An IoT-Based Complete Smart Drainage System for a Smart City

Tarannum Zaki[1], Ismat Tarik Jahan[1], Md Shohrab Hossain[2], Husnu S. Narman[3]
[1]Department of CSE, Military Institute of Science and Technology, Dhaka, Bangladesh
[2]Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology, Bangladesh
[3]Weisberg Division of Computer Science, Marshall University, Huntington, WV, USA
Email: tarannumzaki44@gmail.com, ismat.mou@gmail.com, mshohrabhossain@cse.buet.ac.bd, narman@marshall.edu

***Abstract*—With the technological advancements, every application from our day to day life is becoming Internet-oriented, leading to the concept of Internet of Things (IoT). Various IoT devices and applications can be combined together for making a Smart City where smart drainage system is essential. However, solid wastes from groundwater flowing through the drainage system can create significant obstruction to its unrestricted flow, thereby causing overflows and profound environmental pollution. Thus, it is essential to manage these solid wastes effectively so that they do not obstruct the way of the drainage system. There have been few isolated works focusing on underground drainage monitoring or drainage system management only. However, there has not been any work that focused on both the underground drainage mechanism and the ground surface waste management system. In this paper, we have aimed at solving the particular reason that causes overflow and to manage that cause efficiently. We have proposed a detailed IoT based drainage management system that also incorporates drainage waste management to make the system more effective. We have clearly specified the methods for preventing and managing the solid wastes that are responsible for creating blockage inside drainage pipelines and drain covers.**

***Keywords*—** IoT, Smart City, WSN, biodegradable, protocols, sensors.

I. Introduction

One of the most remarkable technological innovations of modern science is the Internet of Things, which refers to an interconnected network among various physical objects/devices. IoT collects/exchanges data from the interconnected physical objects and performs specific tasks based on some specific analysis [1]. Currently, IoT based applications are widely used in household activities, organizational activities, transportation, health care, agriculture, construction, etc. [2], all of which introduce the concept of Smart City. Smart City can be defined as the electronic infrastructure of an urban area combined with various device/physical objects which are used to collect data in order to utilize it to manage different resources of a city efficiently and establish a significant connection between the urban community and urban infrastructure [1]. Smart City is intended to provide a healthy, secure, and sustainable environment and infrastructure for the welfare of every citizen.

One of the essential parts of a sustainable environment is a healthy drainage system where the excess surface water is being removed from an area and managed naturally or artificially in order to prevent the area from being flooded and to provide clean and hygienic environment to improve quality of life [3]. As the urban areas are expanding gradually, the need for industrial, organizational, and domestic structures are also increasing day by day. As a result, the flow of such excess surface water is also increasing, and the necessity for effective management of the drainage system is on the rise in urban areas. Generally, the groundwater flows through the drainage system towards a wastewater treatment plant to discard all impurities and pollutants [4]. Often solid wastes (e.g., plastic, biodegradable materials, metals, etc.) from the groundwater create blockage inside the drainage pipeline systems, thereby contaminating water from the drainage pipes. Therefore, it is evident that solid wastes from groundwater flowing through the drainage system can create a major obstacle to its unrestricted flow, thereby causing profound environmental impact. Thus, it is essential to manage these solid wastes effectively so that they do not obstruct the natural flow of the drainage system.

Considering the circumstances, it is apparent that the need for a drainage management system along with its waste management system in urban areas is inevitable, especially in a under-developed countries. Manually handling these systems is often time-consuming and requires too much effort (human labor to collect waste that creates obstruction in the drainage system). Hence, the concept of IoT can be applied to automate such systems and consider them as components of Smart City. Therefore, our aim in this paper is to propose an effective smart drain management system.

There have been few research works regarding the drainage management systems using the concept of IoT. There are individual solutions for waste management system [5]–[8], underground drainage pipelines [9] and manhole monitoring system [10], wastewater treatment or recycling system [11]. There are many solutions regarding drainage systems that mainly concerns the aspect that how a drainage system is managed [5], [6], [11] if any overflow occurs, without solving the root cause of overflow. Moreover, there have few works that dealt with smart waste management [7], [8], which can only manage ground surface wastage. Other works focused on systems for underground drainage monitoring only. There has not been any work that focused on both the underground drainage mechanism and the ground surface waste management system. Here lies the novelty of our proposed system.

