Smart Waste Bin: A New Approach for Waste Management in Large Urban Centers

Kellow Pardini[1], Joel J. P. C. Rodrigues[1,2,3], Syed Ali Hassan[4], Neeraj Kumar[5], Vasco Furtado[3]

[1] National Institute of Telecommunications (Inatel), Santa Rita do Sapucaí-MG, Brazil
[2] Instituto de Telecomunicações, Portugal
[3] University of Fortaleza (UNIFOR), Fortaleza-CE, Brazil
[4] National University of Sciences and Technology (NUST), Islamabad, Pakistan
[5] Computer Science and Engineering Department, Thapar University, Patiala (Punjab), India

kellow.pardini@mtel.inatel.br; joeljr@ieee.org; ali.hassan@seecs.edu.pk; neeraj.kumar@thapar.edu; vasco@unifor.br

***Abstract*— Solid waste management is a significant worldwide problem, mainly for municipalities located within large urban areas. Efficient waste management is an essential requisite for a clean and safe environment, and keep cities away from the harm caused by the mismanagement of solid waste produced in urban centers. There are many technologies for managing waste collection as well as recycling, but among the studied related works, none addresses the citizen's perspective, focusing only on the collection performed by the landowners. This paper proposes an integrated system combining identification through ultrasonic sensors and load cell sensors, location by Global Positioning System (GPS), and communication through Global System of Mobile Communications (GSM) / General Packet Radio Service (GPRS). In other words, everything to provide citizens with a better disposal methodology for waste generated in their homes, besides being easily integrated with the municipal collection service to assist in efficient collection scheduling by promoting optimized routes. The solution is demonstrated, validated, and is ready for use.**

***Keywords*— Internet of Things, Smart Cities, Smart Waste Bin, Solid Waste Management, Waste Disposal System**

I. Introduction

The solid waste is an issue that has been increasing considerably in major urban centers around the world and consequently has substantial urban impacts when municipalities do not have an adequate management of these wastes [1]. The absence of a proper solid waste management program, either domestic or industrial, results in a danger to society. The threat can arise through diseases caused by exposure to waste and through environmental impacts, such as soil contamination and water resources. However, another negative aspect is the visual degradation of cities. In many parts of the world, the solid waste management system has been perpetuating over the centuries without any innovation, remaining with very inefficient collection model, with weekly agendas and trucks traveling long distances to collect the waste that is often laid out on sidewalks and public roads [2]. With the unbridled and disorganized growth of the population and all chances of abandonment of the rural area, urbanization has assumed increasingly extreme proportions, and consequently, the generation of waste has become a major urban problem, which leads to reflection on the importance of reducing the waste generation around the world. However, more effective management of the waste generated by these large urban centers is essential, which is a challenge for the competent authorities. The concept of Smart Cities with its "smart" technology projects makes the future of citizens increasingly sustainable and comfortable, taking urban development to integrate multiple solutions of information and communication technologies into an Internet of Things (IoT) sensitive context and thus manage the assets of a city. The European Union defined Smart City as a system where people interact and use energy, materials, and services to stimulate economic development and improve the quality of life [3]. However, these interactions flows are considered intelligent because they make strategic use of infrastructure, services, information, and communication in the planning of urban management, way to meet the social and economic needs of society. The city resources may include, but are not limited to, information systems for local departments, schools, libraries, transportation systems, hospitals, power plants, law

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enforcement, vehicle traffic, waste management, and other community services [4].

Based on the above-described concept of smart cities, this paper proposes an efficient waste management model for large urban centers focused on the citizen perspective, differently of other studies that focus only on the collection performed by the landowners. It includes a sensor system where waste information can be collected from the containers (things), in real time, and then transmitted, through the Internet, to a database where citizens can access and check the availability of bottles scattered around the city. A real prototype of the smart container was created. It is evaluated, demonstrated, and validated, and is ready being mapped in a real solution.

The remainder of this paper is organized as follows. Section II presents a research-related relevant models for waste management. Section III discusses available intelligent waste management solutions considering the model proposed in this paper performing a comparison to other models. Section IV presents the results obtained in this project as the construction of a practical model of the proposed solution (prototype validation). Finally, the conclusion and future works are identified in Section V.

