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IoT E-Waste Monitoring System to Support Smart City Initiatives

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Abstract: This project introduces the design and development of IoT E-waste monitoring system to support Green City initiatives in real-time. The main objective of this system is to design an IoT-based recycle e-waste monitoring system that will provide an efficient solution to electronics waste collection and generation data. The hazardous chemical components of e-waste have potentially adverse impacts on ecosystems and human health if not managed and monitored properly. Hence, the importance to constantly monitor the condition of the e-waste bin. The system measures and delivers up-to-date information to the system's administrator on the waste level and bin's current temperature in real-time. In case of fire, the system will give notification via its flame indicator. Agile Model is used as the research methodology as it offers an adaptive approach in respect to what features need to be developed. The proposed system consists of HC - SR04 Ultrasonic sensor which measures the waste level, a DS18B20 temperature sensor that detects the temperature in the bin, KY- 026 flame sensor, a Raspberry Pi 3 Model B+ as a microcontroller and ThingSpeak as an IoT web platform. ThingSpeak concurrently stores data for future use and analysis, such as prediction of the peak level of waste bin. This system is expected to increase the usage of e-waste recycle bin, hence supporting the Green City initiatives and creating a greener environment by monitoring and controlling the collection of e-waste smartly through the concept of Internet-of-Things (IoT).

1. Introduction

Electronic waste is generated when an electronic product or devices has reached the end of its working time period. After that, the waste is nothing more than the trash that accumulates heavy metals and toxic chemicals into the environment. Waste management is defined as devoted to the presentation and discussion of information on solid waste generation, characterization, minimization, collection, separation, treatment and disposal, as well as manuscripts that address waste management policy, education, and economic and environmental assessments in [1]. The main objective of this project is to design an IoT-based recycle E-Waste Monitoring System that will provide an efficient solution to waste collection and waste generation data in terms of monitoring and controlling the condition of the e-waste bin. The waste level, bin's temperature and risk of fire are monitored regularly. The system implements a waste's level priority scheduling that assures the collection of e-waste as soon as the waste level reaches its maximum filled.

2. Related Works

Smart waste collection solutions on the market that track waste levels and provide route optimization and operational analytics had been explored in [2]. Municipalities and waste service managers are realizing that these solutions can help them meet sustainability goals such as zero waste, improve services for residents and reduce operational costs. A standard set of elements found in most smart waste collection systems include sensors that monitor fill level and other indicators

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such as temperature and tilt within waste containers, a communication node to transport data and a software suite for accessing, managing and analyzing that data.

In [3], A Smart Bin: Internet-of-Things Garbage Monitoring System developed, was using the ultrasonic sensor as an input and placed at the maximum level of the dustbin. The system consists of the ultrasonic sensor which measures the garbage level and an ARM microcontroller which controls system operation whereas everything will be connected to ThingSpeak. The garbage level will be displayed on the LCD to allow the users to know the level of garbage inside the dustbin without opening the dustbin.

While in [4], IoT Based Waste Management for Smart City – Smart Dustbin, multiple dustbins are used and located throughout the city. These dustbins are provided with low cost embedded device which helps in tracking the level of the garbage bins, and a unique ID will be provided for every dustbin in the city to help identify which dustbin is full. If the level reaches the threshold limit, the device will transmit the level along with the unique ID provided. The concern authorities can access these details from their place with the help of the Internet, and immediate action can be made to clean the dustbins. These dustbins are interfaced with a microcontroller-based system with IR Sensors and RF (radio frequency) modules. This IR (infrared) sensor detects the level of the garbage in dustbin and sends the signals to microcontroller. The same signal was encoded and send through RF (radio frequency) transmitter, and it is received and decoded by RF (radio frequency) receiver at the Central System (Intel Galileo) and an Internet connection is enabled through a LAN (local area network) cable from the modem. The data has been received, analyzed, and processed in the cloud, which displays the status of the garbage in the dustbin on the GUI (graphical user interface) in the web browser.

