REAL TIME SOLID WASTE MONITORING USING CLOUD AND SENSORS TECHNOLOGIES

Eunice Likotiko[1], Dmitry Petrov[2], Joseph Mwangoka[1], Ulrich Hilleringmann[2]

Information Communication Science and Engineering, NM-AIST, Tanzania[1]

Sensor Technology, University of Paderborn, Germany[2]

Corresponding Author: likotikou@nm-aist.ac.tz

Abstract: The rise of urbanization and increase of human population correspond to the amount of solid waste produced. Inappropriate solid waste management poses risk to the environment as well as to the healthy living of people. Outmoded way of solid waste management is a cumbersome and complex process, which utilizes more valued human effort, time and cost and is not well matched with advancement in technologies. In this work, a smart bin solution is shown with a three-layered architecture for IoT real time solid waste monitoring. The lower layer is installed with sensors for measuring waste levels in smart bins; the middle layer is comprised with both Wi-Fi and GSM technologies for data transmission to a central system. A cloud service for receiving and storing data from the sensors is on the upper layer. In order to collect waste, the corresponding cleaning service is notified whenever a smart bin level threshold is reached. Ultrasonic ranger sensor and laser distance sensors were implemented and tested. A web based system to store user's information necessary for monitoring was also developed. The technologies used in the proposed system can solve the problem associated with solid waste monitoring and management and thus provides green environment.

Keywords: Solid waste, Ultrasonic ranger sensor, Laser distance sensor, Cloud service, Smart bin, Real time solid waste monitoring.

Introduction

Solid waste refers to all non-liquid wastes which are produced from different sources such as households, commercials, institutions, parking and industries. Solid waste management is the most important service provided by every city government and serves as a prerequisite for the wellbeing of its residents. Inappropriate solid waste management poses risk to the environment as well as to the healthy living of the people. Rise of urbanization, increase of human population corresponds the social economic activities which are proportional to the amount of solid waste produced. Currently, world cities generate about 1.3 billion tonnes of solid waste per year. This volume is expected to increase to 2.2 billion tonnes by 2025. Waste generation rates will be more than double over the next twenty years in lower income countries (Hoornweg & Bhada, 2012). Solid waste management is advanced in developed countries and less so in growing economies. For instance, over the last two decades, European countries have increasingly shifted their focus with regard to municipal waste from disposal methods to prevention and recycling (States *et al*., 2016).

On the contrary (Mwesigye *et al*., 2009), waste management in growing economies is not coping with the growth of urban areas thus leading to poor waste management. Most of Municipal waste management efforts by local authorities are severely affected by low capacity to collect and transport waste. The authorities need more tools (e.g. a moving vehicle) and personnel, and better mechanisms to sustain municipal waste management operations (Zurbrugg & Eawag, 2003; Mwesigye *et al*., 2009). Although a direct solution would be to increase expensive and improve the infrastructure, efficiency of the existing capacity can be improved to mitigate the impact of poor municipal waste management to the environment through the application of Information and Communication Technology (ICT).

In recent past, several research activities were actively involved with Internet of Things (IoT), for instance in smart home applications an implementation of IoT for environmental condition monitoring in homes was done by Kelly *et al*.,(2013). also in resolving transportation issues a novel modular and multilayered vehicular data cloud platform based on cloud computing and IoT technologies was developed (He, Yan, & Xu, 2014), where by a novel software architecture for the vehicular data clouds in the IoT environment which has the capabilities to integrate numerous devices available within vehicles and devices in the road infrastructure was proposed. Likewise in health systems a health industrial internet of Things (IIoT) enabled monitoring framework (Hossain & Muhammad, 2015) developed, where electrocardiogram (ECG) and other healthcare data are collected by mobile devices and sensors and securely sent to the cloud for seamless access by healthcare professionals, to mention but a few.

Unquestionably there also several efforts invested in solid waste management with IoT, in general, smart waste monitoring system consists of sensors and transmission medium, collecting different types of data regarding the waste detection level found inside a smart bin.

An automatic smart waste management system (Bashir & Banday, 2013) designed and implemented, the overall system of waste detection divided into four subsystems; viz smart trash system, smart vehicle system, local base station and smart monitoring and controlling hut, two load sensor and IR proximity sensor entangled, RF transmitter used to send the detection of waste to local base station where the RF receiver is placed, the local base station decodes the trash bin location and accordingly sends a signal to the smart monitoring and controlling hut which sends signal to Smart vehicular system about the location of the trash bin.