We have aimed at solving the particular reason that caused overflow and to manage that cause efficiently.

The contributions of this paper are (i) proposing an comprehensive smart solution for both surface drainage mechanism and waste management system, (ii) detailing the crucial components of the proposed system, (iii) specifying the methods for preventing and managing the solid wastes that are responsible for creating blockage inside drainage pipelines and drain covers.

We have illustrated our proposed smart drainage system in details. We have emphasized that if the root cause for drain clogging can be solved, the city can be protected against the consequences of environment pollution.

The rest of the paper is organized as follows. A brief overview of some related works regarding IoT, Smart City, drainage, and waste management system using IoT have been depicted in Section II. Next, the conceptual features and system architecture and the technical details of the proposed system design have been described elaborately in Section III. The work-flow of the system is also illustrated in this Section IV. Finally, the system's limitations and future work have been presented, followed by some concluding remarks and references.

II. Related Works

A short description is provided in this section on different related research works and development that was performed by the research community..

Lazarescu [12] presented the tiered structure of a WSN (Wireless Sensor Network) platform and how it is functionally designed and implemented in the field of IoT based environmental monitoring applications. An urban IoT architecture, along with the concept and services of Smart City and some practical IoT based guidelines accepted for Padova Smart City Project in Italy, was discussed by Zanella et al. [13].

An application of a cost-effective automated drainage management system was studied in [9] concerning how drain clogs could be detected in the sewage pipelines using acoustic sensors and also providing communication with a server through the WSN platform so that immediate actions can be taken. SK and Rao [10] presented the design and implementation of an IoT based smart manhole monitoring system using IoT that will generate an alarm based on the status of the manhole (i.e., open lid, overflow, overpressure, etc.).

For the waste management system, some significant works were performed based on RFID technology, such as a smart bin for proper disposal and recycling of products [5] and a real-time multi-layered architecture for a waste management system [6] that can track stolen waste bin and identify weight and types of waste . Huang et al. [11] introduced a new approach for recognizing multi-featured objects using optical sensor-based technology for processing solid wastes. Anuradha et al. [8] found out an easy way to monitor dustbins by using a unique ID where all dustbins are interconnected through an Android App which sends a message to the concerned people when the bins are full. Ultrasonic sensors are used to detect the level of trash in the dustbin, and the presence of toxic gas can also be detected. Anotehr waste detection system was introduced with four subsystems [7] which are Smart Trash System, Vehicle System, Local Base Station and Smart Monitoring, and Controlling Hut. Ultrasonic sensors, load sensors, and ZigBee protocols are used in this system. Through load sensors, the load and level of trash are detected, and the information is transmitted a high-level signal through ZigBee to the controlling hut and from there to the vehicle, which will go to that place to clean trash.

However, most of the works regarding automated drainage management systems have been focusing on individual problems, and drainage waste management has been hardly taken into consideration. This paper has proposed a system design that conjointly considers smart drainage mechanism for infrastructures and roadside drains as well as adequate drainage waste management has also been taken into account.

III. Proposed System

The proposed system design has been classified into two parts: *conceptual features* - presenting the main features of the system design and *system architecture* - presenting a detailed description of the entire system architecture and its components along with the technical details.

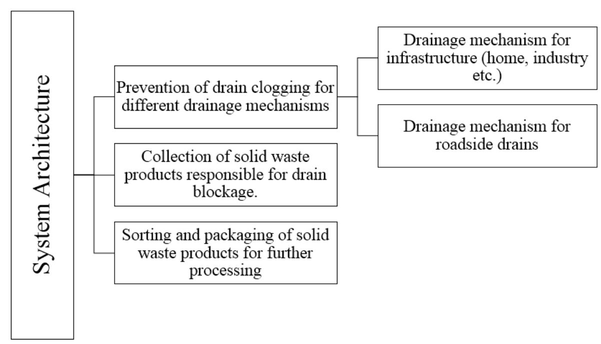

Fig. 1: Flow diagram for system architecture.