II. Related Work

Several papers available in the literature are covering different aspects of IoT technology for waste management solutions. As example, the survey, by A. S. Wijaya - Z. Zainuddin - M. Niswar [5], proposes a model to manage whole containers of a city and monitoring the entire process. The proposal includes a sensing unit based on level and load sensors installed in the cover and the bottom of the container, respectively. A microcontroller is programmed to control the load of the bin by activating the sensors after a specific time interval. A transmission unit based on Bluetooth modules (used for maintenance in case of system failure) and Global System for Mobile Communications (GSM) for communication with the server. A WEB-based monitoring unit (where all data is managed) and a Mobile application that receives the information from the Web unit through GSM, so the collection is done efficiently. It uses GSM for communication.

In [6], the authors address a model of the waste management focused on a model where the base is the energy saving device. It is based on a bin, called the Field Unit, which features a lid opening mechanism and it is made with a durable hard plastic coupled to a detection unit based on ultrasonic sensors that are more advantageous in providing variation measurements independently of the contained objects. The data stream is transmitted through RFID which was chosen based on the cost of implementation, but with a greater emphasis on the energy considerations where the energy consumption of the node and the sensors must be minimal to prolong the life use of the battery (externally coupled). It presents the advantage of not relying on any communication infrastructure. The other unit in the system, called Mobile Sink, is based on a RFID reader, a Raspberry Pi, and a corresponding RFID middleware. A staff can perform the Mobile Sink or installed in a vehicle of the existing organized transport systems to collect data discreetly as the vehicle travels through the city. To download the data is used a network interface that can be Bluetooth, Ethernet, or Wi-Fi. The approach used for the communication on the described model is RFID (Global System for Mobile Communications).

The authors of [7] provide a structure designed in three segments. The first one is a bin with ultrasonic and load sensors that measure the deposited waste rate and send data to the second segment, a gateway. It integrates two different communication technologies, ZigBee that communicates with the bins receiving the measured data and, a second, via GSM/GPRS. The gateway is a bridge between the first and the third segment. This gateway is a built-in Meshlium device based on the Linux operating system of Libelium. Finally, the third segment is a data processing base, composed by servers that store data and some applications to represent the level of bins usage. The communication approach used was ZigBee-PRO that is technology in an open standard based on IEEE 802.15.4.

The work presented in [8] addresses a model of three main parts designated as Smart Bin, gateway, and control station. The Smart Bin includes sensors installed in the bin lid, as an accelerometer sensor that accompanies when the compartment cover is opening. The Hall Effect sensor that monitors whether the compartment cover is open or closed, which also predicts an overload of the bin, and an ultrasonic sensor that measures the waste level into the container. At the bottom container, load sensors are installed to measure the weight of the waste, as well as temperature and humidity sensors. The data measured by the sensors is sent to a gateway via ZigBee-PRO communication. The gateway stores the data in a local database and relays it to the control station via GPRS through a Meshlium from Libelium system. The control station has a database that receives the data sent by the gateway and stores it to be made available via WEB to collection users' interactions. The approach used for the communication was ZigBee-PRO.

In [9], it is proposed an integrated solution system of waste collection and monitoring of collection trucks. The system uses communication technologies, such as RFID, where the dumps are equipped with an RFID tag that contains the ID information. The bin address, as well as an RFID reader, is placed in the garbage trucks that read the tag information and stores them along with the exact date and place of waste collection, every time the bin is empty. There is also a Camera that photographs the containers before and after being flushed and the information is also stored and then transmitted via GPRS to the data processing point. A GPS system is coupled to the truck control box that verifies the coordinates of the bin at the collection time so, after, via GIS system can be displayed on a map to best route for collection. The communication used on the described model is RFID.

The work proposed in [10] shows a model where the bin is equipped with ultrasonic and infrared sensors for monitoring the level of waste of each item, a Raspberry Pi device and an Arduino system. After the waste level exceeds a threshold, the data is sent to the Raspberry that triggers an alert via SMS, and via e-mail, in parallel, the information is also sent to an Arduino system that, via Wi-Fi communication, transmits the data to a Microsoft Azure platform and a Power Bi platform for data processing. This communication is performed via Wi-Fi.

