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RESEARCH PAPER

A COMPREHENSIVE APPROACH TO DOMESTIC WASTE MANAGEMENT

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ABSTRACT
This paper presents a comprehensive method to manage domestic waste and provides a detailed design of an alert sub-system, which is one of the blocks of the proposed waste management system. The waste management system entails various blocks on activities, from preparatory to implementation. The alert sub-system uses an ultrasonic sensor to monitor the level of waste in a bin and notifies a waste collection company when the bin is full and requires emptying, via short messaging service (SMS). It also allows the user to query the state of the bin at any time. The alert sub-system is simple to implement, inexpensive, uses less power, and will enable effective and efficient waste collection. The implementation of the proposed waste management system should improve the collection and disposal of domestic waste.

Keywords: *Microcontroller, smart bin, waste disposal, waste collection*

INTRODUCTION

In recent times, there has been significant rise in waste generation globally (Wahlen, 2018). The world's cities generated 2.01 billion tons of solid waste, amounting to a footprint of 0.74 kilograms per person per day in 2016 (Chavez, 2018). With rapid population growth and urbanization, globally annual waste generation, is projected to grow by 70% from 2016 levels to 3.40 billion tons in 2050 (Chavez, 2018) .

Ghana, as middle-income country, is confronted with a lot of challenges in waste management. According to Miezah *et al.* (2015), the rate of waste generation in Ghana is high, with waste generation estimated at 0.47 kg/person/ day. Meizah *et al*. (2015) also concluded that in Ghana, biodegradable waste (organics and papers) constitutes nearly 68% of the daily waste generation, with the rest being non-biodegradables or recyclables (metals, glass, textiles, leather and rubbers). Generally, in Ghana, solid wastes are not sorted into biodegradables and non-biodegradables before disposal. A huge fraction of the solid waste is organic and susceptible to putrefaction. Consequently, delays in collection of waste lead to putrefaction and generation of stench. Moreo-

ver, there is the attraction of vermin (flies, cockroaches, beetles, etc.) and scavengers that pose a threat to public health. Ghana's waste management problem is further compounded by the lack of effective and efficient waste collection and disposal systems. There is the need for timely waste collection and appropriate disposal.

Generally, there are three modes of waste collection and disposal in Ghana. The first mode requires persons who generate waste to carry it, by any preferred means, to a damping site within the community. Waste at such sites are occasionally burnt, releasing toxic gases into the atmosphere, or left to form a huge pile, breeding all manner of pathogens, before being carted to a landfill site. In the second mode, skips are placed within communities for inhabitants to damp waste into them. These skips are later emptied by waste management companies (WMCs) when they become full. However, it is common to find such containers overflowing with waste, undergoing putrefaction and resulting in unpleasant stench and the breeding of pathogens. The third mode entails households and institutions acquiring their own waste bins and dumping waste into them. These waste bins are emptied by WMCs who drive through the various communities with waste trucks. This mode is environmentally good and in synch with international best practices. However, not many communities have such waste collection services. Therefore, there is the need to scale up such services across the nation.

The success or failure of scaling up individual ownership of waste bins largely depends on timeous emptying of them. This will involve the extensive use of trucks, with its associated costs. Studies show that the cost of waste collection constitutes 60-80% of the overall cost of waste management (Ansari and Pakrou, 2015; Beliën *et al*., 2014; Sulemana *et al*., 2019). This is due to the high cost of fuel and maintenance (Li *et al*., 2014) and Tavares *et al.*, 2009). This cost is further compounded when trucks drive to locations where bins need not be emptied. Such cost can be reduced or completely eradicated via the deployment of technologies that alert WMCs when waste bins need to be emptied. Such technologies will be beneficial to both WMCs and households.

Researchers have developed various approaches to aid the detection and location of waste bins that get full (Gutierrez *et. al*., 2015 Zavare *et. al*., 2017 and Nirde *et. al*.,2017). However, these approaches are beset with challenges that make them either too expensive to implement or not practically feasible. For example, the work in Zavare *et. al*. (2017) requires internet availability at all waste locations, which is not practically feasible, especially in developing economies where there is limited internet access. The approach in Samann (2017) incorporates extraneous devices including passive infrared sensors, memory cards, speakers and solar panels which increase cost and complexity. Therefore, there is the need to develop systems that are economically and practically feasible.