Smart Garbage Management System (Bhor & Morajkar, 2015), according to author four IR sensors embedded on a dustbin for waste level detection, GSM 900 modem used to send waste level data collected by Microcontroller, to the control station whereas monitoring of the distributed dustbin is been done, the same GSM module is connected to the computer and used to send the message to the contractor for cleaning the dustbin in additional a graphical user interface using MATLAB software was developed.

According to Hassan (2016) a smart city service for real time waste monitoring and collection was designed and developed, The system consists smart bins, each bin installed with Arduino Uno, ultrasonic sensor and Radio Frequency (RF) transmitter on the top of the container. When the container is full of waste, it sends signal to the control center which will have the level of waste in the containers and through GSM/GPRS, a message (SMS) will send to the mobile phone of the truck driver of which waste bin is full and need to be empty.

Furthermore, a Wireless sensor network prototype for solid waste bin monitoring with energy efficient sensing algorithm (Mamun *et al.*, 2013b), researchers proposed a three tier architecture system whereas sensor resides on the lower tier formed with wireless sensor networks, with ZigBee-PRO and GSM/GPRS embraced in middle tier. The gateways which is the middle tier are acting as a bridge between the sensor nodes in the lower tier and the servers in the upper tier. It receives ZigBee data from the sensor nodes and transmit the data to the servers through GSM/GPRS, the system provides real time bin information with a developed web application to monitor the output.

Nonetheless, Intelligent system for valorizing solid urban waste, the developed iEcoSys system (Intelligent Ecologic System) encouraging waste recycling and separation (Reis *et al.*, 2014), according to the author RFID technology, ZigBee technology and XBee modules together with Arduino Microcontroller were involved. The flow of information in the iEcoSys system begins with the citizen who acquires iBags, which allows him to be identified at the act of depositing waste. the system insists on GAYT (Get As You Throw) citizens are credited with the amount receivable for the recycled waste.

To date, only few studies detailed on solutions which have a consideration on communication technologies constraints found within an area. In this study both Wi-Fi and GSM technologies prototypes implemented and can used as indoor/outdoor based solution, become more convenient to users depending on type of communication technology accessible while using contemporary technology and thus giving users a wide range of choices to use. The table below provides the literature summary of different technologies, methods and some important features for real time monitoring such as map and alerts in solving the problem of solid waste management.

Table 1: A summary of systems that used different communication technologies and methods to monitor and manage solid waste over the last years.

S/n	Authors	Communication Technologies	Location Map	Real Time Monitoring	Notification (Alert)
1.	Hassan (2016)	GSM/GPRS, RF(Tx/Rx)	NO	YES	YES
2.	Mamun *et al.*, (2016)	GSM/GPRS, ZigBee	NO	YES	YES
3.	Bhor & Morajkar (2015)	GSM/GPRS	NO	YES	YES
4.	Reis *et al.*, (2014)	ZigBee, FID	NO	YES	YES
5.	Bashir & Banday (2013)	RFID	NO	YES	YES
6.	Mamun, et al., (2013a)	RFID, ZigBee	NO	NO	NO
7	Catania & Ventura (2014)	ZigBee, Wi-Fi, GSM/GPRS	NO	YES	NO
8	Chowdhury & Chowdhury (2007)	RFID, Wi-Fi	NO	YES	NO

The realm of this paper is to design and develop an IoT based and real time solid waste monitoring prototypes. The developed system intends to reduce valued human resources effort, time and cost as well as to protect the environment and health living of the people. Modern technologies such as cloud system, Wi-Fi, GSM as well as ultrasonic ranger sensor and laser distance sensor are implemented. Offering a substantial way to optimize solid waste management increasing collection throughput and improve its sustainability.

The rest of the paper is organized as follows; materials and tools used in the study with the architectural designs of the system. Followed by practical implementation together with results and discussion of the developed system prototypes. Lastly, is the conclusion of the presented study.

Methods and tools

Proposed real time solid waste monitoring system architectures.

IoT real time solid waste monitoring can revolutionize today's solid waste management activities by enhancing smart waste management and building quality service for citizens. Figure 1 is the general architecture, it gives the overview of the designed solution for real time waste monitoring based on IoT. The general architecture portrays the interaction and communication among the distributed smart bins at different citizen's buildings (home, church, mosque, hospital, school e.t.c) after been registered into a web database of cleaning service central system where waste monitoring is done, also including a seamless transmission of waste data and storage to the cloud platform via internet service. Central system administrator browses and retrieves the processed information for waste monitoring and collection through the developed web platform.