In [11], the authors describe a solution of smart bin equipped with a Passive Infrared sensor (PIR) to detect movement. An ultrasonic sensor to measure the usage level of the container, temperature sensor for checking the temperature inside the tray, and a proximity sensor for bin cleaning and attendance monitoring, LCD, real-time clock, and servo engine. An Arduino Uno board is used to automation the entire system and an Ethernet shield/Wi-Fi shield are used along with the Arduino to provide internet connectivity and support transmission of real-time data. The operation is activated when the PIR sensor detects a person approaching the bin. It sends a signal to the Arduino that, in turn, instructs the servo engine to rotate and open the bin lid. The container remains open for approximately 20 - 30 seconds then automatically closes to prevent the entry of animals and depending on natural conditions, fill the compartment. Once the lid is closed, the ultrasonic sensor that measures the fill compartment is activated. The LCD connected to the chamber continuously displays the percentage of fill, date, and time. This approach uses Wi-Fi communication.

The authors of [12] present a smart Bin design using ultrasonic sensors positioned at 120° from each other on the compartment cover and covered by a protection. On the bottom bin (in the corners), a load cell that is used as a secondary form of measurement, is placed to be used such as backup when the ultrasonic sensors fail. There is an amplifier coupled to the cell output. The measured data is sent to a base of waste collection via a GSM module with GPS combined to provide the bin coordinates. A microcontroller is programmed to monitor the level of waste, thus allowing the voltage to flow through the sensors after a certain period that will lead to minimizing waste energy through sensors. When the trash is full, a GSM modem will send an SMS to the base that will collect the waste. After collected, the residues are taken to a separate station where the plastic will be separated from the remaining residues by infrared reflectance spectroscopy.

Among the works above described, they follow the same waste management approach, having as central vision the collection system. The model proposed in this study differs from others because it assumes citizens as the primary focus, i.e., it aims to provide the user with prior information, through a mobile application, about the use of each container positioned near his residence. When filled, can offer the user another container with availability or even induce him to discard his waste at the most opportune moment, thus avoiding overflow and agglomeration of waste on public roads.

III. PROPOSED SYSTEM

The primary motivation for this work is to achieve complete monitoring of solid waste produced by urban centers. Through this process, the measurement data from waste can be treated and made available for citizen's benefit, offering opportune moments for waste disposal, as well as the municipal authorities responsible for the collection. They can, through statistical data stipulate, better schedules and even better routes for collecting the waste generated in the cities. This process saves money by reducing the fuel consumption of trucks and offers a higher collection efficiency. Through citizen interaction with smart bins, it is possible to know in advance container's utilization level located nearest him/her. Then, they can choose discarding their waste at that moment or wait for a more appropriated time, after the next collection by waste trucks, without even leaving home avoiding the waste agglomeration at the bins. It is an excellent way to promote citizenship, i. e., the intelligent trash that does not overflow prevents terrible consequences for citizens life, such as the clogging of Fluvial water gallery, the cause of the flood, diseases proliferation, and the degradation of appearance presented by residues scattered along the sidewalks, as illustrated in Fig. 1.

Fig. 1. Consequences of lack of waste management.

A. *General Architecture*

The proposed Smart Waste Bin system can be adapted into general waste-bin and it includes sensing units, a GPS module for location, a GPRS/GSM module for data transmission, the main microcontroller, and power supply. The general architecture of this proposal is shown in Fig. 2.

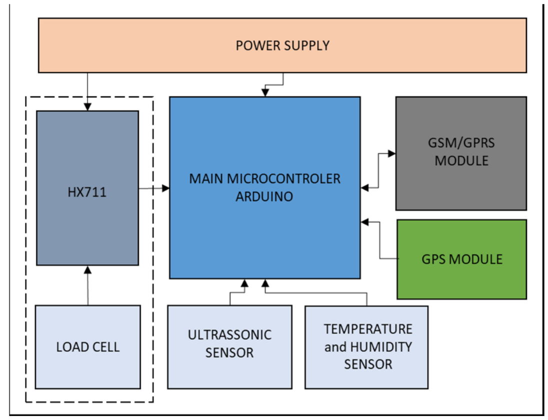

Fig. 2. Illustration of the Smart Waste Bin architecture.

