Chapter 9
Smart Bin with Automated Metal Segregation and Optimal Distribution of the Bins

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Abstract Waste management has become a serious issue, especially in developing countries with very high population. Lack of bins or proper disposal facilities remains a problem to date. Various governments are also trying hard to push for a cleaner nation by helping curb pollution and improving public sanitation. The smart bin is an important and significant application to deliver cleanliness. A smart bin with automated metal and non-metal segregator is modeled. Using NodeMCU, the level of the bin is monitored in real time and sent to the cloud for further analysis. A novel mathematical model to calculate the most optimal way of distributing the bins in one dimension has also been discussed. Tourist areas, parks, educational institutions, etc., can use the bins in a network to improve sanitation.

Keywords Smart waste management · IoT · ThingSpeak · IFTTT · Smart bin

9.1 Introduction

Conventional waste collection techniques can be dirty and tedious with overflowing bins being emptied too late, and garbage trucks wasting fuel due to poorly planned collection routes and timings. However, smart waste management technologies offer promising solutions to reduce the operational costs and environmental problems associated with the inefficient waste collection. Smart bins are one of the most important

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applications among smart waste management technologies. It helps to reduce human effort and improve the quality of disposal. Generally, communication chips are used to transfer the data recorded from suitable sensors in the bin. Recycling of waste is an important aspect, but since waste is generally heterogeneous, it becomes difficult to extract the required material. This problem can be overcome by segregating wastes at the source. Information such as fill level can help higher authorities to ensure smooth working of the waste management system.

Much of the literature related to smart bins have fill-level monitoring systems. Ramson et al. [1] have made such a system that sends data to a centralized system. Their work includes waste level sensing, communication to a central system, and an application to display the gathered information. Ultrasonic sensors have widely been used for fill-level identification. In some papers, image processing has been used to determine the fill level. Hannan et al. [2] have used a content-based image retrieval system to estimate the bin level more accurately than the usual ultrasonic setup. Aziz et al. [3] have also used image processing to detect the position and orientation of the bin to check if the bin is empty, partially filled, or full. Optimization of the collection route is also an important result to be determined from fill-level data [4]. The GIS and remote sensing techniques have also been able to reduce the distance travelled by garbage trucks [5]. A wide range of communication devices has been incorporated with smart bins for IoT applications. Frugal Labs have incorporated LoRa technology which uses low power for data communication. MQTT protocol is used for uploading the data to the cloud [6]. ZigBee-PRO and GPRS have also been used for the communication of data from ultrasonic sensors [7]. Wireless monitoring unit (WMU) and wireless access point unit (WAPU) have also been utilized. Power consumption can be minimized by powering the sensors via an RFID tag [8, 9]. A smart recycle bin has also been proposed for selective materials using RFID technology. It can assist the user in classifying materials and calculate the weight of waste thrown inside [10]. Waste segregation at the source helps in efficient recycling. Razari Tomari et al. [11] have developed a reverse vending machine which is said to be an efficient system for recycling. Rajkamal et al. [12] have proposed a GREENBIN which can segregate waste automatically and is also used to generate energy from waste.

Much of the existing literature focuses on using fill-level data for calculating optimal collection routes. A novel method of using fill-level data to compute the optimal placement of bins is shown here. The algorithm is stated and the results when tested with MATLAB have been included. The level of the proposed bin is monitored using an ultrasonic sensor. The bin can also segregate metal and non-metals using a basic RLC circuit which is activated only in the presence of a user. This can help to segregate wastes and maintain cleanliness, besides saving fuel costs of garbage trucks and reducing manpower. Internet of Things (IoT) has been employed to monitor the level of the bin and transmit data. ThingSpeak, an IOT platform is used to store and visualize data from the ultrasonic sensor that is sent via NodeMCU. If This Then That (IFTTT), a free Web-based service, is linked to Thingspeak and is used to trigger an alert email.

The details of the hardware of the bin with appropriate pictures and a flowchart explaining the logic of operation have been discussed in Sect. 9.2. The role of IoT to monitor the level of the bin and the transfer of data is described in Sect. 9.3. Analysis of real-time data is also done with the help of an algorithm for finding the optimal distribution of bins. The results have been presented in Sect. 9.4. Conclusion and the future scope of the project are highlighted in Sect. 9.5.