This paper presents a comprehensive approach to manage domestic waste. The proposed system builds a database of all bins including their locations. Alert systems are installed in the bins to alert waste management companies when they are full. Waste management trucks move in to collect waste when alerts are received. The routes of waste trucks to bins to be emptied are optimized to promote effective and efficient collection. A detailed design of the alert devices is presented in Section 3.0. The devices employ ultrasonic sensors to monitor the levels of waste in bins and notify the waste collection company, via short messaging service (SMS), for collection to be done. The proposed comprehensive waste management system together with its subsystems are simple to implement and will enable affordable, effective and efficient domestic waste management.

MATERIALS AND METHODS

The proposed waste management system comprises two phases. The phases are (1) preparatory phase and (2) implementation phase. Fig. 1 shows a flowchart that describes the activities of the preparatory phase. The preparatory phase entails three major activities. The activities are as follows: (A) Creation of database of waste bins including their locations, (B) setting up of a management software to regulate

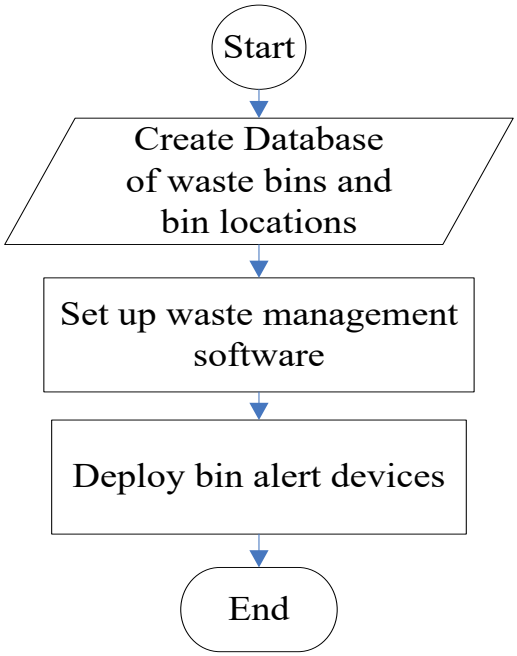

Fig. 1: Flowchart of activities for preparatory phase

the entire waste management operations, and (C) deployment of bin alert devices.

The first preparatory activity (activity A) entails the enrolment of all waste bins within the operational area of a WMC. Here, it is recommended that each customer acquires multiple bins in which sorted waste is deposited. Each bin is given a unique identification number and classified based on the waste categorization approach adopted by the WMC. Also, the GPS location of each bin is determined to allow for easy location in the implementation phase. For the second activity (activity B), a software developed to manage waste collection is set up. The software will host the database created in activity A. It will also allow for the receipt of notifications from devices to be installed in the enrolled bins that will alert the WMC when the bins require emptying. Furthermore, the software will collate all received notifications, plot optimal route maps for waste collection, schedule and dispatch waste trucks. The final preparatory activity (activity C) involves the deployment of bin alert devices on the registered bins.

A flowchart outlining the implementation phase is presented as Fig. 2. It begins by checking for notifications from bin alert devices. When no notifications are received, the system waits for a period 10 minutes and checks again. This can be adjusted depending on experiences gathered during implementation. Consequently, the waste management software allows for this period to be adjusted. When notifications are received, the software extracts the bins that correspond with the received notifications and proceeds to determine the optimal routes for collection. A further assessment is done to determine the cost efficiency. This assessment is proposed to be based on the number of bins in the route and the cost of collection. Where the assessment

