Analysis of IoT-enabled Solutions in Smart Waste Management

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***Abstract*—Internet of Things (IoT) has attracted widespread applicability not only limited to smart cities and communities but also in water, waste management and so on. It strength lies in the high impacts it created in the daily life and the potential user's behavior. However, for it to be more effective and increase its adoption, it is require to be energy efficient, able to communicate and share information across extended coverage. Existing technology such as Low Power Wide Area Network (LPWAN) with Long Range (LoRa) has been promising. In the perspective of waste management, several different IoT-enable solutions have been proffered with each having its own strengths and weaknesses that requires improvements. Therefore, this paper performs a review of existing IoT-enabled solutions in smart cites' waste management to bring together the state-of-the-art. The objective is to gain insights into the strengths and weaknesses in order to bring improvements and innovations to manage waste effectively and efficiently as well as maintain a healthy environment in our cities. We performed reviews on 15 research articles in the literature and the results obtained shows that existing solutions were similar in the technologies used but have some drawbacks such as sensing accuracy hindered by various weather conditions, users prone to unauthorized access and short range capabilities. This thus, calls for further improvement and innovation.**

Keywords— Waste Management, IoT, Smart Cities, Sensors, Garbage.

I. INTRODUCTION

Internet of Things (IoT) is a new communication paradigm projected as a global network of physical objects and devices having the capability to interact with each other. It constitute a network of physical objects, devices, machines, homes and so on, equipped with electronics, sensors, software and network connectivity with appropriate protocol stacks that makes them able to collect and interchange data with one another [1, 25, 26]. In IoT, a 'thing' can be any natural or artificial objects that can be uniquely identified with numbers, names or addresses and equipped with the capability to share data over the network. Today, IoT is gaining considerable attention in several industries and has been known as one of the most promising areas of future technology [27, 28]. For instance, IoT true value for enterprises is realizable when connected devices are able to interact and integrate with their systems and operations.

With the advent of IoT, the has witnessed devices proliferation and these new generation of IoT devices have been tagged 'smart', having the capability to sense, compute, communicate, and integrate effortlessly with the surrounding environment [2]. Smart devices are embedded with electronics considered as sensory swarm and heterogeneous in nature with respect to lifespan, resource capabilities and communication technologies [2, 23]. Moreover, these smart devices have predicted to exceed the number of other classic devices in accessing the Internet in the near future [3, 24]. In particular, [3] has estimated that about 26 billion smart devices will be connected over the Internet by 2020. Presently, the application scenarios driven by IoT are in environmental monitoring, smart logistics, automotive and smart mobility, smart energy and smart grid, smart cities and communities, healthcare, video surveillance, smart home, smart waste management and smart metering [4][29][30]. Thus, IoT strength lies in the high impacts it created in the daily life and the potential user's behaviour.

In the perspective of the application of IoT in smart cities, waste management is an important area that is commonly addressed. As population is ever increasing, more waste is generated daily in the equation. However, one of the key challenges in cities is the inability to effectively manage these wastes. The approaches to manage wastes are very limited and require much human efforts or interventions. Consequently, some governments or organizations do not have the capability to monitor and track the daily generation of wastes in cities and people are then forced to live in unhealthy environments. Thus, it is important to keep a clean environment because of the impacts it has on the health of the people and reputation of the entire city. With the limitations of human interventions in solving waste problems in cities, IoT-enable solution such as Lower-Power Wide Area Network (LPWAN) using long range (LoRa) [5, 6] technology emerged as viable solutions. LoRa is an IoT technology which is wireless, long ranged, low power and utilized radio spectrum that is unlicensed in the industrial, scientific, and medical radio band (ISM) band [7]. It is considered cost-effective, eliminate repeaters, prolong device battery lifespan, improve network performance, and support connected heterogeneous devices [5]. With LoRa, several IoT-enabled solutions have been developed in the management of wastes in cities. Each of these solutions has its own design, operational approach, strengths and weaknesses.

Therefore, this paper brings together the state-of-the-art of the different IoT-enabled solutions with a focus on the design and implementation of a smart waste collection system, the benefits and their limitations. The objective is to gain insights into the challenges of managing and collecting waste bins in cities in order to bring improvement and innovation to maintain healthy environments. We performed the review on existing research articles in the literature. Our findings shows that though the systems used similar IoT technologies, they suffered from sensing accuracy, prone to unauthorized access and short range capability.