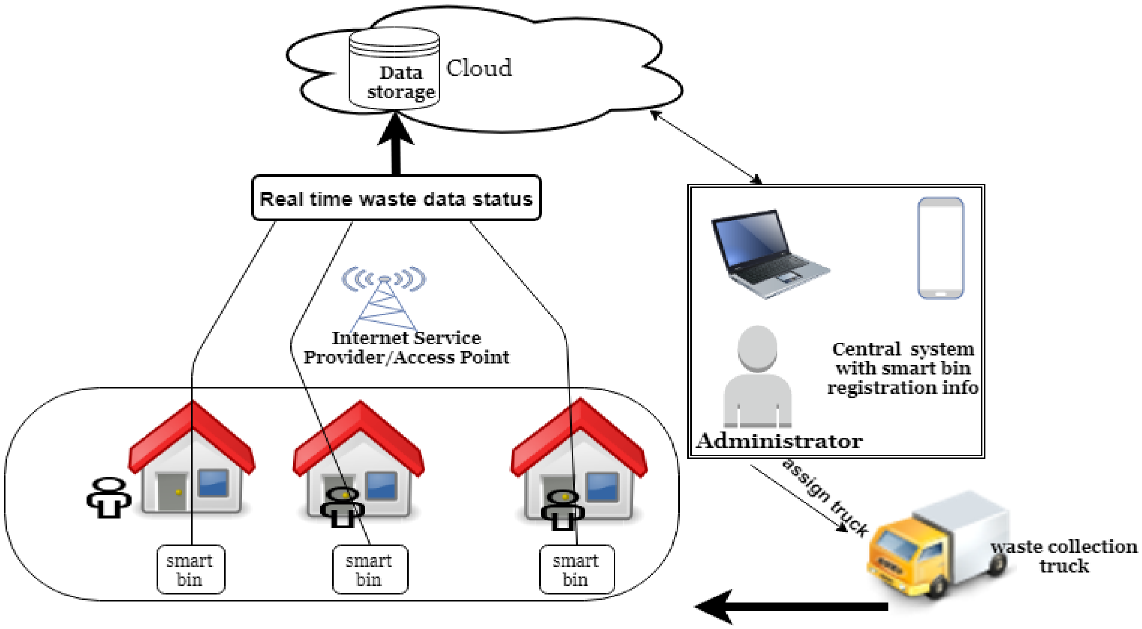


Figure 1. General architecture solution for real time waste monitoring and collection.

Figure 2, shows a smart bin prototypes solution's block diagram with a three-layered architecture for IoT real time solid waste monitoring, which are Lower layer, Middle layer and Upper layer.

The lower layer, is installed with Ultrasonic ranger srf05 sensors for measuring waste levels in smart bins, and 500mAh 3.7 V Lipoly batteries power supply source connected to microcontroller.

The middle layer, consists of the gateway which act as the bridge between the lower and upper layer, both Wi-Fi and GSM technologies integrated with the microcontrollers were applied in this layer, where by Adafruit Feather M0 Wi-Fi w/ATWINC1500 with a Wi-Fi module and 32u4 FONA SIM 800L with a GSM module were used for transmission of the detected solid waste data to the cleaning service central system cloud storage.

The upper layer, comprised with a cloud open source platform for the Internet of Things "Thingger.io" which is used for receiving, updating, storing and analyzing incoming data from the imbedded smart bin's sensor via the gateway after establishing connection with the server. The developed web based interface is also installed in the upper layer linked with the Thingeri.io, with role based restrictions for administrator to monitor the incoming sensor data in real time. During monitoring an administrator is been notified wherever the smart bin level threshold is achieved, administrator can visualize the location of the smart bin from the map and assign a driver to collect waste.