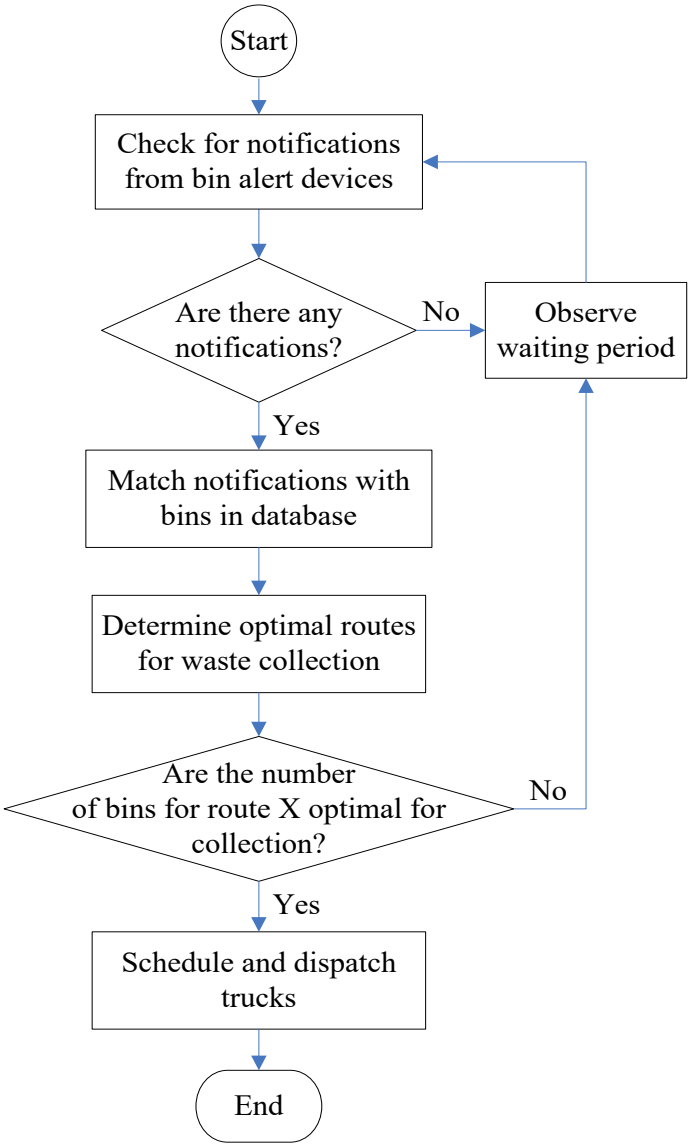

Fig. 2: Flowchart for implementation phase

points to a positive cost effectiveness, waste trucks are scheduled and dispatched. When the assessment turns out to be uneconomical, the algorithm waits and checks for more notifications to ensure cost-effective operations. The fact that domestic waste is generated mainly in the mornings and evenings would not make such deferment of collection on grounds of economy inimical to waste collection efforts.