9.2 System Description

A bin is divided into two halves by means of a partition. A plate is fixed to the bin such that its diameter is attached to the top end of the partition (Fig. 9.1). An Arduino Uno and an ESP8266 Wi-Fi SoC powered by a 9 V battery are used. The bin has three basic features.

9.2.1 Metal/Non-metal Segregator

A basic RLC metal detector circuit is used as shown in Fig. 9.2. It is excited with a square wave pulse and the output voltage is taken across the capacitor. When a metal is placed in the vicinity of the coil, the inductance of the coil will increase. This will change the output voltage across the capacitor. If the change is beyond a threshold, the object is classified as a metal and the plate tilts to one side. If a metal is not detected, the plate tilts to the other side. The plate tilts with the help of a servo motor attached in diametrically opposite ends of the bin. Through this method, metal/non-metal segregation is achieved within the bin itself. The collected metal

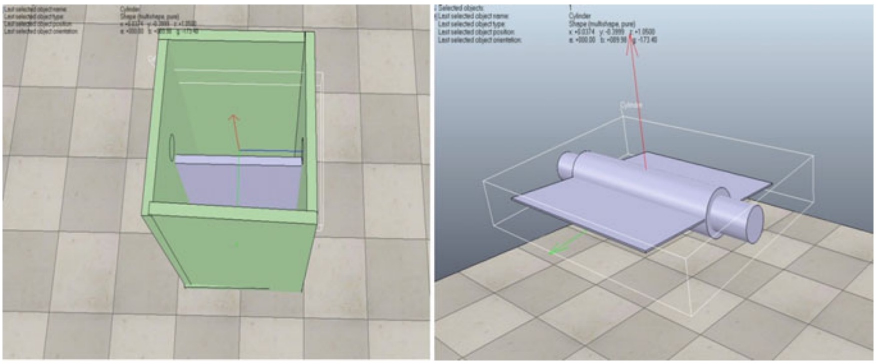

Fig. 9.1 Partition and view of the tilting plate

Fig. 9.2 RLC circuit with the bin used

can later be sent to industries as scrap. This is one of the key features in the bin and can help link scrap collection and waste collection.

9.2.2 User Detector

An ultrasonic sensor is placed on the front of the bin. When a person comes close enough to throw the waste, the sensor sends a signal to the Arduino, thereby enabling the rest of the circuits in the bin. This distance is set to forty-five centimeters and will help to minimize power consumption.

9.2.3 Level Monitor

Ultrasonic sensor is used for sensing the fill level. A sensor is placed at the center of each partition which is the optimum position for the sensor. An alert will be sent when the waste level reaches a specified threshold. The alert mechanism modeled has two stages in which two different authority levels are notified. The first would be the people directly in charge of the waste collection. The next level is their supervisors. This event-driven process will help garbage trucks to be more efficient by operating when needed.

