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Designing of Cleaning System for Garbage and Sewage of Smart City with Cloud Based Predictive Analytics

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Abstract: The major objective of a smart city is to provide ripest and rightest services to its residents with minimal human intervention. The data collected from various sensors, receptors and receivers can be stored in a reliable, cost effective and manageable cloud storage. Predictive analytics such as predictive modelling and machine learning can be used to analyze the latest and past data from the cloud to forecast the near and far future. The predictive analytics will immediately send notifications and the appropriate actions to be taken to the concerned system so that the residents can get equable life. Waste management such as sewage management and trash management are one of the major exertions in a smart city. In this paper, predictive analytics is applied on the cloud data collected from various sensors attached on the waste management resources such as trash bins and sewage pipes. Firstly, group of trash bins and sewage pipes are attached with radio wave sensors which in turn connected to an IoT enabled receiver to provide cost effective data collection. Secondly, the data from the receivers are stored in a cloud. Thirdly, predictive analytics using K-means clustering are proposed for applying on the data in the cloud. Finally, actions like redirecting the trash collection truck and sewage clearing robot based on the priority can be done automatically and long-term actions can be directed to the concerned authorities with notifications and alerts to take necessary actions. In this paper, designing of an immaculate smart city is proposed which can be achieved by developing IoT based trash collection and sewage cleaning system. For analysis purpose synthetic data is considered where levels for garbage cleaning bins at different time and liquid levels of drainage pipes at different time are represented with different numbers.

Keywords: Cloud Storage, Iot, K-Means Clustering, Machine Learning, Predictive Analytics, Sewage Cleaning System, Smart City, Trash Collection

1. INTRODUCTION

In the recent years, migration of people to nearby cities to seek better education, career, health care and technology access is increased tremendously. This in turn results in a rapid growth of the city. As predicted, more than 60% of the population live in cities by 2030 which motivates the development of smart cities. A smart city integrates the infrastructure such as buildings, transport and environment with services like healthcare, energy and waste management intellectually using information and communication technologies. A smart city [1-5] is an urban center which utilizes information and communication technologies to improve quality of life of the people live in the city. A typical smart city is represented in Fig. 1. Electronics sensors have been deployed in many commercial, consumer and governmental environments such as buildings, flats, hospitals, trash bins, drainage pipes, roads and in energy sectors. All the establishments can be made smart to promote the urban center as a smart city. In this paper we propose smart way of managing the waste to make the city immaculate. The waste produced by the different establishments can be roughly divided into two major types. The first one is solid waste and the second is liquid waste. City residents can use trash bins provided by the municipality to cast off the solid waste. All the liquid waste from the city can be sent through the drainage pipes to the closest underground drainage systems which would finally be connected to the nearest effluent treatment plant. The treated water can be used to water the road side plants and to the agriculture land based on the water quality. RFID sensors can be deployed on the trash bins, drainage pipes and in the inlet water pipes and are connected to the closest IoT [6-9] enabled receiver to make the system smart. Since the outlet water from any establishment is directly proportional to the inlet water, the inlet water for different establishments are measured

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periodically. This helps in forecasting the near and far future requirements of the water demand as well as drainage system capacity. If there is a prediction of considerable changes in the inlet and outlet water capacity, then the smart system will indicate the concerned officials to make the necessary modifications. This gives hassle-free water management system in all ways.

2. Literature Review

Information and communication technology are the backbone of any smart cities. Different attributes of any components of the city can be measured using technologies like electronics sensors, receivers with IoT that will make any application smart. The collected data from the sensors should be stored in medium with scalable and elastic IT-enabled capabilities. The following points are critically analyzed through literature review.