The smart bin consists of a container with a lid, equipped with measuring devices that are divided into two paths, where the first path is assembled on the compartment cover and the other is placed at the bottom of the compartment. The other devices (Arduino board, temperature sensor, GSM/GPRS transmission system, GPS system and power devices) are placed in the back of the smart bin. All the used instruments are shown in Fig. 3.

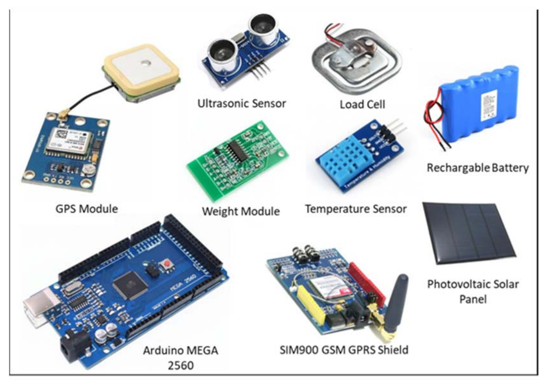

Fig. 3. Smart bin devices used in the proposed solution.

B. *Measuring device*

The measuring device is created with an ultrasonic sensor [13] connected to the upper side of the bin. Ultrasonic sensors are advantageous in providing amplitude measurements because they do not depend on the object's shape which their sound wave will be reflected, making possible the corresponding translation in level measurements. They are more suitable for this type of solution as they can be positioned on the container lid and thus avoid adverse conditions (contact with waste, washing procedure, etc.). Ultrasonic sensors such as HC - SR04 can have a beam with a full field of view operating at a detection distance of 2cm to 450cm so the entire housing can be sensed without cabling and interconnection needs. This type of sensor is typically based on a single transceiver unit that is capable of emitting and detecting sound, so a sonic pulse that is beyond the human ear listening range is created, and most solid objects can reflect these sound waves. The transceiver uses a timer to accurately determine how long an ultrasonic pulse takes to "bump" on an object, and return to the unit. From then, the fill level of the smart bin can be measured.

Another measuring device used in this solution is the load cell [14]. This sensor is mounted in the lower part of the compartment below a (plastic) board, simulating a weighing scale, so as to avoid problems during the washing procedure. Load cells exploit the variation of electrical resistance that occurs when specific materials are subjected to compression or traction. A load cell is composed of a metal bar, characterized by a central cutout, to facilitate flexing when a force is applied. The most important part of the sensor is strain gages that, placed on the bar, can provide information to scale the resistance change. To be interpreted by a specific driver, such as an HX711 (24-bit precision analog-to-digital converter designed for interface directly with a load sensor), allows the Microcontroller to formulate information about the stress (weight) loaded on the bar. The level sensor operating in parallel with the load sensor, aiming to add to the solution an efficient identification model of the deposited residues. Then, it is possible to identify types of low waste volume with high weight and high volume, but low weight.

The last measuring device used in this solution is a temperature and humidity sensor, like DHT11, which allows reading temperatures between 0 to 50 Celsius and humidity between 20 to 90%. The purpose of these sensors are to add information to the solution beyond waste management and to provide citizens with well-being during waste disposal times. Through this sensor, the citizen can monitor, in real time, the temperature of the environment where the box is located.

C. *GPS System*

The smart bin global location via GPS is so important to the entire solution as the volume and weight information measured by the sensors. Through these coordinates, it is possible to identify the exact location where the bin is positioned and thus reference the path of the citizens during the process of garbage disposal, and for the optimization of collection routes for the municipal service [15]. The Global Positioning System was created by United States Department of Defense and has as its essential function to identify the receiver located on the surface of the earth. Because GPS is currently the most modern and accurate way to determine a point on the earth's surface, its use is crucial for the exact location of the smart bin. Then, in the future, an application installed on the user's smartphone provides the positioning of the containers and the citizen can choose the nearest available collector container to serve him/her.