This system only designed to solve overflown dustbins issue and provide details of the dustbin located in the different areas throughout the city. Same as a previous existing project, the main idea of this system is to detect waste level inside the dustbin, which is commonly proposed in the smart bin management system.

In [5], a Smart Garbage Collection Bin Overflows Indicator using Internet of Things had been developed. This existing system has built a framework in which a camera will be set at each garbage collection point alongside a load cell sensor at the base of the trash can. The camera will take continuous snapshots of the garbage can. A threshold level is set, which compares the output of the camera and load sensor. The comparison is made with the help of microcontroller. After analyzing the image, an idea about the level of garbage in the can and from the load cell sensor, weight of garbage can be known. Accordingly, information is processed that is controller checks if the threshold level is exceeded or not. This is convenient to use but economically, not reliable.

IoT Based Intelligent Bin for Smart Cities in had been introduced in [6], where smart bins had been equipped with ultrasonic sensors which measure the level of dustbin being filled up. The container is divided into three levels of garbage being collected in it. Every time the garbage crosses a level, the sensors receive the data of the fill level. This data is further sent to the garbage analyzer as an instant message using the GSM module. Placing three ultrasonic sensors at three different levels of the container may be a disadvantage as the cost of the dustbin increases due to the sensors, and also the sensors can be damaged due to the rough action by the users.

A load cell is a weight sensor that converts a load or force acting on it into an electronic signal. It is used in [7] where the voltage signal is the electronic signal that later will be amplified accordingly. If an object's weight changes over time, the load cell simply senses the presence of the objects by measuring the load applied to its surface bar. The load cell is placed in the recycle bin and is used to measure the weight of the recycle waste that being threw into the recycle bin. RFID (radio frequency identification) is a technique facilitating identification of any product or item without the requirement of any line of sight amid transponder and reader. RFID module used here consists of the tag and its reader, where the reader is used to scan the tag that represents the details of the user. The reason for choosing RFID as the data collection technology is mainly based on low price and the application environment. The low price enables the disposable feature of the tags, and the RFID system can overcome the difficulties of barcode and/or written identification systems as it is less prone to contamination from the waste and/or weather conditions.

Controller used in this project is Arduino Uno, where it controls the inputs and outputs of the project. As for the output, the LCD is used to display in real-time the weight of the recycle waste and rebate points to the users. To realize an IoT-based recycle management system, this project has also been interfaced to a Webpage as a platform for the users to check and update their total rebate points. The Webpage will also display the users' details based on the information acquired by the database. The database gets these data from the RFID reader and the detection of the load cell. Ethernet shield is used as the platform to connect the Arduino with database and Webpage by using the Internet network.

3. Methodology

The methodology used in developing this project is an Agile model. Agile methodology promotes continuous iteration of development and testing throughout the development lifecycle of the project. Both development and testing activities are concurrent. This allows earlier and frequent opportunities to look at the project and make a decision and changes if any, to the project. The process can be broken into individual blocks or models where errors can be fixed in the middle of the project. It is a feature-driven development, thus clarity on future tasks only in respect of what features need to be developed. User interaction is the backbone of Agile methodology, and open communication with minimum documentation are the typical features of Agile development environment. This IoT e-waste monitoring system went through the following phases that plays a vital role in the project development as depicts in Fig. 1.