A. Cloud Computing

The U.S. National Institute of Standards and Technology (NIST) defines cloud computing as a model for omnipresent, commodious, on-demand network access to a shared pool of computing resources. The computing resources should be provisioned and released rapidly with minimal service provider or management effort. The major advantages of cloud computing are scalable architecture, increased availability, reliability, reduction of cost in acquiring new infrastructure and ongoing ownership, reduced operational overhead and measured usage. Cloud offers Infrastructure as a service (IaaS), Platform as a service (PaaS) and software as a service (SaaS) delivery models. Cloud provides Public cloud, Community cloud, Private cloud and Hybrid cloud deployment models. Sensitive data can be stored in private cloud whereas insensitive data can be stored in any other cloud deployment models. So, cloud storage best suits the need for storing the data from different parameters of the smart city. The data in the cloud can then be analyzed by a predictive analyzer.

B. Predictive Analyzer

Predictive analytics covers various types of statistical techniques such as data mining, machine learning and predictive modelling that study current and historical data to forecast future or unknown events. Predictive Analysis can be applied to almost all the fields ranging from small home to intercontinental organizations. Predictive analysis identifies the potential risk and opportunities in the field in which the predictive analysis is applied. It can be used to predict the future and helps to make better decision for individuals and organizations.

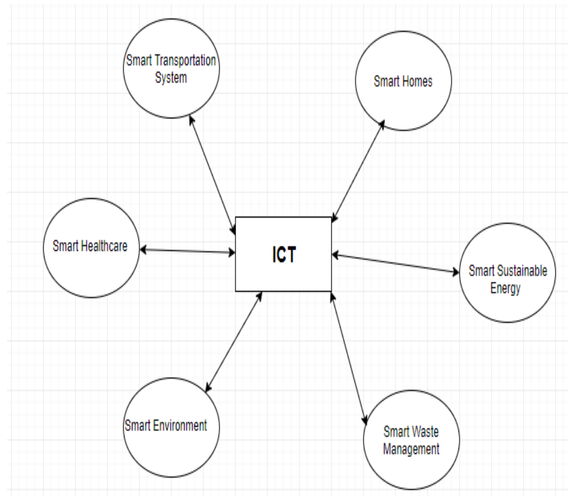

Figure 1. Pictorial representation of a typical smart city

C. Predictive Analysis Process

Fig. 2 illustrates the complete process of predictive analyser. The data for the analysis should be collected first. The collected data can be analysed by scrutinizing, cleaning and modelling to determine useful information and conclusion. The analysed data can then be passed to a statistical analyser to support the assumptions and verify them using standard statistical models. Predictive modelling enables the power of creating accurate predictive models. Options can be selected in the multi-modal evaluation. Deployment is the process in which the complete analyser is installed on the system to get the requisite results. Model monitoring can be used to monitor and review the performance of the models.

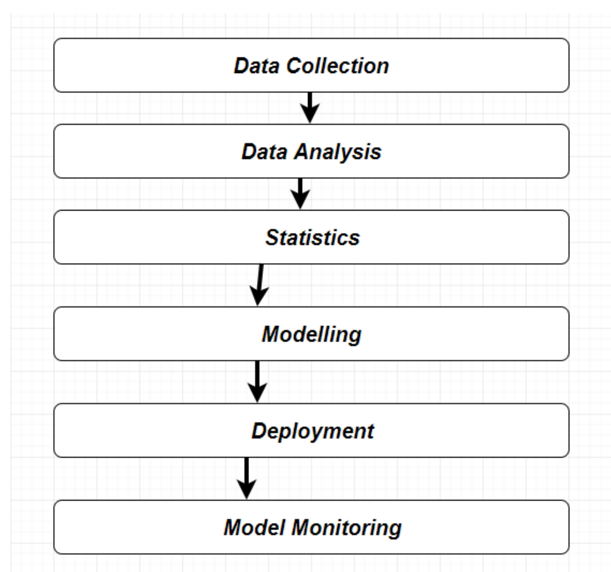

Figure 2. Complete process of predictive analyser

D. Data Sources

To transform a city into smart, cities need reliable data to stem their long-run decision. Admittedly, data sources could be created by deploying different sensors across various city infrastructure including resident's smart phone. Furthermore, Big data analytics can be applied on the collected data to help the city planners to monitor and anticipate future urban phenomenon. Generally, information technology components like Internet of Things (IoT) plays a key role in smart city for collecting data. Typically, in IoT, connected devices are communicating and exchanging data through wireless connections, internet and other communication channels. Particularly, IoT devices fetch data and process it effectively in a smart city environment. In addition, several smart city gate ways with sensors and connected devices collects data and analyze it for further processing.