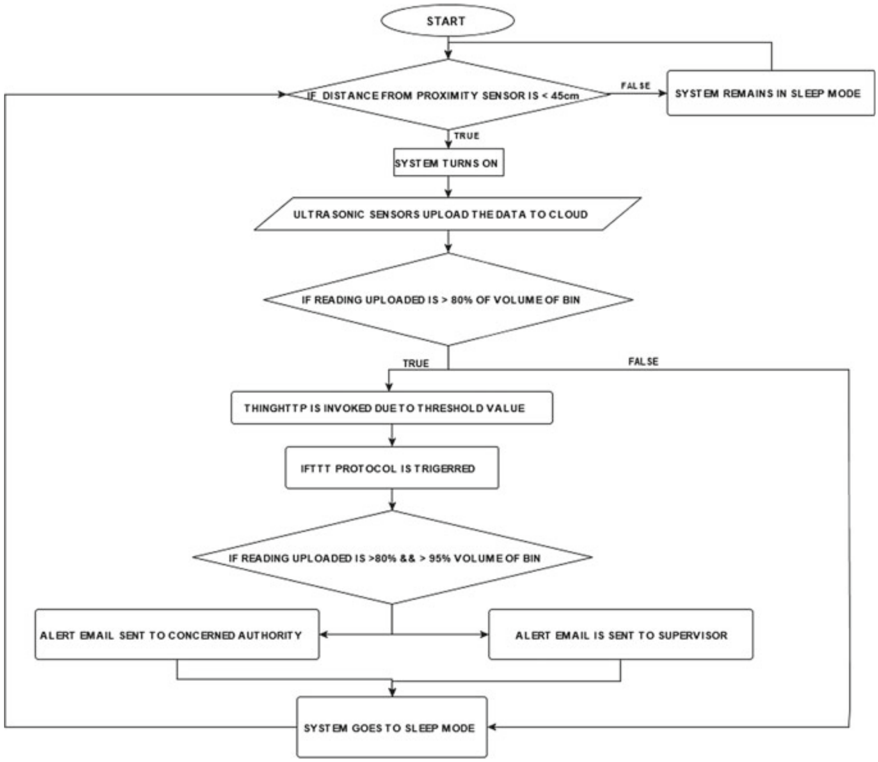

Fig. 9.3 Flowchart for the process

9.3 Network of Bins

NodeMCU, which runs on the ESP8266 Wi-Fi SoC is used to communicate the values read by the ultrasonic sensor to a server. The chip is placed in all bins, and a channel for storing the data recorded by the ultrasonic sensors is established in ThingSpeak. Using IFTTT, we send an email to the concerned when the bin is eighty percent and ninety-five percent full. The former is sent to the garbage trucks whereas the latter can be sent to a supervisor to ensure strict sanitary measures (Fig. 9.3).

Currently, bins in public areas are uniformly spaced or placed by intuition. But practically, some bins can fill faster than others due to higher population density or higher garbage generation closer to the bins. This will reduces the efficiency of garbage trucks and be inconvenient to users if some bins fill up faster. The surrounding bins may fill up sporadically. Hence, it is important to find the most optimal way of positioning the bins in a particular area. This is done by using the data from the ultrasonic sensors. Initially, the bins have to be placed conventionally over an area. Garbage trucks will be notified if any one bin in the area reaches eighty percent. All the bins are emptied when it happens and the level in each bin before emptying is used for mathematical modelling.

Bins placed in a one-dimensional path are considered. The placement of bins is optimal if the waste in the bins at a given time is nearly uniform. For this purpose, a waste generation density curve is modeled. A waste generation curve $f(x)$ implies a plot between the wastes generated (y-axis) and the position of bins (x-axis). It has been assumed that the waste generated at a point would be dropped in the nearest bin and that all bins have the same dimensions. For the waste generation density curve, a plot between $f(x)$ and x is considered, where $f(x)$ refers to the waste generated per unit distance and x is the position of the bin. The vicinity of a bin refers to the surrounding area of the bin, where the waste generated is assumed to be placed in that bin. The points that are closest to a bin will fall in the vicinity of the bin. In this way, the one-dimensional line can be divided into n regions where "n" is the number of bins.

The aim is to find $f(x)$ versus x curve.

$$f(x) = a_n x^{n-1} + a_{n-1} x^{n-2} + a_{n-2} x^{n-3} + \cdots + a_3 x^2 + a_2 x + a_1 \tag{9.1}$$

The area under the curve between two points in the x-axis would give the waste generated between the points. The waste generated in the vicinity of Bin1 is assumed to be dropped in Bin1 itself. Therefore, the definite integral from the starting point of the vicinity of Bin1 to the end point of the vicinity of Bin1 should be equal to the waste in Bin1.

$$W \text{ for } B\text{in}1 = \int_{s(0)}^{s(1)} f(x)\mathrm{d}x \tag{9.2}$$

where W is the height till which the bin has been filled (which is directly proportional to the waste in the bin), $s(0)$ is the starting point of vicinity of Bin1 and $s(1)$ is the ending point of vicinity of Bin1.

$$F(x) = \int f(x)\mathrm{d}x \tag{9.3}$$

$$\begin{aligned} F(x) = {} & \left(a_n x^n\right)/n + \left(a_{n-1} x^{n-1}\right)/(n-1) \\ & + \left(a_{n-2} x^{n-2}\right)/(n-2) + \cdots + \left(a_3 x^3\right)/3 + \left(a_2 x^2\right)/2 + a_1 x + C \end{aligned} \tag{9.4}$$

$$W \text{ of Bin1} = F(s(1)) - F(s(0))\ W(1) = W \text{ of Bin1} = F(s(1)) - F(s(0)) \tag{9.5}$$