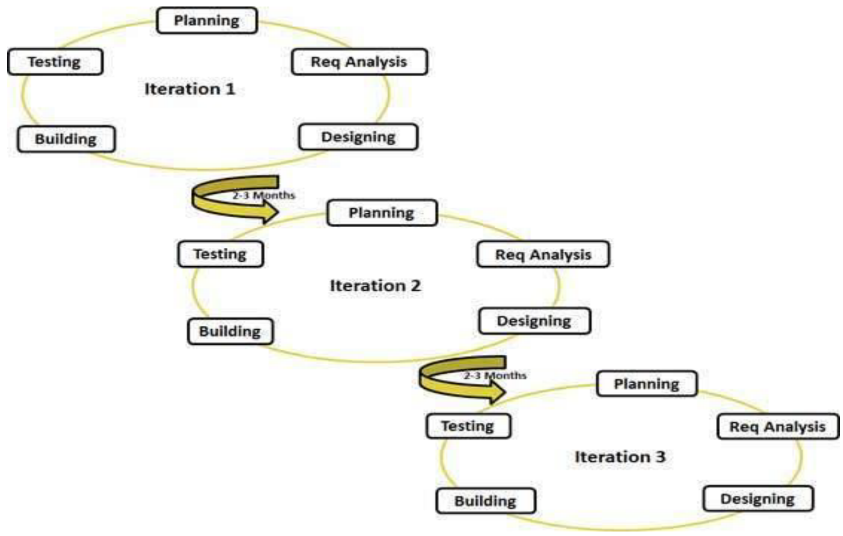

Fig. 1 - Graphical illustration of the Agile model

3.1 Agile Model Phases

Since the Agile model allows the developer to make changes, it is easier to add or remove features in this project. At the end of each iteration, the project is evaluated and tested. This allows any feedback to be considered until the desired end product is successfully obtained.

Planning phase associates the proposal writing of the idea of the whole system. The objectives and scopes of the project will be projected, followed by an estimation resource for both software and hardware. Project design and requirements are developed in this phase to get a clear picture of the system. Development activities schedule can be tracked using a Gantt Chart. Requirement analysis phase documented all related requirement from the previous phase as a basis for further analysis. This phase will transform the needs and high-level requirements specified in earlier phase into unambiguous (measurable and testable), traceable, complete, consistent, and stakeholder-approved requirements.

Any procurement needed for the project will also be conducted in this phase. Literature reviews have been done to support the research analysis and to come out with comparisons of the proposed system with previous works. It is crucial to understand the current needs and the implications, should there if any.

Designing phase gives a better understanding of the project, where all the tasks have been broken down into individual blocks or models. Proper diagrammatic representation such as block diagram as shown in Fig. 2 or other useful modelling techniques is built, followed by preparation of scenario test for each task.

The system consists of a flame sensor that able to detect heat for prevention of fire which may lead to an explosion, an ultrasonic sensor uses to detect the level of the waste dumped in the bin, and a temperature sensor uses to measure the inside temperature of the waste bin. Raspberry Pi 3 Model B+ as a controller will process these input signals and link all input data accordingly to provide desired output signals.

Development, construction, installation and integration of the hardware and software of the project were conducted in the next phase – building phase.

The system exchanges information with each other using a wireless network. Fig. 3 demonstrates the use of Internet-of-Things (IoT) in the development life cycle of the system that allows the e-waste collection administrator to monitor the overall condition of the waste bin. The IoT platform used in this project is ThingSpeak. It is an IoT analytics platform service that sends sensor data privately to the cloud, analyze and visualize the data and trigger a reaction by creating instant visualization of live data, and send alerts. The communication is done through the Wi-Fi module using the HTTP protocol over the Internet or via a Local Area Network.

This system monitors the level of the e-waste in the bin and doesn't wait for the bin to be 100% full as the longer they will be in the bin, the higher the risk of hazard might occur. Hence, level-priority-scheduling is implemented in this system. When any of the bins have filled up until 90%, and should there an increase in temperature or detection of heat flame, there will be an immediate indication displayed on the ThingSpeak webpage or dashboard. The system will alert the administrator to immediately attend the specified e-waste bin. This phase is, after all, signify the start of production of the prototype model.