Basically, there are three layers of data. Firstly, the sensors with high-speed communication network and vital aggregate of smartphones that form a technology base. Secondly, the mission specific applications that transform raw data into alerts and action. Finally, usage by organizations, companies and general public. Since the alerts and actions are taken based on real time data, it is crucial that the data need to be shared real time. Clearly, portability between various data collection devices is a major challenge in smart city initiative.

Data sharing is a key factor along with effective collection and storage so that it can be analyzed across departments and provide effective usage of data. Various technologies can be incorporated to achieve maximum functionality in a smart city. A network gathers data, a field gateway collects and compress data, a cloud gateway ensures secure data transmission, a data streaming processor combines data from various data streams and diffuses them to a data lake, a data lake stores data, data warehouse keeps the cleansed and structured data and data analytics for analyzing and visualizing data.

3. INTERNET OF THINGS (IOT)

Internet of things [10-12] refers to the astronomical physical devices connected to the internet that collects and shares data. With the ubiquity of wireless networks and low-price hardware devices, something as small as a tiny toy to something as big as an aircraft can be turned into a part of IoT. Typically, any physical object can be transformed into an IoT device by connecting it to the internet and controlled through applications remotely with or without minimal human action. The sensors, actuators, hardware and software computing resources, medium of communication and application interfaces are the basic elements of IoT. Specifically, with the inclusion of smart sensors into IoT, an IoT device can be transformed into an intelligent device.

Generally, the aggregation of sensors, data, networks and services are the basic components of any IoT architecture. In the first place, sensors located at the bottom layer make wireless sensor network which are inherent part of IoT environments. Further, edge devices located after the sensor perform significant amount of computation, communication and storage to ascertain integrity, consistency, availability and reliability of real time data. In addition, high-end computing capability resources are added in the cloud server to perform super-power tasks like data mining. Eventually, IoT applications deliver the designated services to users in ubiquitous manner. Security is a major concern in IoT framework. Security vulnerabilities such as insufficient testing and updating, brute force attack, small IoT attacks that evade detection, home invasion, remote vehicle access and untrustworthy communication are possible in IoT environment. Considering this, various security solutions for IoT framework are emerging based on the requirement.

4. CURRENT WASTE MANAGEMENT

Huge quantities of waste are produced in almost all the cities due to rapid industrialization, growing urbanization, heightened consumerism and rise in standards of living. The major challenge for any municipality is to store, transport, treat and dispose the waste. Governments are spending large amount of human as well as financial resources to tackle the waste. The solid waste generation rate of GCC countries including Bahrain is extremely high ranging from 470 to 700 kg/capita/year [13]. The Municipal Solid Waste (MSW) comprise of trash from domestic residences, markets and commercial buildings, organizational wastes from educational organizations and offices, flora wastes and animal carcasses. The quantity of MSW is increasing rapidly every year. The MSW is either collected in plastic bin or metallic bins. Compactor in the truck empties the bin and carried to landfill site for disposal. Usually the truck collects the waste during night time to avoid traffic congestion and to avert inconvenience caused by the blockage of roads. Some rapidly growing areas and over populous areas may face the shortage of trash bins. This results in overflowing waste bins and the surrounding areas experiences obnoxious odors, growing insects and rodents. This in turn triggers health problems ranging from epidermis allergies to severe lungs problem. Currently the MSW is managed manually. The Liquid waste from domestic buildings, commercial markets and other organizations are connected to underground drainage system. The sewerage water then flows through the effluent treatment plant to treat the water so that it can be used to irrigate from roadside plants to small scale agriculture. Only limited automation is done in the management of sewerage water. In both MSW and drainage water management, predictions are done manually which is inefficient and will not cover the complete scope due to rapidly growing urbanization. Fig. 3 depicts the pictorial representation of current waste management system.