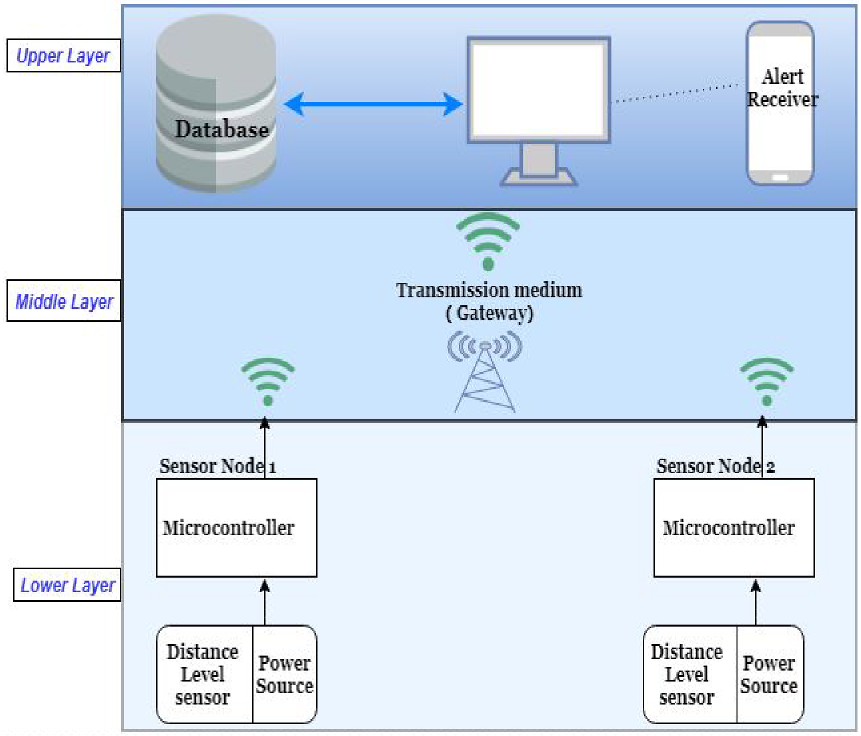


Figure 2. Block diagram of the smart waste monitoring and collection system

The flow chart diagram Figure 3 describes the architectural building blocks and logical decision involved from the detection of solid waste obstacle as soon as someone throws waste into a bin to waste collection process. The diagrams provide an impression on how the developed system prototypes will achieve real time monitoring and collection of solid waste. It also describes the working principles of the designed system block diagram and general architecture Figure 1 and Figure 2 for Internet of Things and Wireless sensor network in achieving real time solid waste monitoring.