The remaining parts of the paper is organized as follows: Section II presents the analysis of the existing works in waste management, Section III is the paper discussion and Section IV is the conclusion of the paper.

II. Analysis of Existing Works In IoT-enableed Waste Management

This section presents analysis of some of the existing works in IoT-enabled wastes management. There are discussed as follows.

A. Smartbin: Smart Waste Management System [8]

Folianto, *et al.* [8] proposed a system that identifies the when a litter bin is completely full. In this system, data is collected and transmitted via a wireless mesh network. Moreover, to reduce the amount of power consume and maximize the time efficiency of the operations, the system employs duty cycle technique. However, the technology employed uses short range connection for the system such as WiFi and Ethernet Internet connections. Also, the use of ultrasonic sensors used affected the optimum performance of the system, because these sensors are sensitive to certain temperature variation.

B. Smart City waste management using GSM [9]

Zavare *et al.* [9] proposed a system for the identification and collection of wastes in a garbage bin. In this system, the garbage containers transmit signals to the appropriate authority indicating that it is over 80% or 90% full and requires to be emptied. Once the garbage bin is full, a signal or notification is then sent via a mobile communication network to a web-based application used by the waste management authorities and the garbage collecting vehicle. By using the Global Systems for Mobile communications (GSM) technology, a unique id is assigned to every bin and it will send its location coordinates to the vehicle. The entire system is made up of ultrasonic sensors, the GSM module and a power supply. Nonetheless, the drawbacks of this solution are that: the GSM is prone to bandwidth lag and that the fill level is considered too high (80-90%), meaning that should there be a delay in the collection of the bin. It would be found overflowing and waste lying around which could pose health risks to the environment.

With this type of system, an enhancement would be employing a web server with effective graphic user interface and controlling actions. All bins will be equipped with GPRS enabled embedded system. Central servers receive information from bins and store all necessary information such as bin level history, number of dispatched waste collecting vehicles etc. Thus, based on the prediction of collected data on bin level, it enables the optimization of number of vehicles to be used. An application for smartphone will be developed, through which people can report to the appropriate authority with fill level, photos, comment, etc. With the integration of all the technologies, a new way of waste management system will emerge. Thus, this could lead to a significant reduction in the amount of garbage in the city, the cost of transportation and the realization of clean and convenient environment.

C. IoT based smart garbage and waste collection [10]

Navghane *et al.* [10] also proposed a smart waste collection bin using the combination of sensors such as weight and infra ray (IR) sensors. These sensors are equipped with the capability of sensing the weight and different levels of garbage respectively. In this case, the IR sensors will show the various levels of garbage in the dustbins and activate the weight sensor to transmit the results ahead when its threshold level is reached. The receiver end is also equipped with a mobile handset connected to a WiFi router in order to display the details of the garbage bin using HTML in a web browser. However, the limitation of the system is that, in the event that a user doesn't have access to phone or in the event of battery failure or Internet failure, the user will not be able to receive notifications of the bins' status and allocate collection trucks. In the future, the system could be improved by sending the status of the bin directly to the cleaning vehicle instead of the authorized persons' office.

D. Smart garbage monitoring and clearance system using IoT [11]

Kumar *et al.* [11] in their work proposed an IoT-based smart waste clean management system where sensor systems are used to constantly checking the waste level of the garbage bins. In this approach, once the waste level over the dustbins is detected, the system automatically alerts the authorized person via GSM/GPRS. They system operates by using microcontroller which provides interface between the sensor and the GSM/GPRS system. Moreover, an Android application is used to monitor and integrate the relevant information relating to the various level of waste found in different locations. With this system, a new user can only register on the system and not just the admin. However, anyone can create an account and the system also grant access to users not intended for. This system can be improved by placing two bins to separately collect dry and wet wastes. In this case, the wet waste can be further processed and be used for the production of biogas, made durable by making it compact and cost effective.

E. Smart garage monitoring system for waste management [12]

Abdullah *et al.* [12] developed a smart garbage monitoring system which is used in the measurement of garbage level in real-time and alerts the appropriate authority through SMS text messages. The system is designed to monitor the waste bin and send the messages in the form of warnings when sensed to be

full or almost full in order to facilitate its removal of the bin on time. The importance of the system is to improve the efficiency of solid waste disposal management at all times. However, the drawback is that the notification of the bins' status doesn't include the location of the bin or its coordinates, making it cumbersome to locate and collect the waste bins promptly.