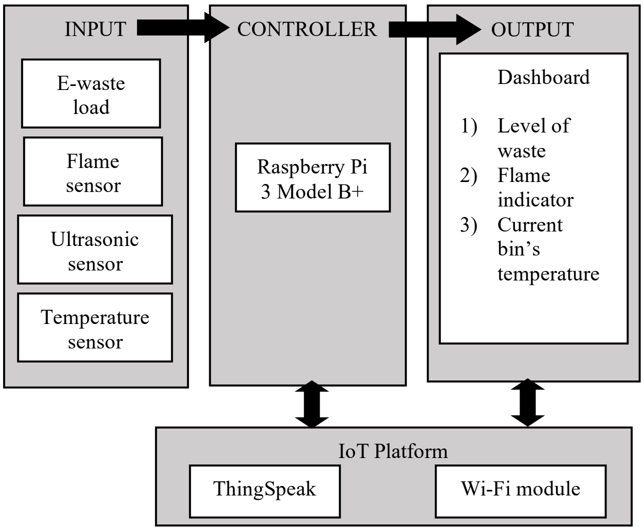

Fig. 2 - IoT E-waste monitoring system block diagram

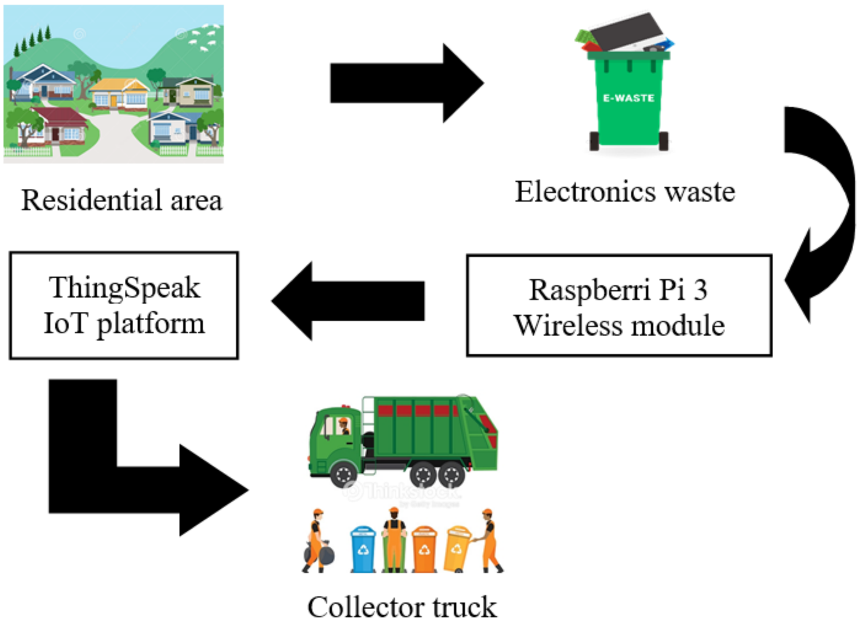

Fig. 3 - Development life cycle of IoT e-waste monitoring system

This system monitors the level of the e-waste in the bin and doesn't wait for the bin to be 100% full as the longer they will be in the bin, the higher the risk of hazard might occur. Hence, level-priority-scheduling is implemented in this system. When any of the bins have filled up until 90%, and should there an increase in temperature or detection of heat flame, there will be an immediate indication displayed on the ThingSpeak webpage or dashboard. The system will alert the administrator to immediately attend the specified e-waste bin. This phase is, after all, signify the start of production of the prototype model.

Due to specific system models, system architecture and detailed design of the project, the building phase will be using Raspbian Software with NOOBS platform and Raspberry Pi 3 tools with JavaScript programming language as the primary coding language. Once the prototype model of the project has been developed accordingly, the system then went through a testing phase.

The testing phase is important to ensure that the proposed design meets the initial set of measurable goals. Testing may be repeated, individually to check for errors, bugs and interoperability. Testing will be performed until the result is acceptable. Other parts of this phase are verification and validation, both of which will help to ensure the project objectives are successfully completed.