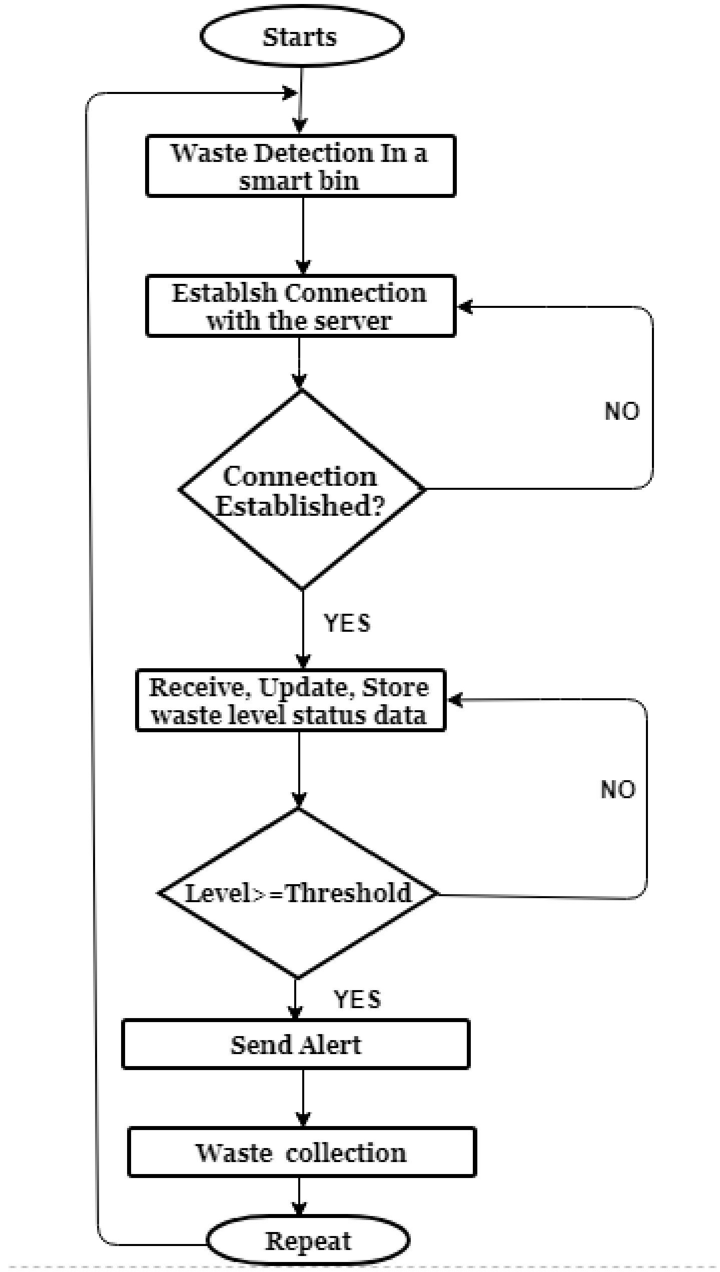


Figure 3. Flow chart diagram of the smart waste monitoring and collection system

Practical implementation of the developed prototype

The practical implementation of the developed system consists of monitoring processes from the sensors measurements and communication of the system prototype which is the heart of the whole structure of system, it shows how the designed system working and communicate with the hardware devices for the successful real-time monitoring. It consists of Microcontroller units; the Adafruit Feather M0 Wi-Fi w/ATWINC1500, 32u4 FONA SIM 800L GSM, Ultrasonic ranger srf05 sensors, 500mAh 3.7 V Lipoly batteries and LED backpack. A sketch (source codes) in C/ C++ with specific standard library written in Arduino IDE compiled and uploaded into the feather boards via Universal Serial Bus (USB) and thus became the brain of the boards, by controlling and coordinating all the hardware components defined operations systematically. The detected solid waste data and time of detection are transmitted to a cloud storage Thinger.io for monitoring purposes. Figure 4 and Figure 5 shows the hardware components of solid waste monitoring system prototype.