F. Smart garbage collection system in residential areas [13]

Prajakta *et al.* [13] proposed a garbage collection system that is automatic having information collection system based on the processing of images taken and GSM module. To achieve this capability, the system employs a camera which is placed at every position where garbage is collected alongside a load cell sensor positioned at the base of the garbage bin. In this case, the camera will constantly takes snapshots of the garbage bin while the load cell sensor takes the weight to determine if full or not. Moreover, a threshold level is set which is used to compare the result of the camera and load sensor. Once the threshold is reached, the controller transmit a message via the GSM module to the appropriate authority notifying them that the garbage bin is full and should be disposed. Accordingly, the garbage bin collection vehicle is dispatched to collect the garbage using a robot mechanism. However, pitfall is that the camera takes pictures throughout even though its threshold is reached but only considers the most recent to determine collection. Thus, the use of camera is unnecessary or unimportant.

G. Smart garbage monitoring system using IoT [14]

Chaware, *et al.* [14] proposed a waste collection system considered innovative to assist in keeping cities clean. The system operates by monitoring garbage bins and notify the authorities and the garbage collection vehicles about the level of garbage stored or contained in the garbage bin through a web application. Nonetheless, the system uses ultrasonic sensors in which their sensing accuracy can be affected by changes in temperature. In addition, it employs WiFi which is inherently a short range connection tool. Thus, these drawbacks affect the optimum performance of the system.

H. Intelligent bi management system for smart cities using mobile application [15]

Kalpana, *et al.* [15] proposed an intelligent bin management system which stores all the details about the dustbins and their location on the server. In this system, the users are responsible for monitoring the level of the garbage in the bin as well as sending such information to the server. The details are accessed by the appropriate authorities at the receiving end via the Internet and immediate response can be initiated to dispose the bin of the garbage. In this system the bin can only be emptied when a user sends the status of the bin to the server through a mobile application. Thus, the disadvantage is that concerned authorities cannot monitor the waste level in real-time but rather have to wait for messages. Also, if a user is unable to send the message it means that the environment will be littered with waste when the bin is full.

I. SWACHH: An effective real time solid waste management system for municipality [16]

Sanket, *et al.* [16] in their work proposed a system having the capability to provide information about waste bins when they are full or the garbage level is reached. In this case, alerts are sent to the appropriate authorities to inform them about the immediate collection of the waste in bin in order to keep the environment clean. This employed ZigBee and GSM technology to enable solid waste bin to be monitor remotely in real-time mode and send notification to the appropriate authorities about the status of the garbage bin especially when is almost full. However, drawbacks are the limitations of the technologies used; for instance, GSM is bandwidth lag, Ultrasonic sensor sensing accuracy is affected in changing weather conditions and ZigBee has low transmission rate. These factors affect the optimum performance of the system. For the future perspective, a web server can be built which effective GUI and controlling action as well as the all the bins equipped with GPRS enabled embedded system.

J. Smart and wireless waste management [17]

Thakker, *et al.* [17] proposed smart garbage bin integrated with alarms that operates in the same way as other systems. The system has the capability to inform the appropriate authorities when the garbage bin is about to or completely full. Moreover, instead of dumping the all forms of waste on landfill area, the work proposes a method to separate biodegradable from non- biodegradable wastes using NIR spectroscopy. However, the disadvantage of NIR is that it contains less information on the spectra and the accuracy can be affected.

K. Waste bin monitoring system using integrated technologies [18]

Mahajan *et al.* [18], developed an approach for garbage collection. In this system, sensors are integrated with the common garbage bin placed at the public places and when the level of the sensor is reached by the garbage bin, the ARM 7 controller will send a notification to the garbage collection truck driver. The notification is to inform authorities that the garbage bin is completely filled and should be removed urgently. Nonetheless, the limitation of the technologies used affects the optimum performance of the system as stated in [18].

L. A versatile scalable smart waste-bin system based on resource limited embedded devices [19]

Papalambrou *et al.* [19] presented an architecture of a multipurpose and scalable system for waste bins that can sense and send accurate waste level of the bins while consuming less resources and having cost-effective components. The system operates by utilizing ultrasonic sensors that senses and transmits waste fill-level estimations. The system was modelled, simulated using MATLAB and physical implemented. In the implementation, RFID technology is employed having an active RFID tags that stores the information as well as RFID readers that reads and interpret the information. Moreover, the simulation statistical analysis alongside the experiments and testing performed in the field confirmed the accuracy and efficiency of the system using a

tiny data-load fingerprint. However, the drawback of this work include the limitations of the technologies used such as RFID tag can be less reliable and ultrasonic sensor having sensing accuracy affected in changing weather conditions. These significantly hindered the optimum performance of the system.