A. Conceptual Features

The target feature of this system design is to prevent the clogging of drains using the concept of IoT so that it does not lead to drainage overflow and further inconvenience. In order to achieve this feature, it is required to consider all types of sources (home, industry, roadside drains, etc.) and their drainage mechanisms. Different infrastructure such as apartment, industry might have separate drainage mechanisms. On the other hand, roadside drains might have another type of drainage mechanism. Thus, it is important to integrate all types of drainage mechanisms of different sources to apply the target feature. The target feature leads to some additional features inferring from the causes of drain clogging. Drain clogging often occurs due to blockage of different materials (plastic, paper, biodegradable products, etc.) inside drainage pipelines and over drain covers due to natural or human-made occurrences. These materials should be managed efficiently using IoT, which aims to our additional features. All types of materials are collected and sorted using a smart sorting system. An associated database with this sorting system will record the type and amount of incoming materials of a particular area. Next, the sorted materials are packaged separately, which notifies various organizations that can further process these materials for recycling, fertilizer production, etc. There will be another database associated with this packaging system that will generate monthly/weekly/yearly reports regarding the amount and type of outgoing packaged materials to different organizations. These are the core features of the proposed system design that can result in an effective smart drainage management system.

B. System Architecture

An IoT based system architecture has been planned to incorporate all the outlined features, which are summarized as follows along with a flow diagram shown in Fig.1. This figure shows that the system architecture is primarily classified into three sequential phases. Firstly, preventing the drain clogging, then collecting different solid waste products that are responsible for drain blockage and, finally, preparing the solid waste products for further processing (e.g., recycling). Now, the prevention of drain clogging is provided for two types of drainage mechanisms - drainage mechanism for infrastructure (e.g., home, industry, etc.) and drainage mechanism for roadside drains.

- Prevention of drain clogging for different drainage mechanisms (i.e., infrastructure – home, industry, etc. and roadside drains).
- Collection of solid waste products responsible for drain blockage.
- Sorting and packaging of solid waste products for further processing.

The detailed workflow along with necessary technical details for the above features are depicted as follows:

1) Prevention of drain clogging: Two considerations have been taken for the prevention of drain clogging for different drainage mechanism as explained below:

(a) *Drainage mechanism for infrastructure* Different infrastructures, such as a house, educational institution, industry, corporate organizations, etc. have different drainage pipes that lead to a central drainage system. These drainage pipes might get clogged by various materials used for domestic use, industrial wastes, and many more solid wastes. To monitor unrestricted flow of waste water through these drainage pipes, a waterproof active ultrasonic sensor (as shown in Fig. 2) [14] is used, which can detect the presence of an object by measuring distance through the transmission of sound waves. Separate ultrasonic sensors are used in drainage pipelines of different areas. These sensors collect data if any object creates blockage inside pipes. A particular area's sensor is connected with a particular server (see Fig. 2) that receives the transmitted data and stores the particular area's pipeline's location where the blockage has occurred. Further, these servers send message notification to the corresponding area's drainage maintenance authority that a blockage has occurred inside a drainage pipeline which needs to be examined immediately. Furthermore, all these servers are connected to a central server (shown as the top server in Fig. 2), which analyzes whether a particular area's drain clogging occurrences have increased/decreased over time and warns to the respective area's inhabitants basing on the analyzed results.
Three types of communication protocols [15], [16] are required for this entire procedure.
- sensor to server requires MQTT or message queuing telemetry transport protocol (collects sensor data and sends to server),
- server to server requires AMQP or advanced message queuing protocol (provides connection among servers), and
- server to the device requires XMPP or extensible messaging and presence protocol (provides text communication to people).

As shown in Fig. 2 that data regarding blockage in the pipeline of Area 01, Area 02, and Area 03, respectively is transmitted to the corresponding servers. Basing on the information from the servers, necessary notifications are sent to the concerned authority.