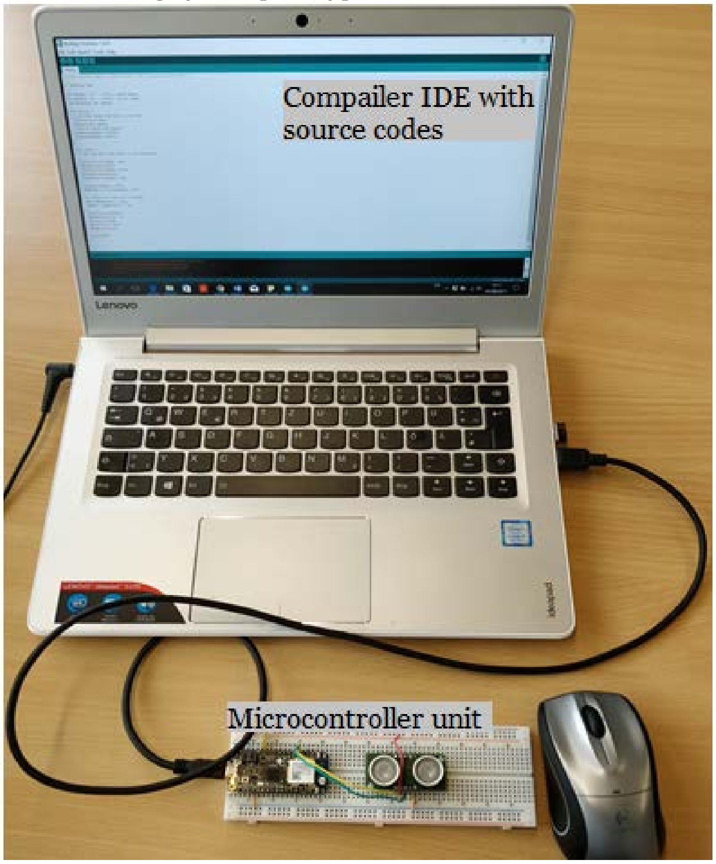


Figure 4. Communication with PC

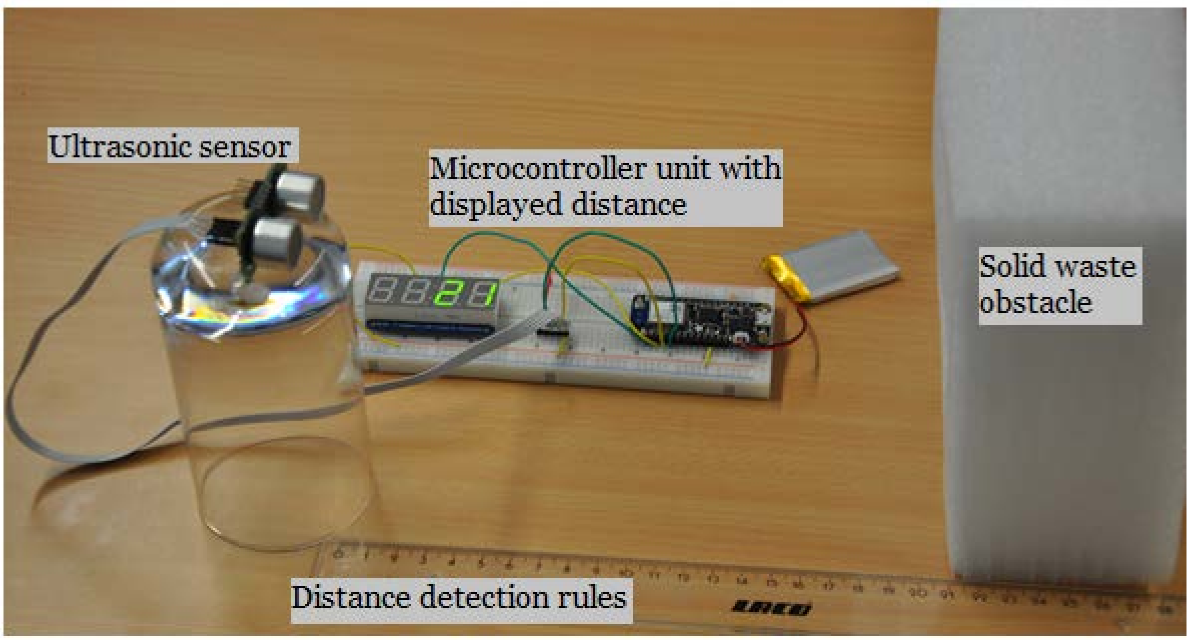


Figure 5. A working sensor prototype

Results and Discussion

In this section results obtained from the implementation of the developed prototypes are discussed. Number of test cases were run with different materials at different distance measurements from the sensor. With the successful internet connection between the sensor and cloud storage via the gateway. Real time solid waste sensor data in centimetres unit of measure, were transmitted at the specified programming time interval and plotted for visualisation. When the smart bin threshold is reached the visualisation remained constant means no more solid waste level was detected as shown in Figure 6, until waste collection service is completely done. A location map Figure 8 was given, depicting the actual location where the smart bin is installed during the monitoring, this is important for the planning of route during waste collection.

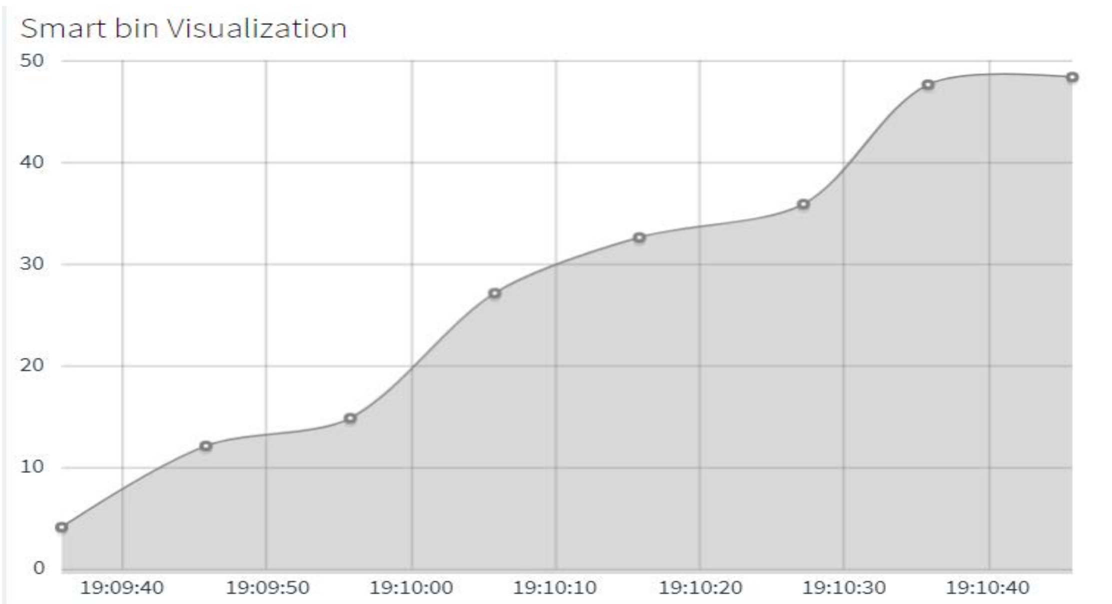
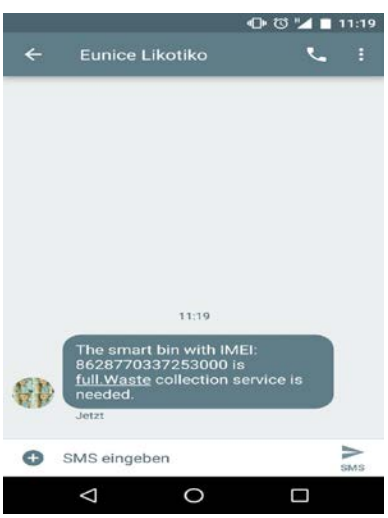