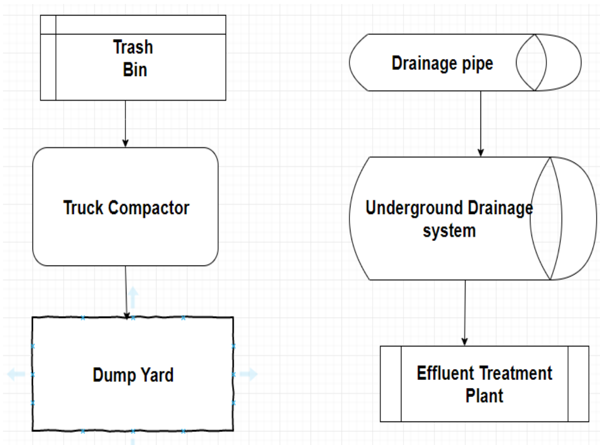

Figure 3. Current waste management system

5. Proposed Smart Management System

A sound collection, transportation and disposal of both solid and liquid waste is crucial for any city. Recent smart technologies can be applied to waste management to make the system better and more relevant. In this paper, we propose smart methods to both solid and liquid waste. An RFID system can be used to acquire data from any components of the waste management.

A. RFID Systems

Radio Frequency Identification system was used in military application initially. Later, RFID system has been extended to commercial applications like tracking and identifying objects, people and animals. An RFID system has a collection of tags and receivers. The tags can be passive, semi-passive or active. The tags and receivers can be used to identify the tagged items using radio transmission. The active tags are battery operated whereas passive tags use the energy induced by the receiver. An active tag consists of small integrated circuit with micro control logic and data storage, antenna and battery encapsulated as a package otherwise known as transponder. The super high frequency active RFID tags have the read range of up to 100 meters whereas the ultra-high frequency RFID tags have the read range of up to 500 meters. The active RFID tags are completely automated. Active RFID readers are about half the price comparing to passive RFID readers. Active RFID system is generally used for real time location tracking. When compared to the overall system cost, active RFID is a cheap alternative to other technologies like infrared, WiFi and ultra-wide-band (UWB). Due to its long-read range, active RFID systems are easily scalable. The battery life is long ranging from 3 to 10 years. For real time data and more automation, one can use active RFID system. Fig. 4 shows the Active RFID tags and Active RFID Reader. The existing solid waste management system can be enhanced to smart by reading the trash bin fill level data using the RFID tags. Active RFID systems use battery-powered RFID tags that connect to active RFID receiver which in turn sends data to the storage area. The data from the RFID reader can be stored in the cloud to make use of ubiquitous, reliable, available and low-cost features of cloud.

Figure 4. Active RFID tags and Active RFID Reader

B. E-Tracking of Trash Bin

An active RFID tag can be attached to the trash bin which in turn connected to an Internet of Things (IoT) [14-22] enabled RFID reader. Since the read range of active RFID tag is higher, a single reader can monitor group of trash bin to collect data with optimal cost. The active RFID tag attached to the trash bin sends the level details of the bin to the closest RFID receiver. The active RFID receiver sends the data from RFID tags to the cloud. The data from the cloud [23-29] can be analysed using predictive analyser.

C. E-Tracking of Underground Drainage System

The same kind of RFID tags can be attached to drainage system to monitor the level and to find out any blockage in the system. The IoT enabled RFID receiver used to measure trash bin readings can also be used to measure the data from drainage system to make the complete system more economical. If there is a considerable change in the drainage level, then the predictive analyser finds out the change and will notify the same to the authorities. RFID tags can also be attached to the water inlet of all the premises. For all the premises, municipality can set a threshold limit for the water inlet. If any premise uses beyond the threshold level continuously, then the predictive analyser which monitor the level can send alerts to the concerned officials. This helps in future planning of the municipal water supply as well as any modifications to the existing system.