(b) *Drainage mechanism for roadside drains*: Roadside drains usually have drain covers through which wastewater flows. Any object that is unable to pass through the drain cover would eventually result in obstruction to the way of the unrestricted flow of water. Hence, a width/thickness measurement sensor (using a triangulation reflection method for non-contact measurement) [17] is used on the street lamp post over the drain cover (shown in Fig.3), This thickness measurement sensor can detect objects of specific width/thickness that are unable to pass through the drain cover. The sensor collects the data and sends it to a server, which further communicates with another server that collects data from a motion sensor. Because it is required to check whether the object of a specific width is a living object (i.e., rat), which is checked using a motion sensor (using infrared radiation) [18]. This motion sensor is also used on the lamp post over the drain cover. Now, if the object is of a particular width and not a living object, then an actuator allows the object to pass through the drain cover. Two types of communication protocols [15], [16] are required for this entire procedure – sensor to a server requires MQTT protocol (collects sensor data and sends to a server), and server to server requires AMQP protocol (provides connection among servers). This feature is precisely illustrated in Fig. 3, which shows that two types of data are collected from the drain cover that lies beside roadside drains. These data indicate whether the actuator associated with

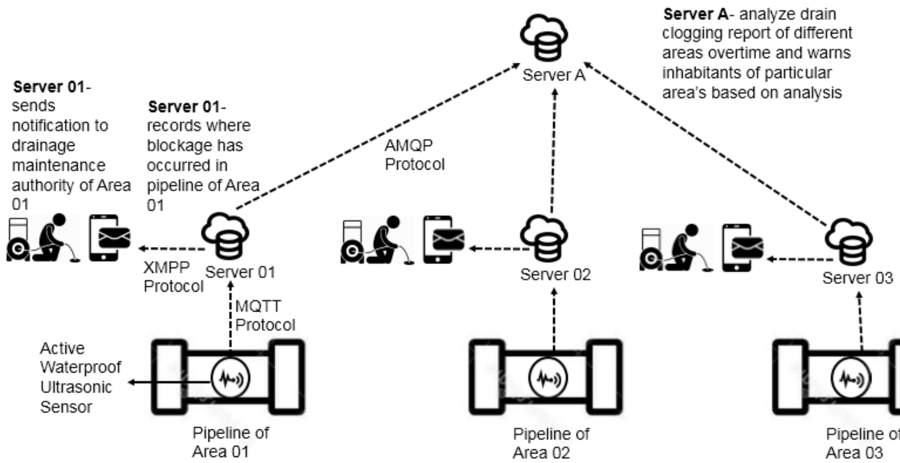

Fig. 2: Drainage mechanism for infrastructure.

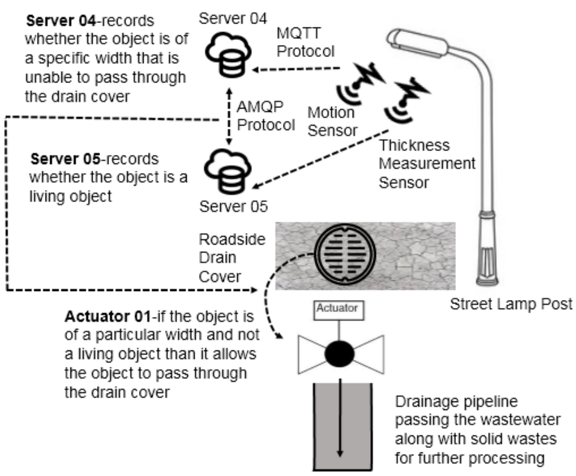

Fig. 3: Drainage mechanism for roadside drains.

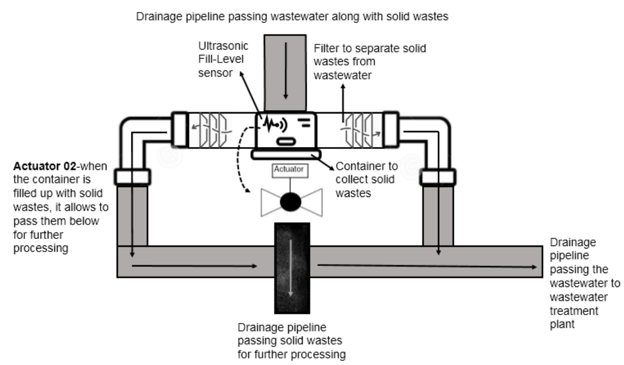

Fig. 4: Collection of solid waste products responsible for drain blockage.

the drain cover allows solid wastes of a particular width along with wastewater to pass into the drainage pipeline for further processing.