Figure 6. Real time solid waste distance level detection

An alert, both SMS and email were sent to the corresponding cleaning service administrator whenever the smart bin threshold is archived to take an action of assigning truck to go and collect waste. Figure 7 shows the SMS notification sent to the Android Mobile Phone during running of the tests. The SMS consists with the International Mobile Equipment Identity (IMEI) of the GSM module from the microntroller's board for the identification of the smart bin.



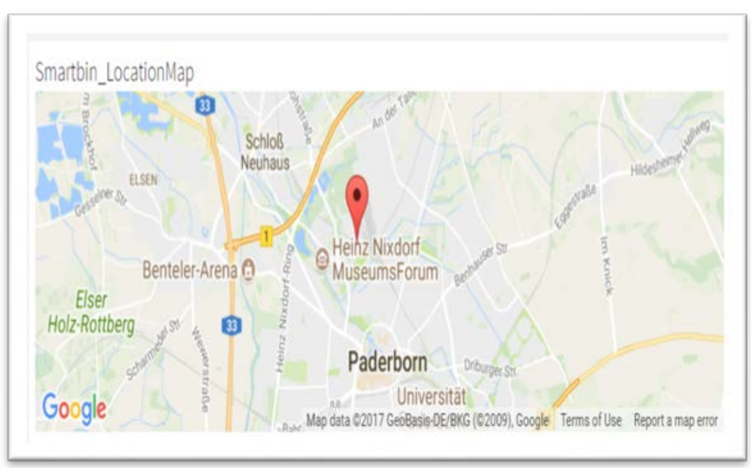


Figure 7. SMS notification

Figure 8. Sensor node location in a map

The developed web based interface Figure 9 was linked with the cloud platform Thinger.io for administrator to browse and retrieve monitoring information. The web also provided the interface for smart bin registration and storage of necessary information regarding smart bin such as *owner's category*, *Bin_id*, *first name*, *last name*, *location*, *email*, and *phone number*. The device IMEI from the GSM module and MAC ID from Wi-Fi module are unique and thus were used as *Bin_id* in the database for the administrator to identify the registered information of the smart bin during assignment of truck for waste collection.

Figure 9. Central system web based platform for smart bin

Ultrasonic ranger srf05 and VL53L0X Time of Flight distance sensor were also tested for the detection of different materials. The study selected materials in a consideration that were common known materials in generation of solid waste, such materials were; Paper, Glass, Polyurethane, Grasses (organic), Bubble wrap, Plastic, Nylon, and Aluminium foil, see Table 2. Both sensors detected the specified material at a time, difference of the sensor performance was observed. VL53L0X ToF sensor was extra sharp and very quickly to detect the even gesture of the material with it thin light source when light bounce back to the sensor in a fraction of second. Even though the sensor was not able to detect an obstacle far beyond 120 centimetres. On the other hand, Ultrasonic ranger srf05 detected material from a far up to 400 centimetres which is two-time maximum distance detection of the VL53L0X ToF sensor with high linearity from the obstacle distance. The triggered sensor sound wave took up to 25ms to make output level detection. The presented results are being useful for the selection of the right sensor for the development of the similar application.

Table 2: Sensors testing table

	Material	Results
1.	Paper	Detected
2.	Glass	Detected
3.	Polyurethane	Detected
4.	Grasses (organic)	Detected
5.	Bubble wrap	Detected
6.	Plastic	Detected
7.	Nylon	Detected
8.	Aluminium foil	Detected

Conclusion

In this work, an innovative three-layer architecture of real time solid waste bin monitoring system based on IoT has been designed and implemented. The system uses wireless sensor network and different communication technologies to monitor the solid waste bin status in real time. A notification is sent wherever the condition is reached and a smart bin location is shown on a map. The developed solution system can be used to reduce valued human resources like human effort, time and cost and improve the sustainability of the solid waste operations and obtaining green environment. Moreover, the study suggested some areas for extension such as waste collection route optimization, power optimization and actual implementation of the proposed architecture and prototypes.