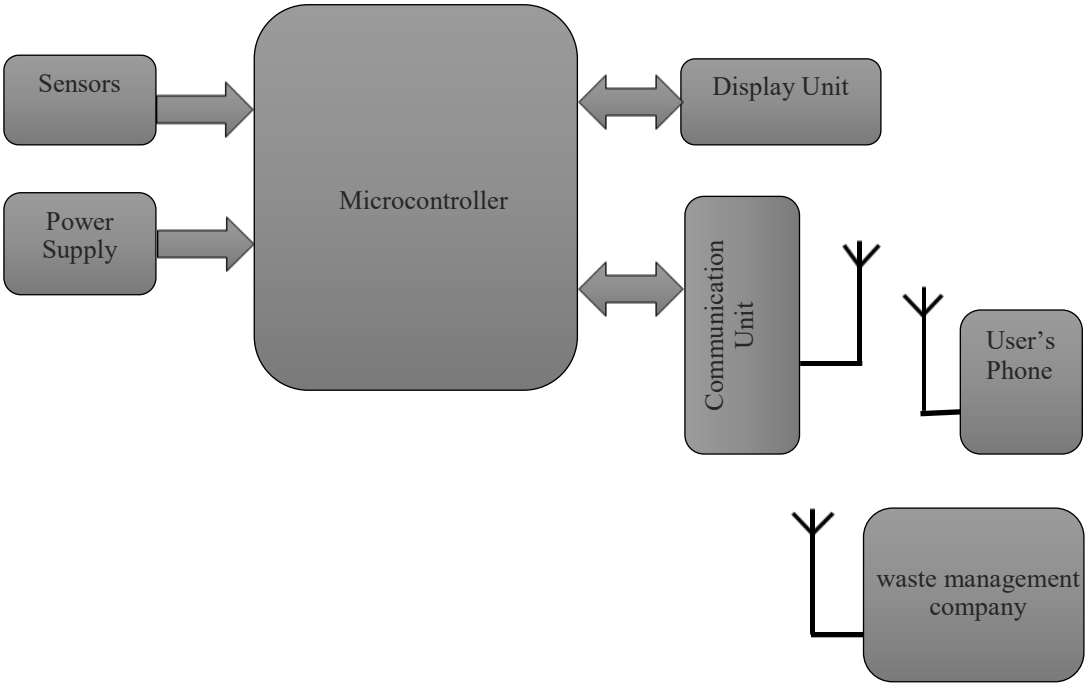

Fig. 3: Block diagram of proposed design

Bin alert device

Fig. 3 shows a block diagram of the proposed alert device. The device will be integrated into the lid of bins. It consists of four units namely, power unit, sensing unit, processing unit and communication unit. The power unit comprises a 9V DC battery and supplies the needed power to all the units of the device. The sensing unit comprises an ultrasonic sensor module which detects the level of waste in the bin using time of flight. An Arduino microcontroller was used for data processing. The microcontroller was programmed using Arduino Integrated Development Environment (IDE). A Global System for Mobile Communications (GSM) module was used as the communication unit. This unit sends Short Message Service (SMS) alerts to the waste management company and user's phone.

The module is controlled by sending AT commands over its 5V serial port. The Rx pin of GSM module is connected to analog pin 9 on the Arduino Uno and the Tx pin of the module is connected to pin 10 of the Arduino Uno board. Pin 9 and 10 are turned into Transmitter (Tx) and Receiver (Rx) pins using a software library since the GSM module relies on serial communication (Samann, 2017).

Simulation of the system design in Proteus

The proposed design was simulated using the proteus simulation software to assess its validity before prototyping. A snapshot of the simulation is presented in Fig. 4. In Fig. 4, Block A shows ultrasonic sensors, Block B depicts GSM module, Block C indicates LCD display and Block D, variable resistors. The variable resistors were used to simulate the levels of waste in the bin.