D. *Communications*

The communication technology used in this waste management solution is GSM/GPRS [16]. This approach is responsible for transmitting all the information related to the waste bin, such as the level and weight of the waste, global location, temperature, and humidity. For a future middleware platform that will be responsible to store and handle data. Then, an user (citizen) can access them through an application and thus visualize the capacity of the bin. A middleware is the software that runs between the operating system and the applications running on it, mainly functioning as a hidden layer of translation, allowing communication and data management for distributed applications. In [17], a plethora of available IoT middleware are studied in detail in order to find the most suitable one that best performs to support these applications in the near future.

When the waste bin is reaching the maximum level of filling, a notification is sent to the service of garbage collection. The SIM900 was the chosen option for this solution. It is a quad-band module that works on frequencies GSM 850MHz, EGSM 900MHz, DCS 1800 MHz, and PCS 1900MHz with features GPRS multi-slot class 10 / class 8 and supports the GPRS Coding Schemes, CS-1, CS-2, CS-3, and CS-4, that provide different levels of error detection and correction dependent upon the radio frequency signal conditions and the requirements for the data being sent. It has 68 SMT pads, and provide hardware to interface between the module and customers' boards, integrates a IP architecture a non-connection-oriented network service provided. The GSM/GPRS technology was taken into consideration; firstly because of the small amount of information to be transmitted, another relevant point is the IP protocol support that is the basis of the Internet connectivity (facilitating interactivity with other systems). Coverage is a determining factor since this proposal is developed for an outdoor environment. Currently, there is an excellent availability of 2G networks with low license cost and without the need for investments with infrastructure, when compared to technologies like LoRa, SigFox, and LTE, but they are robust technologies that can be an option as well as Wi-Fi (most urban centers already have good coverage).

E. *Microcontroller*

The Arduino board is being considered as prototyping to achieve automation. For a high-scale solution, several chipsets can be used turning the solution cheaper, but the Arduino provides simplicity and low assembly time of the prototype. It acts as the central processing unit and controls the interaction and synchronization of the sensors allowing the voltage flowing across sensors after a certain period, which reduces energy waste through sensors. It also controls the GPS modules responsible for the information received from the satellites and the GSM/GPRS module used to transmit the data to a middleware platform. For this, an important aspect is the standard Arduino connection mode that allows CPU being interconnected to other expansive modules, known as shields. Its board consists of an 8-bit Atmel AVR microcontroller with complementary components to facilitate programming and incorporation into other circuits, including a 5-volt linear regulator and a 16-MHz crystal oscillator (which may be variants with a ceramic resonator). In addition for being a microcontroller, the component is also pre-programmed with a bootloader, which simplifies program loading for the built-in flash memory chip.

F. *Power Supply*

The power supply consists in an external rechargeable battery, coupled to a photovoltaic solar panel that enables the recharge of the battery throughout a day, avoiding the need to replace the module after some time of usage.

All of these devices working together form the smart waste bin solution. The ultrasonic sensor with the load cell is responsible for measuring the level and weight of the discarded waste to identify when the container needs to be unloaded or stop receiving waste, either by filling its volume or by the maximum weight reached. The GPS module determines the exact geographic coordinates of the container so that its future location is possible. The temperature sensor checks the outside temperature, relevant information to the moment the user leaves home to discard their waste.

All information from the smart bin is transmitted to a Middleware platform through the GSM / GPRS module so that the citizen can, through a mobile application, check the status of these containers online. The complete solution is illustrated in Fig. 4.

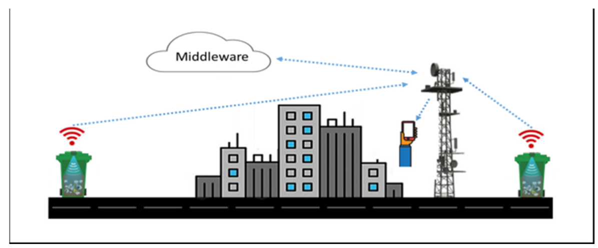

Fig. 4. Smart Waste Bin Solution.