3.2 Prototype Development

The three sensors; HC-SR04 ultrasonic sensor, DS18B20 temperature sensor and KY-026 flame sensor were placed inside the waste bin. Fig. 4 shows the prototype of the e-waste bin where the ultrasonic sensor is specifically placed on the bottom part of the bin’s cover facing downward as it will measure the level of the waste according to the bin’s depth as shown in Fig. 5.

Fig. 6 shows the flame sensor that is also attached to the bin’s bottom cover. This flame sensor detects the infrared light emitted by the fire. The temperature sensor is placed inside of the bin at approximately half of the height of the bin, as shown in Fig. 7.

Once the Raspberry Pi is switched on, all sensors will be activated, and the system is ready to run. Few electronics devices such as cell phone, electronics circuit boards and secondary raw materials such as copper and steel were dumped in the waste bin for testing purpose. A burning candle was used to test the flame sensor and the temperature sensor. It’s been directed towards the flame sensor in the distance that is not too close.

Fig. 4 - Prototype model of IoT E-waste monitoring system

Fig. 5 - Attachment of the ultrasonic sensor

Fig. 6 - Placement of the flame sensor

Fig. 7 - Attachment of the temperature sensor

3.3 Software Development

ThingSpeak is an IoT analytics platform service that allows to aggregate, visualize and analyse live data streams in the cloud. ThingSpeak provides instant visualizations of data posted by Raspberry Pi to ThingSpeak. With the ability to execute MATLAB code in ThingSpeak, it can perform online analysis and processing of the data as it comes in. ThingSpeak is used for prototyping and proof of concept IoT systems that require analytics. Fig. 8 shows the ThingSpeak website

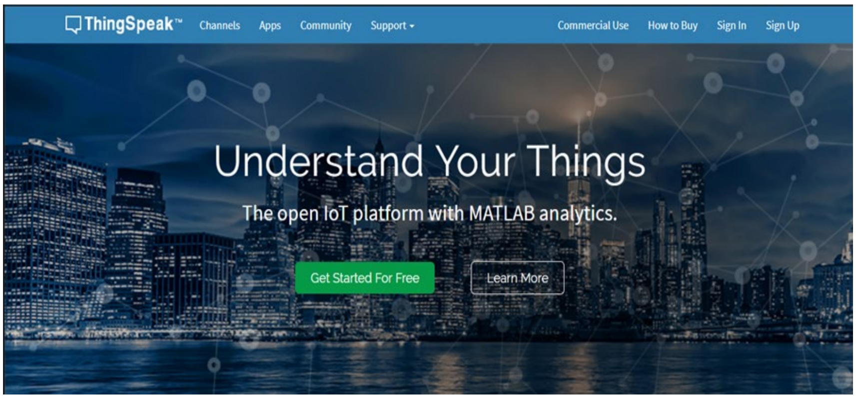

Fig. 8 - ThingSpeak Website

3.3.1 Collect Data in a New Channel

i. Signing in to ThingSpeak using MathWorks account to be able to view the channel.

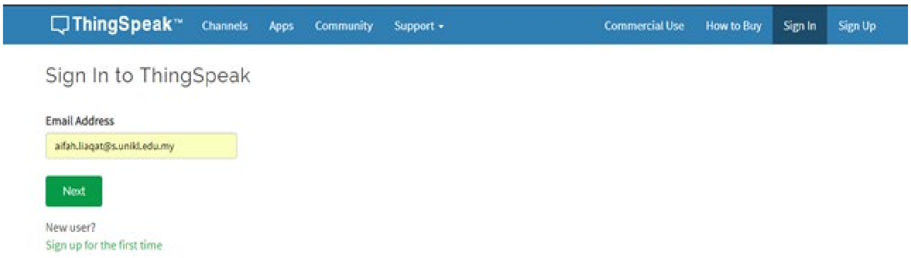

Fig. 9 - Sign in to ThingSpeak

ii. This is the channel that has been created for the IoT (Internet of Things) Recycle Waste Monitoring System to Support Green City Initiatives.