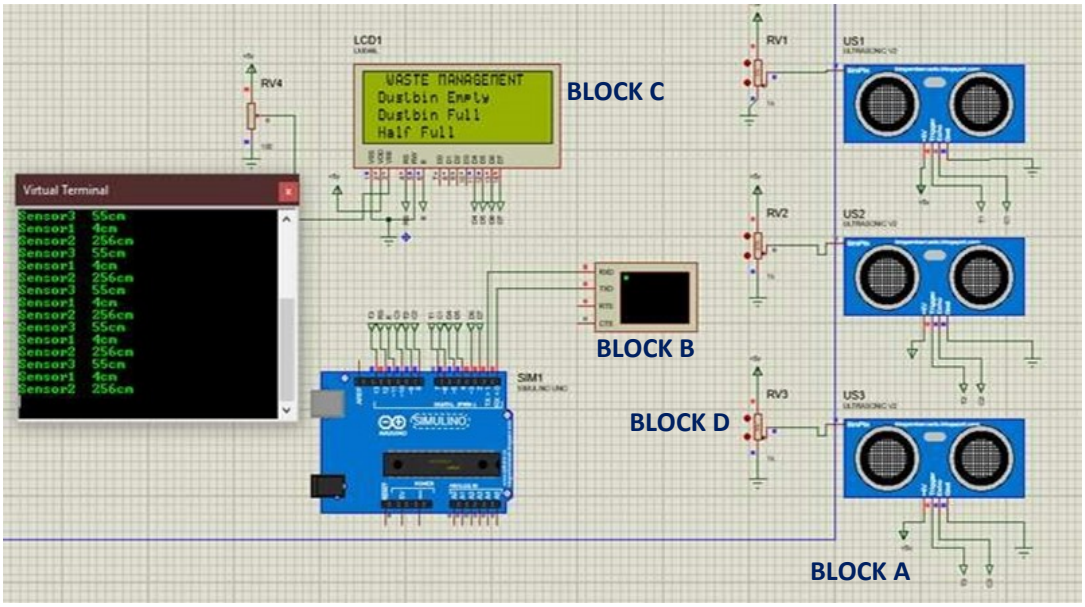

Fig. 4: Snapshot of simulation in Proteus software

Software for monitoring system

The program for the microcontroller was developed using Arduino IDE. Fig. 5 shows a flow chart of the Arduino program. Two libraries were used to mimic communication between the modules. Software serial library is used to communicate with the GSM module and send AT commands to it.

This library transforms pins 9 and 10 into extra Tx and Rx pins to connect the Tx/Rx pins of the GSM module. The Setup function of the Arduino program first defines the used pins as outputs or inputs and then sends AT commands to the GSM module to enable text mode, enable local time/date stamp and store current settings on the GSM module memory. This function is also used to get the phone number and SMS alert text, which will be sent to that number in case of fullness of bin. The final step of setup function is initializing digital pins of the Arduino connected to the Ultrasonic sensor. The Loop function is used to measure the distance between the ultrasonic module and the trash continuously. The measurement period can be changed to suit operating conditions. An IF loop is used to compare the measured distance by the ultrasonic sensor to the set threshold. If there is fullness, an SMS alert is sent to the WMC. The system can also be queried via SMS with "STATE". It returns the state of the bin as full, half full or empty by sending an SMS to the user's phone.

Prototyping of alert device

The proposed device was prototyped using the following components: Ultrasonic sensor, Arduino, GSM and LCD. In field implementations, the LCD module will be removed since its role will not be needful and will only drain the battery power. Figs 6a & b shows the connection of the major components used for the prototype.

RESULTS AND DISCUSSION

The monitoring device was tested on a galvanized metallic bin, with the bin in empty and full states. With the bin empty, the device was initialized following which a text message with the content (STATE) sent to the SIM card