Acknowledgement

The author would like to thank Pro.Dr. Ulrich Hilleringman and Dmitry Petrov of Department of Sensor Technology (Sensorik) at University of Paderborn Germany for the great supervision and technical guidance, and the German Academic Exchange Service (DAAD) for fund support provided.

References

Bashir, A., & Banday, S. A. (2013). Concept , Design and Implementation of Automatic Waste Management System, (July).

Bhor, V., & Morajkar, P. (2015). Smart Garbage Management System. *IJERT*, *4*(3), 1117–1120.

Catania, V., & Ventura, D. (2014). An approch for monitoring and smart planning of urban solid waste management using smart-M3 platform. In *Proceedings of 15th Conference of Open Innovations Association FRUCT* (pp. 24–31). IEEE. https://doi.org/10.1109/FRUCT.2014.6872422

Chowdhury, B., & Chowdhury, M. U. (2007). RFID-based real-time smart waste management system. In *2007 Australasian Telecommunication Networks and Applications Conference* (pp. 175–180). IEEE. https://doi.org/10.1109/ATNAC.2007.4665232

Hassan, S. A. (2016). International Journal of Advanced Research in Smart Solid Waste Monitoring and Collection System. *Ijarcsse*, *6*(10), 7–12. Retrieved from https://www.ijarcsse.com/docs/papers/Volume_6/10_October2016/V6I9-01914.pdf

He, W., Yan, G., & Xu, L. Da. (2014). Developing vehicular data cloud services in the IoT environment. *IEEE Transactions on Industrial Informatics*, *10*(2), 1587–1595. https://doi.org/10.1109/TII.2014.2299233

Hoornweg, D., & Bhada, P. (2012). What a Waste. A Global Review of Solid Waste Management. *Urban Development Series Knowledge Papers*, *281*(19), 44 p. https://doi.org/10.1111/febs.13058

Hossain, M. S., & Muhammad, G. (2015). Cloud-assisted Industrial Internet of Things (IIoT) - Enabled framework for health monitoring. *Computer Networks*, *101*, 192–202. https://doi.org/10.1016/j.comnet.2016.01.009

Kelly, S. D. T., Suryadevara, N. K., & Mukhopadhyay, S. C. (2013). Towards the implementation of IoT for environmental condition monitoring in homes. *IEEE Sensors Journal*, *13*(10), 3846–3853. https://doi.org/10.1109/JSEN.2013.2263379

Mamun, M. A. Al, Hannan, M. A., Hussain, A., & Basri, H. (2013a). Wireless sensor network prototype for solid waste bin monitoring with energy efficient sensing algorithm. *Proceedings - 16th IEEE International Conference on Computational Science and Engineering, CSE 2013*, 382–387. https://doi.org/10.1109/CSE.2013.65

Mamun, M. A. Al, Hannan, M. A., Hussain, A., & Basri, H. (2013b). Wireless Sensor Network Prototype for Solid Waste Bin Monitoring with Energy Efficient Sensing Algorithm. In *2013 IEEE 16th International Conference on Computational Science and Engineering* (pp. 382–387). IEEE. https://doi.org/10.1109/CSE.2013.65

Mamun, M. A. Al, Hannan, M. A., Hussain, A., & Basri, H. (2016). Theoretical model and implementation of a real time intelligent bin status monitoring system using rule based decision algorithms. *Expert Systems with Applications*, *48*, 76–88. https://doi.org/10.1016/j.eswa.2015.11.025

Mwesigye, P., Mbogoma, J., Nyakang'o, J., Idan, I. A., Kapindula, D., Hassan, S., & Van Berkel, R. (2009). Africa review report on waste management: Integrated assessment of the present status of environmentally-sound management of wastes in Africa., (August), 44.

Reis, P., Pitarma, R., Gonçalves, C., & Caetano, F. (2014). Intelligent system for valorizing solid urban waste. *Iberian Conference on Information Systems and Technologies, CISTI*. https://doi.org/10.1109/CISTI.2014.6876904

States, M., Balkan, W., Directive, L., Directive, P. W., Directive, W. F., & Commission, E. (2016). Resource efficiency and waste, 1–7. Retrieved from https://www.eea.europa.eu/downloads/9dbff3aa9f594a9683b6699ad9ab2d6b/1495552180/municipal-waste-management-across-european-countries.pdf

Zurbrugg, C., & Eawag, S. (2003). Solid Waste Management in Developing Countries *, 1–5. Retrieved from www.sanicon.net 5