Figure 9. Navigation Service for WasteBOT System.

Normal users will be able to access the navigation service to look up for available wastebin nearby and help them to navigate to a selected bin. Figure 9 shows the distribution of the wastebin nearby a user using Google Maps along with a list of available wastebin within a 200 m radius. The user can use the Android built-in Google Maps app to navigate to the chosen wastebin.

VI CONCLUSION

The WasteBot system was proposed to address the unsystematic waste management system in the university campus which improves the current 3R management that requires a lot of manpower. The embedded sensing modules are designed in a way that they are easily attached to the existing wastebin to turn them into a smart bin. The existing bin will be now able to collect information on the waste and its environmental condition. The collected data will be upload to the server and provide web service to the users. Authorities will be able to monitor the status of bins in real-time through the dashboard while the common users can use the web service to help them navigate to the nearest available waste to prevent overflowing of rubbish in hotspot and improve the overall cleanliness of the surrounding environment. A healthy, clean, and green environment with the WasteBOT system is the head start to sustainable development not only on the university campus but also can be in our community and society with the emerging LoRa and 5G wireless technologies.

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