M. IoT-enabled citizen attractive waste management system [20]

Al-Jabi, *et al.* [20] proposed the design of a waste management system which is attractive in nature. The system uses IoT devices, RFID tags, weight and ultrasonic sensors to measure how people interacts with waste management process. However, the limitation of this proposed solution is that each time a person wants to place trash in the bin, an RFID card should be used for an identification via the RFID reader attached to the bin. To this end, in the event that a card is being lost or damaged, the bins' status cannot be sent to the application server. Thus, an improvement to this system can be the introduction of algorithms that take into account the bin filling rate, location of collection truck and the shortest path to the location to efficiently compute the threshold for each bin and to optimize the bin dumping process.

N. Smart bin: An intelligent waste alert and prediction system using machine learning [21]

Baby, *et al.* [21] created a smart waste bin for prompt collection of waste. The system operates by alerting the appropriate authorities of the status of the bin for immediate collection and disposal. They system provides guide to the garbage trucks to collect the garbage in the areas where the bin is completely full. The system will automatically send notification in the form of an email alert and text message to the appropriate authorities when it detects that the waste bin's threshold is reached. The benefits of this system is that it would save the authorities considerable time and money, reduce pollution and prevent spreading of diseases. However, the limitation is that the text message sent upon request for bin collection does not state the bin's details in terms of the specific coordinates and identity.

O. Cloud-based smart waste management system [22]

Aazam, *et al.* [22] proposed a smart waste management mechanism that is a cloud-based in nature. In this system, the waste bins are equipped with sensors which senses and alerting of the waste level status which is sent and stored in the cloud. In addition, for efficient and effective town administration and waste management, route can be optimized and path selected for the collection of waste based on the received statuses of waste bins. The limitation is that, it cannot be implemented for door-to-door collection of waste because it requires that each type of waste has its own bin for recycling purposes. Moreover, the future improvement can be its extension to a particular context or specific waste management trends in a country. In this case, Big Data analysis can be employed in the analysis of the data collected from different localities.

III. DISCUSSIONS

Today, IoT technology has been considered a reality as several and heterogeneous devices are being connected to the Internet as well as influencing our day to day activities in a number of ways. IoT has brought about constant interconnectivity between objects, people, sensors and services. The technology has achieved a widespread application in which cities' waste management is not an exception. In this paper, we have discussed several works on smart waste collecting systems as IoT-enabled solutions for smart cities' waste management. The importance of this study is to identify different works on IoT applications related to smart waste collection, their limitations, possible solutions, technologies used, their efficiency and performance. The summary of the findings is shown in Table I and Fig. 1 shows the generic architecture of smart waste management.