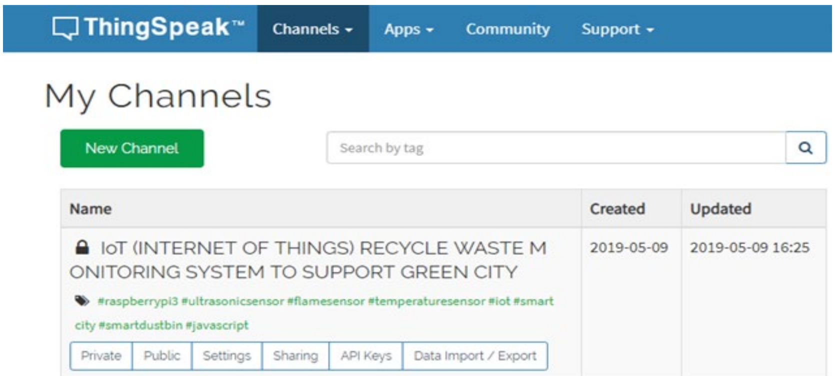

Fig. 10 - ThingSpeak Channel

iii. To connect both ThingSpeak with Raspberry Pi, the API Keys were provided by the ThingSpeak. Here, the keys will be included in the system's code to enable communication and transmitting data from Raspberry Pi to ThingSpeak as the main way to analyze the data.

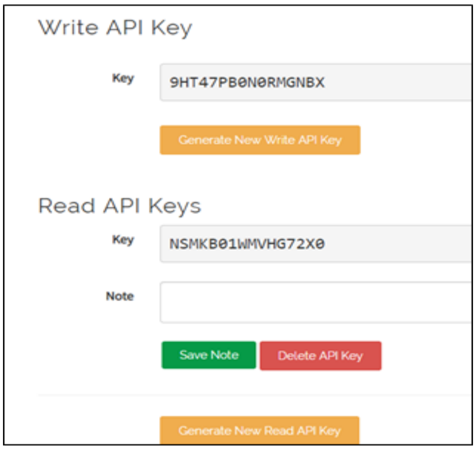

Fig. 11 - API Keys to Write and Read Data

3.3.2 Analyze Data

i. The data received from the Raspberry Pi were analyzed through the ThingSpeak that connected with API Keys. Figure 4. Shows the code used in JavaScript that includes the API Keys that enable the ThingSpeak to read the received data. If the output is displayed accordingly, it means the connec-tion between the Pi and ThingSpeak are successful.