2) Collection of solid waste products: This process is illustrated using Fig. 4. As the wastewater and solid wastes pass towards the central drainage system, a fill-level sensor-based container is positioned horizontally and having a filter on both endpoints. These endpoints are further attached to two vertically positioned pipelines. Thus, as the water enters this container, due to gravity, water pours down through the filters from both sides to the vertically positioned pipelines, further leads to the wastewater treatment plant, and the solid wastes begin to fill up the container. When this container gets filled, an ultrasonic fill-level sensor [19] associated with it enables an actuator that passes the solid wastes to the optical sorting system for further processing.

3) Sorting and packaging of solid waste products for further processing: The solid wastes enter the optical sorting system [20], which detects different materials using a spectrometer as every material creates a unique light signature. This sends data to a server that records the type and amount of different materials over time to generate weekly/monthly/yearly reports regarding drainage solid wastes. After sorting/detecting, all the materials are collected to separate packages containing an ultrasonic fill-level sensor [19] that sends data to a server that notifies various recycling and fertilizer processing companies when the packages are filled. Moreover, this server also records which companies are receiving what type of materials over time. Two types of communication protocols [15], [16] are required for this entire procedure – sensor to a server requires MQTT protocol (collects sensor data and sends to a server), and server to a device requires XMPP protocol (provides text communication to people). This feature is precisely illustrated in Fig. 5, which shows that a sorting system sorts out the solid waste materials into separate packages that are then directed to

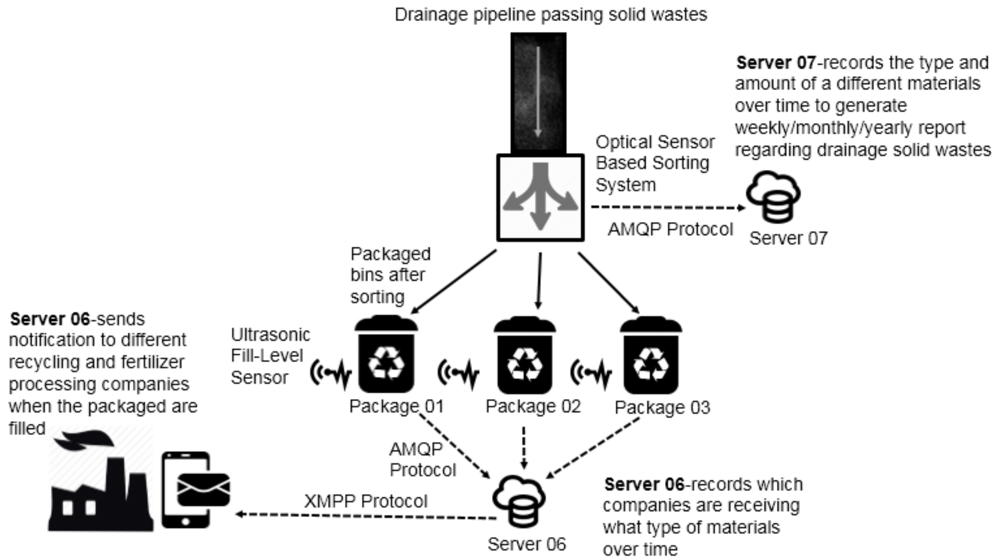

Fig. 5: Sorting and packaging of solid waste products for further processing.