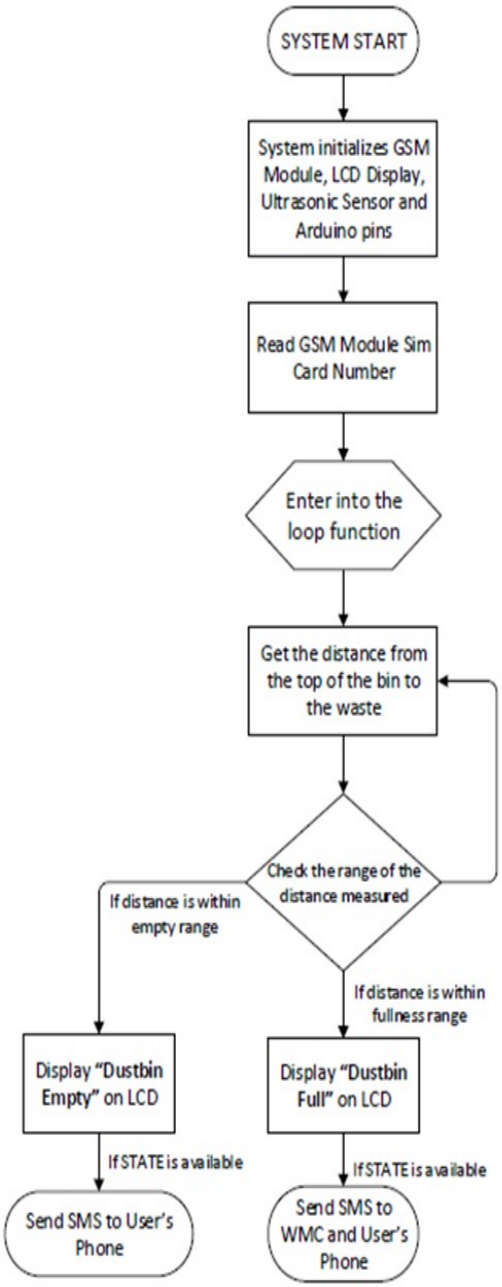

Fig. 5: Flow chart of the code for the prototype

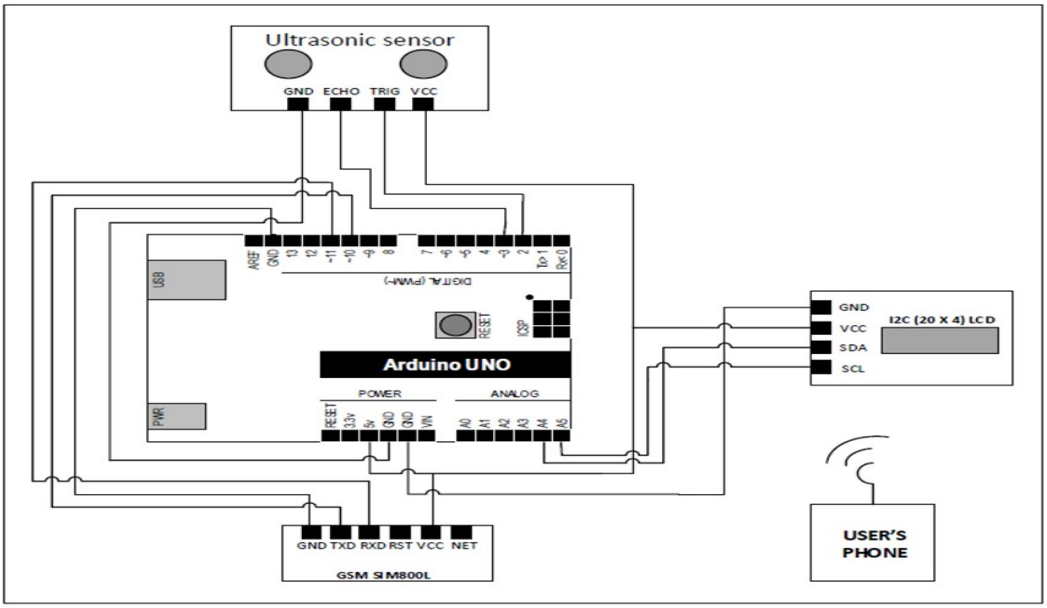

Fig. 6a: Connection diagram of the prototype

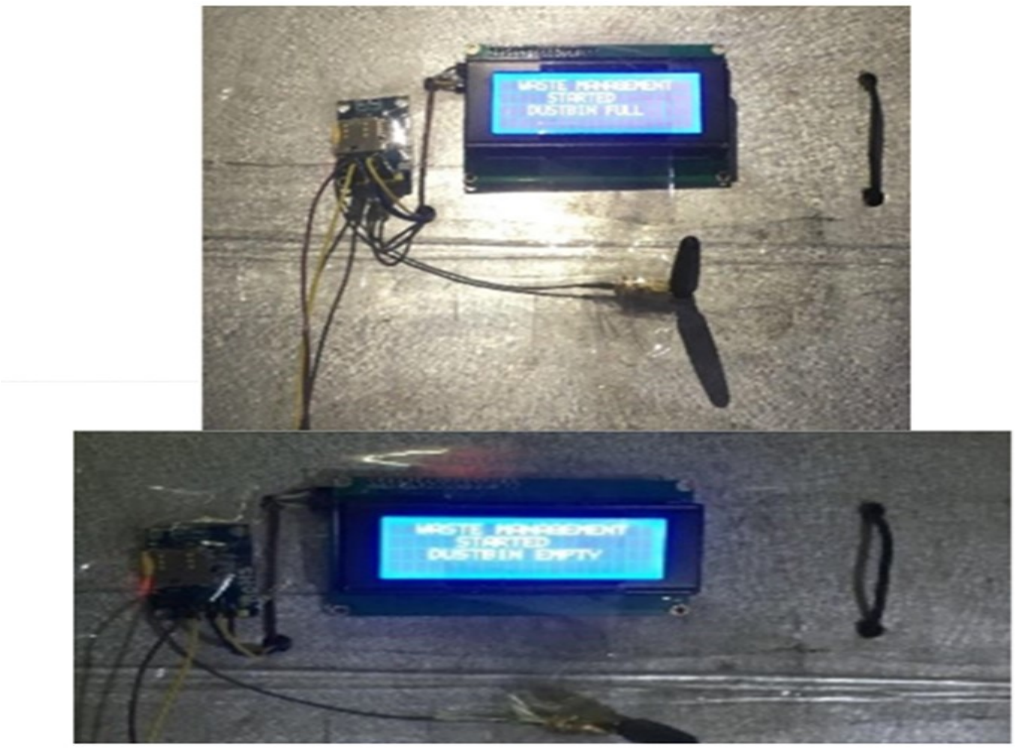

Fig. 6b: LCD and SMS displays during testing

in the GSM module. The state of the bin was returned to the user's phone as being empty. The bin was later filled with paper and the system energized. The system reported the status of the bin to the user's phone with the message "Dustbin full". In both cases, the state of the bin was accurately displayed on the LCD. Fig. 6b shows various displays during the testing.

CONCLUSION

A comprehensive waste management system and a device for monitoring waste have been presented. The waste management system will afford a more organized waste management and improved waste collection. The device for monitoring waste can be easily integrated in the lids of existing bins and does not require any redesign of bins. Since there is broad coverage of cellular networks, the device can be used at all locations. It is user friendly and does not require any expertise to operate. Future works will expand the other sub-systems of the proposed waste management system and deal with putrefaction associated with organic waste, which will necessitate early collection of waste even when bins are not full.

REFERENCES

Ansari, M., and Pakrou, S. (2015). Optimization of MSW collection routes using GIS (Case study: Tabriz City). Current World Environment, 10 (1): 882–890.

Beliën, J., De Boeck, L., and Van Ackere, J. (2014). Municipal solid waste collection and management problems: A Literature Review. Transportation Science, 48 (1): 78–102.