IV. RESULTS AND PROTOTYPE DEMONSTRATION

A Smart Waste Bin prototype was proposed and created, as explained in previous sections. Fig. 5a shows the internal view of the prototype, indicating the load cell at the bottom and the level sensor at the top of the compartment. Fig. 5b shows the top image of the prototype, indicating the solar photovoltaic plate and the GPS receptor antenna. Fig. 5c presents the back side of the prototype, where the Arduino board, temperature sensor, GSM/GPRS transmission module, GPS module and the battery was mounted. Fig. 5d shows the front view of the Smart Waste Bin. Fig. 6 exhibits the Arduino console photo with all the information needed for the proper waste management. It is presented the location Latitude and Longitude, the age of data received from the satellite (milliseconds), date and time (GMT), speed (km/h), and direction (degree) if the container is in motion, volume and weight of the smart bin, and the temperature and relative humidity of the air.

Fig. 5a. Smart Bin's back image.

Fig. 5b. Smart Bin's frontal image.

Fig. 5c. Smart Bin's back image.

Fig. 5d. Smart Bin's frontal image.

With the prototype ready, it was possible to validate through the Arduino console all the information collected by the sensors. This information is of extreme importance for active and intelligent waste management, that is transmitted to a Middleware platform for being access to a mobile application or Web page. As above-mentioned, a printout of the Arduino console with the respective measurements is shown in Fig. 5. This system was evaluated is a real environment, validated, and it is ready for being integrated into a smart waste management solution.

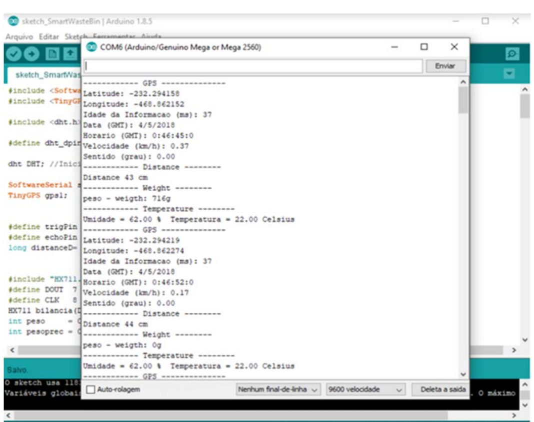

Fig. 6 – Arduino console view.

V. Conclusion and Future Work

Sustainability is a significant challenge of the century to be studied and worked around the world, in turn, cities become the stage in which the social, economic, and environmental dimensions converge with each other to promote this challenge. Under this, smart cities conceptions are being increasingly studied and discussed to face this problem. Following this approach, this work proposed a smart and innovative solution that integrates different detection and communication technology solutions for real-time monitoring of the solid waste produced and discarded in large urban centers. It addresses a new collection and handling design through IoT-based technologies to directly contribute to the social, economic, and environmental aspects of large cities. The proposed smart bin was designed, prototyped, evaluated, demonstrated, and validated and it is ready for a real deployment and use in a smart waste management solution.

As a future work, this solution should be integrated into a middleware platform. Thus a mobile App and a Webpage that will also be supported by this middleware should be developed to provide citizens with information about proximity and level of bins usage as well as providing crucial information for the entities responsible for waste collection and management.

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References

[1] S. Vinoth Kumar, T. Senthil Kumaran, A. Krishna Kumar, and Mahantesh Mathapati, "Smart garbage monitoring and clearance system using internet of things", *IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM 2017)*, Chennai, India, Aug. 2-4, 2017, pp. 184–189.

[2] Nicky Rogge, Simon De Jaeger, "Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model", *Waste Management*, Vol. 32, No. 10, pp. 1968–1978, Oct. 2012.

[3] Adriana Del Borghi, Michela Gallo, Carlo Strazza, Fabio Magrassi, and Marco Castagna, "Waste management in Smart Cities: the application of circular economy in Genoa (Italy)", *Impresa Progetto - Electronic Journal of Management*, no 4, pp. 1–13, 2014.

[4] Andrea Caragliu, Chiara Del Bo, Peter Nijkamp, "Smart Cities in Europe", *3rd Central European Conference in Regional Science (CERS 2009)*, Kosice, Slovakia, Oct. 7-9, 2009, pp. 45-59.