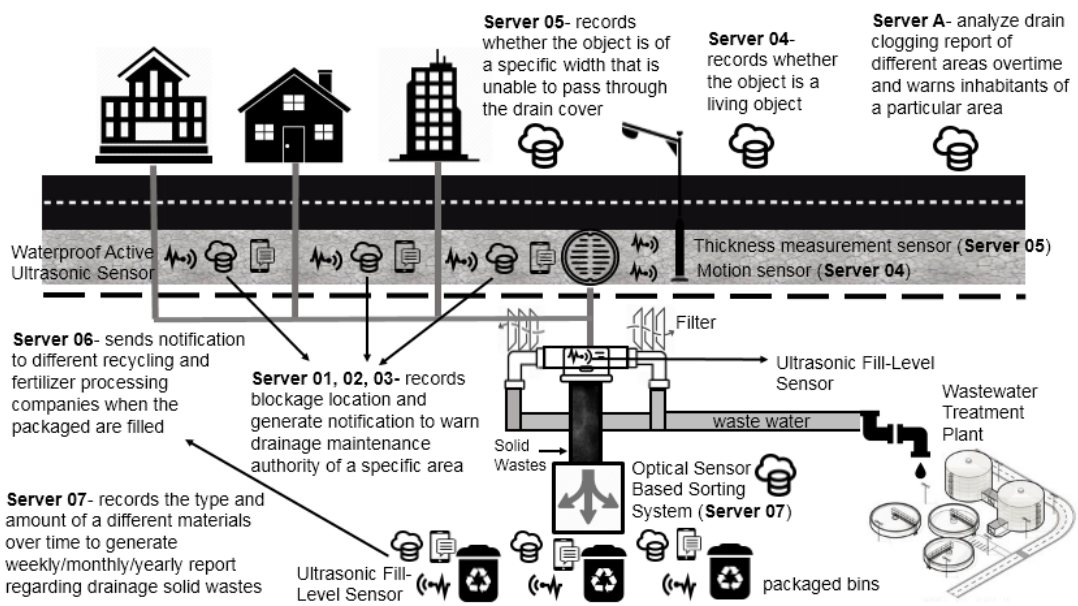

Fig. 6: The proposed complete IoT based drainage management system.

different waste material processing companies through notification. Besides, some associated servers keep record regarding the solid waste materials and their transmission for analytical purposes.

C. Combined system

Finally, Fig.6 shows the combined figure consisting of all the sysmtem components for the IoT based drainage management system that has been described earlier in details. The main features of our comprehensive smart drainage system are as follows:

- Our system can prevent the drain clogging by detecting the presence of solid wastes through the use of waterproof active ultrasonic sensors,
- Our system can automaticcly collect the solid waste products that are responsible for drainage system blockage without human intervention,
- sorting the solid wastes through optical sorting system and separating them for further processing and notifies the concerned parties.

IV. Working Procedure

The sequence of actions for the entire working procedure of the system with the required details is depicted in this section. The figure of the system working procedure is as follows:

(a) The wastewater from two sources is considered.
(b) The pipeline of different areas connected with different infrastructures are checked.
    (i) If the pipeline is blocked, the blockage location is recorded in the particular area's server and further sent to the central server for required analysis with respect to other areas. A notification is also generated to warn the respective area's drainage maintenance authority.
    (ii) If the pipeline is not blocked, the water is passed to a container for filtration.
(c) The drain cover of roadside drains are checked.
    (i) If the drain cover is blocked, the object's width is recorded that is unable to pass through the drain cover.
    (ii) If the drain cover is not blocked, the water is passed to a container for filtration.
    (iii) If the object creating an obstacle is a living object, then it is being recorded. The object is matched to detect whether it is both of a specific width and a living object and hence is not allowed to pass through the drain cover.
    (iv) If the object creating obstacle is not a living object and is of a specific width, it is allowed to pass through the drain cover and further to the container for filtration.
(d) The wastewater, along with solid wastes, goes through a filtration process inside a container.
(e) If it is a solid waste, then it is being stored in a container.
(f) If the container is filled up, they are being sorted using a sorting system. They are recorded basing on their type and amount. Furthermore, they are sent to different recycling/fertilizer processing companies and are also being recorded.