$$\begin{aligned} W(1) = {} & \Big[\Big(a_n(s(1))^n + a_{n-1}(s(1))^{n-1} + a_{n-2}(s(1))^{n-2} \\ & + \cdots + a_3(s(1))^3 + a_2(s(1))^2 + a_1 s(1) + C\Big)\Big] \\ & - \Big[a_n(s(0))^n + \ a_{n-1}(s(0))^{n-1} + a_{n-2}(s(0))^{n-2} \\ & + \cdots + a_3(s(0))^3 + a_2(s(0))^2 + a_1 s(0) + C\Big] \end{aligned} \tag{9.6}$$

$$W(1) = a_n\big((s(1))^n - (s(0))^n\big) + a_{n-1}\big(s(1)^{n-1} - s(0)^{n-1}\big) + \cdots + a_2\big(s(1)^2 - s(0)^2\big) + a_1(s(1) - s(0)) \tag{9.7}$$

Similarly, n equations can be generated to find the $(n-1)$th degree polynomial to fit the $f(x)$ to x curve. The same can be extended for n equations and the coefficients are found by solving these equations. The data were collected from bins in VIT Vellore.

After generating the curve, the area under the entire curve divided by the number of bins gives the waste each bin should collect for uniform waste collection. Thus, the $f(x)$ curve is divided into n equal areas and the midpoint of the boundary of these areas is the optimal position of the bin. Since the load has been equally divided, each bin would fill at nearly the same time. This process can be repeated until the variance of the fill level of the bins becomes low. The process could be repeated if the variance becomes considerably high over a period. Thus, garbage trucks can handle wastes more efficiently.

9.4 Results and Discussion

To get a clear insight on the efficiency of the system with respect to the measurement of the level of the bin, the following test was performed. Wastes with varied geometry were put inside the bin, and the corresponding reading of the ultrasonic sensor was measured. This value was then compared with the actual waste level in the bin. The objective was to calculate the accuracy of readings obtained for various geometry of wastes put in the bin. In the test, it was noticed that the reading was almost coincident with true value when the accumulated waste made an approximate flat surface. However, when the top surface of the waste made an angle ranging from 15° to 20° with respect to the horizontal, an error of ±4 cm was recorded. Similarly, when the top surface made an angle of 40° or more, an error of ±8 cm was recorded. As the area under the partition becomes bigger, more number of ultrasonic sensors could be used as the level of garbage could be uneven.

A setup for bin level monitoring was made as shown in Fig. 9.2. A channel was created to visualize the fill level on ThingSpeak. The fill level obtained is shown in Fig. 9.4. It shows a gradual increase in the fill level followed by a small error due to the difficulties described in the preceding paragraph. An alert email was triggered by IFTTT successfully as shown in Fig. 9.5 after the fill level exceeds the eighty percent threshold value. This email is received by garbage trucks in real time. The bin is emptied and hence the reading resets to the initial value.

Real-time data were gathered from bins in VIT, Vellore along a 450 m linear path. These data along with their relative positions are shown graphically in Fig. 9.6. This graph also elucidates the non-uniform fill level or high variance that prevails in conventional waste collection methods. The vicinity of each bin as discussed in