Chavez, D., 2018. *The World Bank IBRD/IDA.* [Online] Available at: https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management [Accessed 12 December 2019].

Gutierrez, J. M., Jensen M., Henius , M. and Riaz, T. (2015). Smart Waste Collection System Based on Location Intelligence. *Procedia Computer Science,* 61: 120-127.

Miezah, K., Obiri-Danso, K., Kadar, Z., Fei-Baffoe, B. and Mensah, M. Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management,* 46, pp. 15-27.

Nirde, K., Mulay, P. S. and Chaskar, U. M. (2017). *Iota based solid waste management system for smart city.* Madurai, India , International Conference on Intelligent Computing and Control Systems (ICICCS).

Li, C.-Z., Zhang, Y., Liu, Z.-H., Meng, X. and Du, J. (2014). Optimization of MSW collection routing system to reduce fuel consumption and pollutant emissions. Nature Environment and Pollution Technology, 13(1): 177–184.

Samann Faddy, E. F. (2017). The Design and Implementation of Smart Trash Bin. *Academic Journal of Nawroz University, 6(3): 141-148.*

Zavare, S., Parashare, R., Patil, S., Rathod, P. and Babanne, V. (2017). Smart City Waste Management System Using GSM. *International Journal of Computer Science Trends and Technology, 5(3) : 74-78*.

Sulemana, A., Donkor, E.A., Forkuo, E.K. and Oduro-Kwarteng, S. (2019). Effect of optimal routing on travel distance, travel time and fuel consumption of waste collection trucks. Management of Environmental Quality, 30 (4): 803-832.

Tavares, G., Zsigraiova, Z., Semiao, V. and Carvalho, M. G. (2009). Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. *Waste Management*, 29 (3): 1176–1185.

Wahlen, C. B., 2018. *IISD/SDG Knowlege Hub.* [Online] Available at: https://sdg.iisd.org/news/world-bank-report-warns-global-solid-waste-could-increase-70-percent-by-2050/ [Accessed 12 December 2019].