V. Conclusion

In this modern era of scientific innovations, an essential Smart City component is the smart drainage management system that aims to provide an effective and effortless systematic method to preserve a healthy environment. This paper has proposed the comprehensive system design for such a smart drainage management system that collectively considers drainage mechanism for both roadside drains and infrastructures, including a mechanism for drainage waste management. We have explained the system features, system architecture, and working procedure of the system precisely with necessary technical details. Our future work would be to practically implement the system according to the design and perform an experimental analysis to bear significant contribution in preserving a healthy environment for the overall development leading to a healthy, safe, and comfortable lifestyle of the urban community.

References

[1] S. Madakam, R. Ramaswamy, and S. Tripathi, "Internet of things (IoT): A literature review," *Computer and Communications*, vol. 3, no. 5, pp. 1–10, Jan 2015.

[2] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of things (IoT): A vision, architectural elements, and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, Sep 2013.

[3] School of PE, "Basic types of residential drainage systems," Aug 2017. [Online]. Available: https://www.schoolofpe.com/blog/2017/08/

[4] M. Samer, "Biological and chemical wastewater treatment processes," *Wastewater Treatment Engineering*, pp. 1–50, Oct 2015.

[5] Y. Glouche and P. Couderc, "A smart waste management with self-describing objects," in *Proceedings of the Second International Conference on Smart Systems, Devices and Technologies, SMART'13*. Rome, Italy: IARIA, Jun 23-28 2013, pp. 63–70.

[6] B. Chowdhury and M. U. Chowdhury, "RFID-based real-time smart waste management system," in *Proceedings of the Australasian Telecommunication Networks and Applications Conference, ATNAC'07*. Christchurch, New Zealand: IEEE, Dec 02-05 2007, pp. 175–180.

[7] R. HD, H. C. Naik, A. R. Naik, and H. KP, "IoT based automatic waste management system," Mangalore Institute of Engineering and Technology, Department of Telecommunication Engineering, Mangalore, Tech. Rep.

[8] D. Anuradha, A. Vanitha, S. P. Priya, and S. Maheshwari, "Waste management system using IoT," *Computer Science Trends and Technology*, vol. 5, no. 2, pp. 152–155, 2014.

[9] Akshaya.K, D. Ramachandran, and M. B. Prabhu, "Acoustic sensors to detect clogs in sewer pipelines," *Communication Network Security*, vol. 2, no. 2, pp. 2231–1882, 2013.

[10] M. SK and S. Rao, "Automated internet of things for underground drainage and manhole monitoring system for metropolitan cities," *Information and Computation Technology*, vol. 4, no. 12, pp. 0974–2239, 2014.

[11] J. Huang, T. Pretz, and Z. Bian, "Intelligent solid waste processing using optical sensor based sorting technology," in *Proceedings of the Third International Congress on Image and Signal Processing, CISP'10*. Yantai, China: IEEE, Oct 16-18 2010.

[12] M. T. Lazarescu, "Design of a WSN platform for long-term environmental monitoring for IoT applications," *Emerging and Selected Topics in Circuits and Systems*, vol. 3, no. 1, pp. 45–54, Mar 2013.

[13] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of things for smart cities," *Internet of Things*, vol. 1, no. 1, pp. 22–32, Feb 2014.

[14] T. Agarwal, "Ultrasonic detection - basics application." [Online]. Available: https://www.elprocus.com/ultrasonic-detection-basics-application/

[15] Postscapes, "IoT standards and protocols." [Online]. Available: https://www.postscapes.com/internet-of-things-protocols/

[16] S. Scheneider, "Understanding the protocols behind the Internet Of Things," Oct 2013. [Online]. Available: http://www.electronicdesign.com/iot/understanding-protocols-behind-internet-things

[17] Keyence, "Selecting a measurement sensor." [Online]. Available: https://www.keyence.com/ss/products/measure/selecting/thickness_width.jsp

[18] Golab, "How infrared motion detector components work." [Online]. Available: http://www.glolab.com/pirparts/infrared.html

[19] ECUBE Labs, "CleanCAP, the ultrasonic fill-level sensor." [Online]. Available: https://www.ecubelabs.com/ultrasonic-fill-level-sensor/

[20] W. Flower, "A look at optical sorting," Sep 2015. [Online]. Available: http://www.waste360.com/commentary/look-optical-sorting