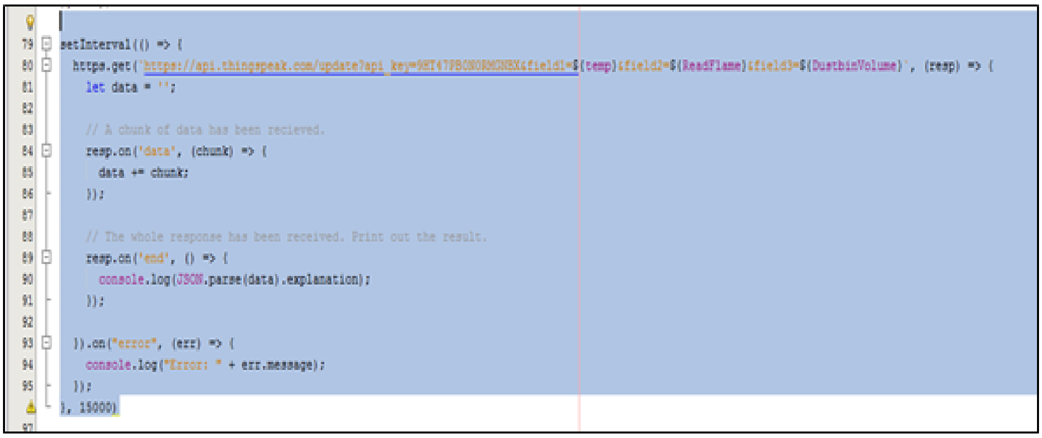

Fig. 12 - Coding to read data with API Keys

4. Results and Findings

The development of this prototype model is expected to increase the usage of e-waste recycle bin, hence supporting the Green City initiatives. This system makes use of smart technology complemented with the concept of IoT, which provide an efficient solution to manage our electronics waste as informal disposal and handling these type of waste can lead to adverse human health effects and environmental pollution. The processes of dismantling and disposing of electronic waste in developing countries led to a number of environmental impacts [8].

The system has been tested with different kind of electronics wastes dumped in the bin and the successful integration of hardware and software on this IoT-based system can be seen in Fig. 13. The output will be displayed on the dashboard of the ThingSpeak – the IoT platform. Measurement of the temperature is in degree Celsius (°C). In the case of fire, there will be an indication of flame that is received as an analogue input signal and will be converted into a percentage (%). Meanwhile, the waste level is measured in the distance in centimetre (cm) together with the percentage (%) of the e-waste in the bin. The output received will be transferred to ThingSpeak for data analyzation for every 15 seconds. Fig. 13 depicts the output displayed on the ThingSpeak dashboard.

There will be three main outputs displayed accordingly as a result of the system. The first widget will display the current temperature inside the waste bin. The second widget is a meter gauge that acts as a level indicator of the waste bin in percentage (%). The blue section indicates 75%-89%, which means the waste bin is almost full. In the meantime, the red section indicates 90%-100% that equivalent to a fully loaded e-waste bin. The last widget is assigned as a flame indicator. When the flame detects more than 50% of analogue data received, which means the fire is emitted, the indicator will turn into a red colour.