[5] Aksan Surya Wijaya, Zahir Zainuddin, and Muhammad Niswar, "Design a smart waste bin for smart waste management", *5th International Conference on Instrumentation, Control, and Automation (ICA 2017)*, Yogyakarta, Indonesia, Aug. 9-11, 2017, pp. 62 – 66.

[6] Dimitris Karadimas, Andreas Papalambrou, John Gialelis, and Stavros Koubias, "An integrated node for Smart-City applications based on active RFID tags; Use case on waste-bins", *IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA 2016)*, Berlin, Germany, Sep. 6-9, 2016, pp. 1–7.

[7] Md. Abdulla Al Mamun, M. A. Hannan, Md. Shafiqul Islam, Aini Hussain, and Hassan Basri, "Integrated sensing and communication technologies for automated solid waste bin monitoring system", I*EEE Student Conference on Research and Development (SCOReD 2013)*, Putrajaya, Malaysia, Dec. 16-17, 2013, pp. 480–484.

[8] Md. Abdulla Al Mamun, M. A. Hannan, and Aini Hussain, "Real-time solid waste bin monitoring system framework using wireless sensor network", *International Conference on Electronics, Information and Communications (ICEIC 2014)*, Kota Kinabalu, Malaysia, Jan. 15-18, 2014, pp. 1 – 2.

[9] Md. Shafiqul Islam, Maher Arebey, M. A. Hannan, and Hasan Basri, "Overview for solid waste bin monitoring and collection system", International Conference on Innovation Management and Technology Research (ICIMTR 2012), Malacca, Malaysia, May 21-22, 2012, pp. 258–262.

[10] Cyril Joe Baby, Harvir Singh, Archit Srivastava, Ritwik Dhawan, and P. Mahalakshmi, "Smart Bin: An Intelligent Waste Alert and Prediction System Using Machine Learning Approach", *International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET 2017)*, Chennai, India, Mar. 22-24, 2017, pp. 771–774.

[11] Hitesh Poddar, Rituraj Paul, Sourangsu Mukherjee, and Budhaditya Bhattacharyya, "Design of Smart Bin For Smarter Cities", *Innovations in Power and Advanced Computing Technologies (i-PACT 2017)*, Vellore, India, Apr. 21-22, 2017, pp. 1–6.

[12] Shubham Thakker, and R. Narayanamoorthi, "Smart and Wireless Waste Management", *IEEE International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS 2015)*, Coimbatore, India, Mar. 19-20, 2015, pp. 1-4.

[13] Teh Pan Fei, Shahreen Kasim, Rohayanti Hassan, Mohd Norasri Ismail, Mohd Zaki Mohd Salikon, Husni Ruslai, Kamaruzzaman Jahidin, and Mohammad Syafwan Arshad, "SWM: Smart waste management for green environment", *6th ICT International Student Project Conference (ICT-ISPC 2017)*, Skudai, Malaysia, May 23-24, 2017, pp. 1–5.

[14] Baihaqi Siregar, Seniman, Dina Fadhillah, Ulfi Andayani, Heru Pranoto, and Fahmi Fahmi, "Simulation of waste transport monitoring based on garbage load capacity using load cell", *IEEE International Conference on ICT for Smart Society (ICISS 2017)*, Tangerang, Indonesia, Sep. 18-19, 2017, pp. 1–7.

[15] Mahmuda Akhtar, M. A. Hannan, and Hassan Basri, "Particle swarm optimization modeling for solid waste collection problem with constraints", *IEEE 3rd International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA 2015)*, Kuala Lumpur, Malaysia, Nov. 24-25, 2015, pp. 1–4.

[16] N. Sathish Kumar, B. Vuayalakshmi, R. Jenifer Prarthana, and A. Shankar, "IOT based smart garbage alert system using Arduino UNO", *2016 IEEE Region 10 Conference (TENCON 2016)*, Singapore, Nov. 25-26, 2016, pp. 1028 – 1034.

[17] Mauro A. A. da Cruz, Joel José P. C. Rodrigues, Jalal Al-Muhtadi, Valery V. Korotaev, and Victor Hugo C. de Albuquerque," *IEEE Internet Things J.*, vol. 5, no 2, pp. 871-883, Apr. 2018.