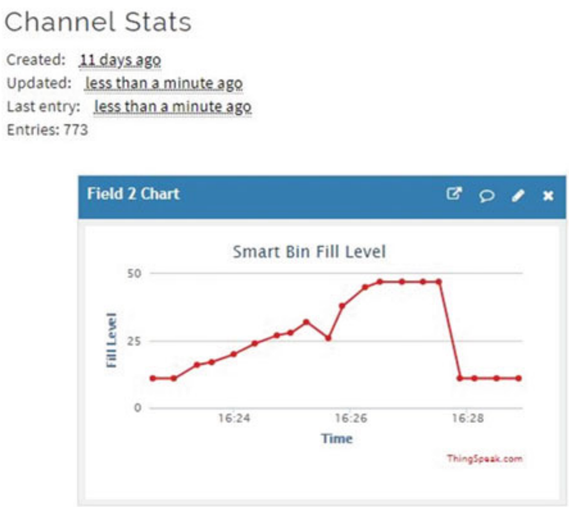

Fig. 9.4 Channel data in ThingSpeak

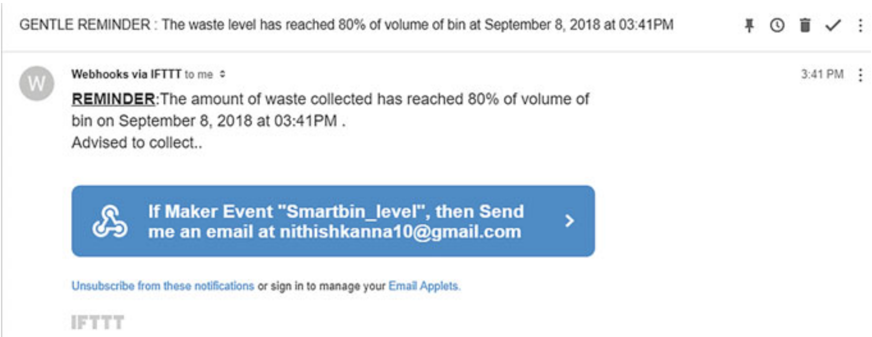

Fig. 9.5 Email reminding the level of the bin through IFTTT

the algorithm is shown in Fig. 9.7. At around three fifty meters, two bins are placed closely owing to higher waste generation from a hostel nearby. Although two bins are still insufficient as the bins collect a considerably higher amount of waste than the rest. At around one twenty meters, there is another small peak observed due to the presence of a shop nearby. The fill-level data clearly reflects the amount of waste generated in the vicinity of the bin. The algorithm for generating the $f(x)$ curve shown in Fig. 9.8 was implemented in MATLAB based on the data obtained from the bins.

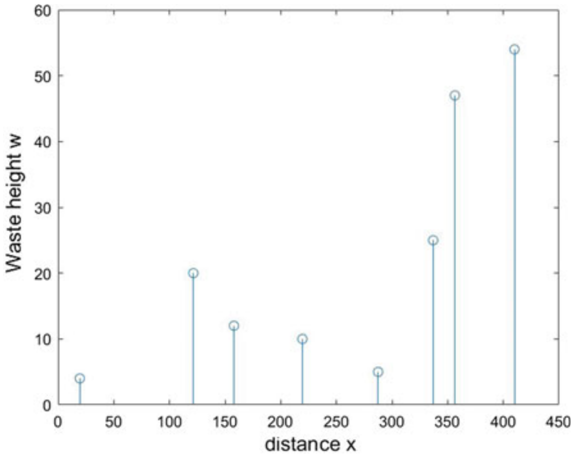

Fig. 9.6 Waste height versus position of bin

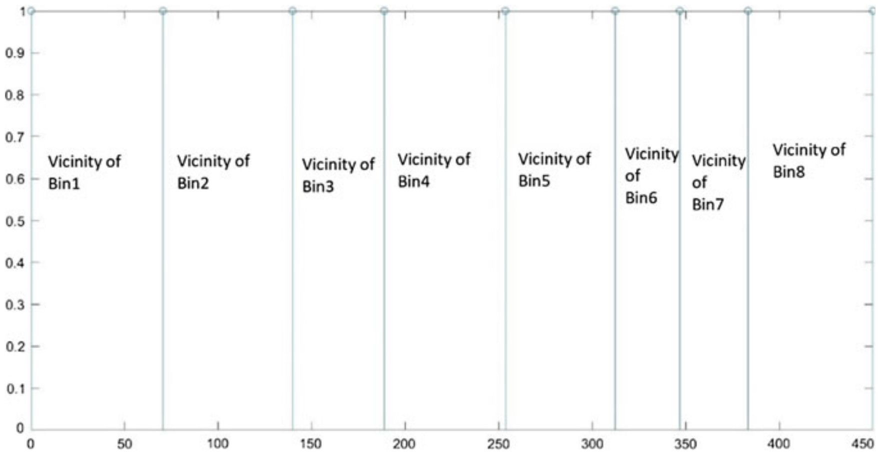

Fig. 9.7 Vicinity of bins

9.5 Conclusion

Efficient waste management solutions are the need of the hour. This smart bin captures an important application pertaining to smart cities worldwide. Making the data available to the public through the cloud can also help improve transparency. The wastes thrown in the bin is generally assumed to be separate and without the involvement of disposable bags. Such wastes cannot be segregated. In addition, weak metals cannot be detected and might slip into the non-metal side. These bins offer tremendous scope for smart cities and are easier to implement on a large scale. They can be improvised by image processing and machine learning to classify different types