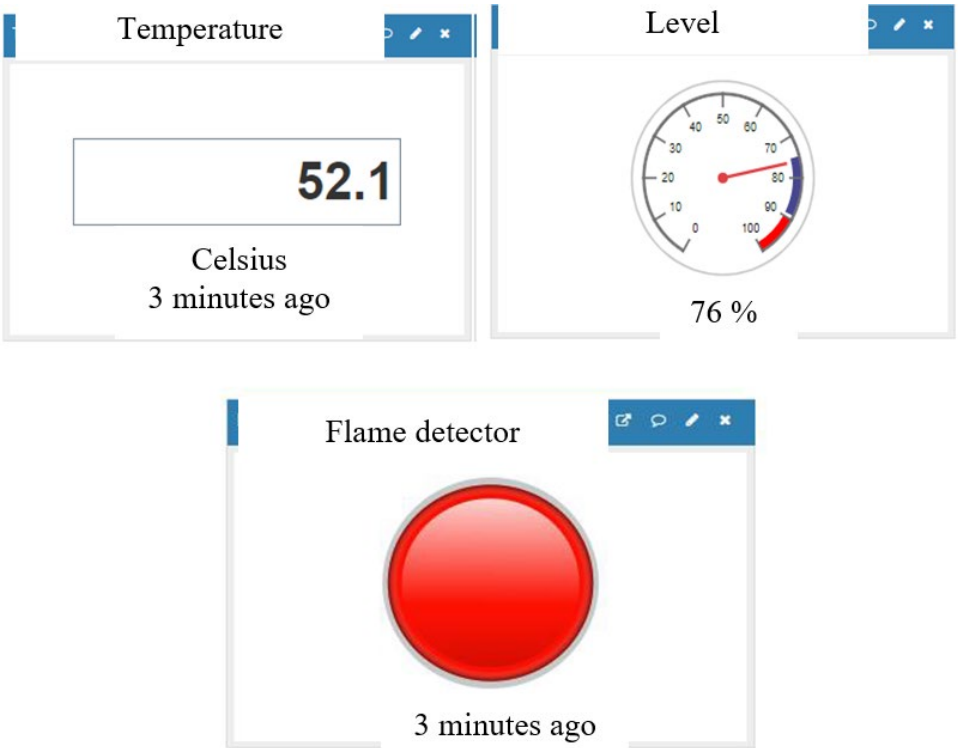

Fig. 13 - ThingSpeak dashboard

The data received from the Raspberry Pi were analyzed through the ThingSpeak that connected with API Keys. To connect both ThingSpeak with Raspberry Pi, the API Keys were provided by the ThingSpeak. Here, the keys will be included in the system's code to enable the communication and transmitting data from Raspberry Pi to ThingSpeak as the main way to analyse the data.

5. Conclusion

Presented through this paper is a practical sensor system built to monitor the level, temperature and fire detection inside the waste bin together with the IoT (Internet of Things). IoT is a system of physical things embedded with sensors, software, electronics and connectivity to allow it to perform better by exchanging information with other connected devices. The 'things' in IoT for this project are ultrasonic sensor, temperature sensor, flame sensor and a Raspberry Pi 3 Model B+. All sensors used in this project have a role as an input of the system. The reading from the input is sent to the Raspberry Pi 3, which had been assigned to API keys and build-in wireless modules. The collected data will be transferred over a network without manual assistance or intervention. The embedded technology in the Raspberry Pi 3 helps the 'things' to interact with the external environment hence influence the decision making.

Development of IoT E-waste monitoring system to support Green City initiatives is an innovation system where the idea is taken from the green initiatives by the government of Malaysia. Putrajaya is the first area that has been aimed to be a green town in Malaysia by the government. The traditional way of collecting and monitoring the e-waste bin is a bit challenging wherein several countries around the world, including in Asia, formal take-back systems have been set up to channel e-waste towards industrialized material and energy recovery facilities. However, of the estimated 48.1 million tonnes e-waste generated globally, only 6.5 million tonnes are collected by the official take-back system [9]. This type of waste collection is inefficient and required a huge amount of human energy.

This real-time basis e-waste management system uses sensors that can be accessed from anywhere at any time. This system will help to inform the status of the waste bin in real-time thus allowing the e-waste collector to pick up the waste when the dustbin is reached its maximum level and check the condition of the waste bin if there is any fire hazard. The ultrasonic sensor's detection range is between 2cm until 400cm. This sensor will compare the depth of the dustbin to show the level of garbage in the bin. Meanwhile, the temperature sensor will detect the temperature inside the bin, and the flame sensor will detect infrared light emitted by a fire. These sensors will collect the data and sent them to Raspberry Pi 3 to be displayed on the controller's terminal. At the same time, these sensors will send real-time data to ThingSpeak and being displayed on the dashboard. Therefore, e-waste management can be monitored.

It can be concluded that this IoT-based E-waste Monitoring System will provide an efficient solution to waste collection and waste generation data. It will also monitor the condition of the waste in terms of waste bin's level and its temperature together with a web-based IoT platform for client interface to check their updated data. This system does support the Green City initiatives to make Putrajaya as the first Green City in Malaysia. It will ease the Malaysia workers in recycling e-waste area to monitor the condition of the recycle e-waste bin. By 2040, carbon emissions from the production and use of electronics, including devices like PCs, laptops, monitors, smartphones and tablets (and their production) will reach 14% of total emissions [10] [11]. Therefore, it is hoped that this system will encourage the usage of e-waste to recycle bin in order to help to reduce the carbon emission.

In future, the system is recommended to include push email. With push notification, the server is responsible for notifying the client of new messages. The person-in-charged can receive immediate notification if any fire detected or the waste bin is already full. A mobile application for this project should be implemented to make this system more user-friendly and make use of the current technologies to enhance the performance of the system's features. The system can also be used in LoRaWan instead of a Wi-Fi coverage where the coverage area is much bigger.

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