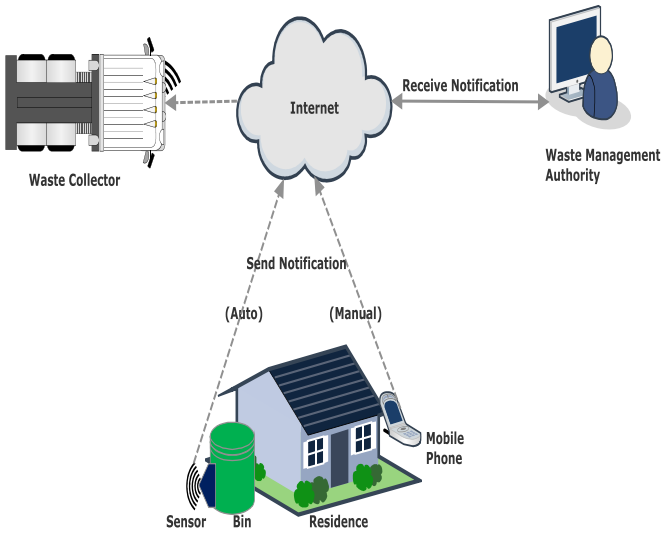

Fig. 1. General smart-waste collection architecture

The analysis performed shows that there are several different solutions to waste management using IoT technologies with each having its approach, strengths and weaknesses. However, all the approaches seems similar but only different with the IoT technologies employed. For instance, all the studies considered in this paper developed a waste collection system using IoT devices which operates by sensing the threshold level of the waste bin and send notification or alerts to the appropriate authorities when the bin is full [8-22]. The communication of this information were achieved using SMS text messages, mobile applications and so on. Also shows shown in Table I are the general challenges faced by the IoT technologies used in the systems. The drawbacks experienced with these devices include sensing accuracy affected in various weather conditions, users prone to unauthorized access especially for RFID card and having short range capabilities that affects the performances. In particular, the tools used to send bin status to the receiver side are short ranged and required installation tools that make them not to be practical in a city application, and some of the systems do not have location tool that alerts the receiver of the location of the full bin.

TABLE I. SUMMARY OF IOT-ENABLED SOLUTIONS IN WASTE COLLECTION

Ref.	IoT Technology	Communication Technology	Pilot Size	Range Achieved	Location information tool	Micro-controller used	Limitation
[8]	Ultrasonic sensor	Ethernet/WiFi OR 3G connection	11 smart bins 2 gateways	240 meters 110 meters (different areas)	GPS	-	Ultrasonic sensors: sensing accuracy can be affected by changes in temperature
[9]	Ultrasonic sensor	GSM	-	-	GPS	Node MCU controller	GSM is prone to bandwidth lag
[10]	Infrared sensor	WiFi	-	-	-	ARM LPC2148 controller	WiFi is a short range connection technology
[11]	Ultrasonic sensor	GSM/GPRS	2 Smartbins	-	GPS	"not specified"	A new user gets register himself, this means anyone can have access to the system
[12]	Ultrasonic sensor	GSM	-	-	-	Arduino Uno microcontroller	It uses a text message to notify the municipality
[13]	Load sensor	GSM	-	-	Robot mechanism	LPC2131/32/34/36/38	GSM is prone to bandwidth lag
[14]	Ultrasonic sensor	WiFi	-	-	-	Arduino Uno microcontroller	WiFi is a shirt range communication technology
[15]	Cloud computing	-	-	-	-	-	A user has to send the status of the bin
[16]	Ultrasonic sensor	ZigBee GSM	-	-	-	Arduino Uno microcontroller	ZigBee is prone to attack from unauthorized people
[17]	Ultrasonic sensor	GSM/GPRS	-	-	GPS	-	NIR contains less information on the spectra
[18]	Ultrasonic sensor	ZigBee GSM	-	-	-	UARP microcontroller	ZigBee is prone to attack from unauthorized people
[19]	Ultrasonic sensor	RFID	-	-	-	ARM 7 controller	RFID is prone to unauthorized access
[20]	Ultrasonic sensor	RFID	-	-	GIS server	-	Requires the person to always have the RFID card upon using the bin for identification
[21]	Ultrasonic sensor IR sensor	Ethernet	-	-	-	Arduino Uno microcontroller	Bins' notifications, do not have location details and ID
[22]	Ultrasonic sensor	-	-	-	-	-	Requires that each type of waste material has a bin thus can't be implemented on door to door.

Moreover, we identified the relevance of choosing appropriate technology when designing IoT-enabled waste collection. That is, technology having less limitations and can work excellently in many or different scenarios. Thus, the communication tools used from the bin to the receiver side is of importance when implementing such solution. The technology should have a large coverage and long battery life. The location tool used to send the bin status should be able to state the location and unique ID of the bin as well as give and an optimized route for waste collection.

IV. CONCLUSION

IoT communication paradigm have provided the capability for devices to communicate and share information in long range distances while utilizing less power. In this paper, we have conducted and presented analysis of smart waste collection systems using IoT technologies. The objective was to identify the technologies used, their challenges, possible solutions and other technical factors. A summary of the findings is shown in Table I. The analysis shows that the current systems are similar in terms of the IoT technology used and the overall operation of the system. However, the application of LoRa on the systems was not found and this negatively impacts their performances. That is, tools used to send bin status to the receiver side are short ranged which required installation tools while some of the systems do not provide location information that alerts the receiver of the specific position of full bin. Therefore, it is important that improvement and innovation be geared to the management of waste in our cities to ensure healthy environment devoid of diseases and infections. Consequently, as a future work we recommend the application of LoRa technology to boost the longevity of IoT-enabled solutions and their performance couple with other innovations. This stems from LoRa's ability to provide extended coverage using less power consumption and its reliability.

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