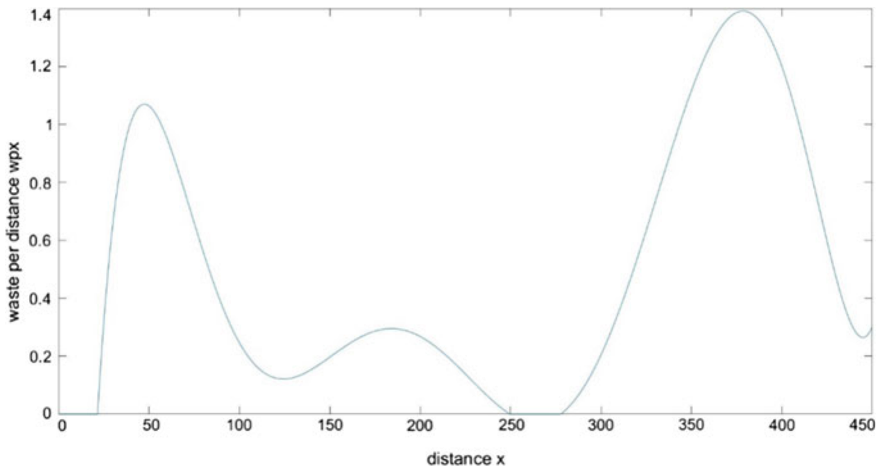

Fig. 9.8 $f(x)$ versus x for data collected from VIT

of wastes with greater accuracy. The mathematical model could be improved when more number of datasets are included. The mathematical model in this paper assumes that the waste per distance is an $(n - 1)$th degree polynomial but this may not be the case. Modeling with other types of functions depending on the scenario could provide more accurate results. The discussion regarding the optimal placement of bins can also be extended to the two and three-dimensional case.

References

1. Ramson, S.J., Moni, D.J.: Wireless sensor networks based smart bin. Comput. Electr. Eng. **64**, 337–353 (2017)
2. Hannan, M.A., et al.: Content-based image retrieval system for solid waste bin level detection and performance evaluation. Waste Manag. **50**, 10–19 (2016)
3. Aziz, F. et al.: Rotation invariant bin detection and solid waste level classification. Measurement **65**, 19–28 (2015)
4. Al Mamun, M.A., Hannan, M.A., Hussain, A., Basri, H.: Theoretical model and implementation of a real time intelligent bin status monitoring system using rule based decision algorithms. Expert Syst. Appl. **48**, 76–88 (2016)
5. Lella, J., Mandla, V.R., Zhu, X.: Solid waste collection/transport optimization and vegetation land cover estimation using Geographic Information System (GIS): a case study of a proposed smart-city. Sustain. Cities and Soc. **35**, 336–349 (2017)
6. Bharadwaj, A. S., Rego, R., Chowdhury, A.: IoT based solid waste management system: a conceptual approach with an architectural solution as a smart city application. In: India Conference (INDICON), 2016 IEEE Annual, pp. 1–6. IEEE (2016, December)
7. Al Mamun, M. A., Hannan, M. A., Hussain, A.: Real time solid waste bin monitoring system framework using wireless sensor network. In: 2014 International Conference on Electronics, Information and Communications (ICEIC), pp. 1–2. IEEE (2014, January)

8. Papalambrou, A., Karadimas, D., Gialelis, J., Voyiatzis, A. G.: A versatile scalable smart waste-bin system based on resource-limited embedded devices. In: 2015 IEEE 20th Conference on Emerging Technologies and Factory Automation (ETFA), pp. 1–8. IEEE (2015, September)
9. Karadimas, D., Papalambrou, A., Gialelis, J., Koubias, S.: An integrated node for smart-city applications based on active RFID tags; Use case on waste-bins. In: 2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA), pp. 1–7. IEEE (2016, September)
10. Wahab, M. H. A., Kadir, A. A., Tomari, M. R., Jabbar, M. H.: Smart recycle bin: a conceptual approach of smart waste management with integrated web based system. In: 2014 International Conference on IT Convergence and Security (ICITCS), pp. 1–4. IEEE (2014, October)
11. Tomari, R. et al.: Development of reverse vending machine (RVM) framework for implementation to a standard recycle bin. Procedia Comput. Sci. **105**: 75–80 (2017)
12. Rajkamal, R. et al.: A novel approach for waste segregation at source level for effective generation of electricity—GREENBIN. In: 2014 International Conference on Science Engineering and Management Research (ICSEMR). IEEE (2014)