D. Machine Learning Based Predictive Algorithms

The stored data from the cloud can be analyzed using machine learning based predictive analyzer to determine areas with overflowing dustbins and any obstruction in the drainage with its exact location. The predictive analyzer can redirect the garbage truck to the area with overflowing trash bins. It can continuously monitor the bins and can suggest the concerned authorities for the inclusion of more bins or collection of trash quicker than the usual if the area has overfilled garbage bins. If there is any blockage in the drainage system, it can be identified by the analyzer and can be notified to the concerned officials immediately with suggestions. Robots can be used to clear the sewage obstruction easily and efficiently. Since cities are growing rapidly, the drainage system may be overloaded. The predictive analyzer can predict the future liquid waste and can notify the same to the municipal planning council to make future planning. Fig. 5 illustrates the proposed system of waste management.

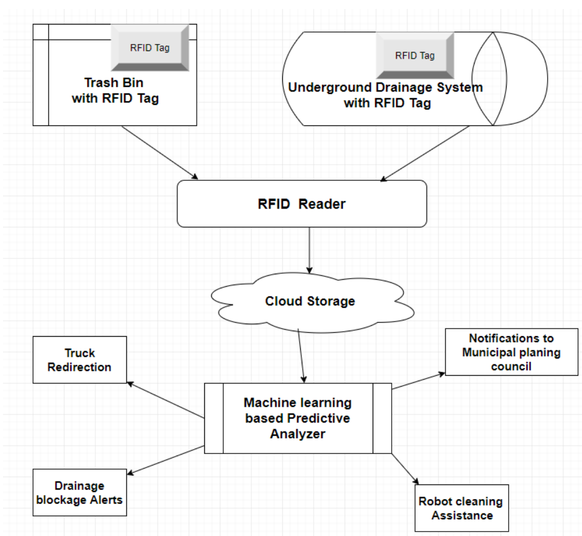

Figure 5. Proposed system of waste management

6. Proposed Machine Learning Technique

To analyse the data in the cloud and to predict the near and far future, we propose the machine learning technique called K-means clustering [30-35].

A. K-Means Clustering

K-means clustering is one of the easiest and famous unsupervised machine learning algorithms. Generally, unsupervised learning algorithm uses input vectors to make inference without referring to labelled outcomes. The K-means clustering algorithm looks for a fixed number(K) of clusters in a dataset to wrap similar data points together to find the underlying pattern. The means in the name refers to the averaging of the data. This algorithm finds k number of centroids and provide every data point to the closet cluster.

7. Experimental Results

We have shown the real hardware system for collecting data. For experimentation purpose, we have used Arduino MKR GSM 1400 board and Arduino IoT cloud beta version. we have added each trash bin as a thing and set property values accordingly. It monitors the level details of the bin every 60 seconds. Fig. 6 and Fig. 7 represent MKR GSM 1400 board and Arduino SIM card respectively. Fig. 8, 9, 10 and 11 show the steps of data collection from the trash bin A1 to cloud storage at a specified interval, 60seconds. Fig. 8 depicts association with trash bin A1 and MKR GSM 1400 board where name of the thing has been entered as a data and the board name is selected from the drop-down menu. Fig. 9 shows the adding property and editing code view of trash bin A1 to the cloud storage. Fig. 10 represents adding new property of trash bin A1 to the cloud storage. Fig. 11 shows the accessibility to the properties of trash bin A1.

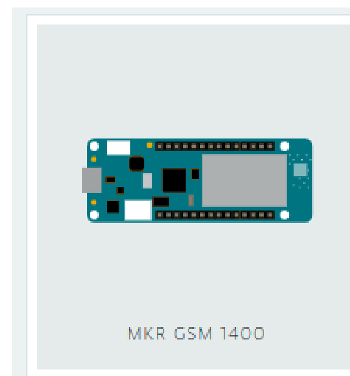

Figure 6. MKR GSM 1400 board

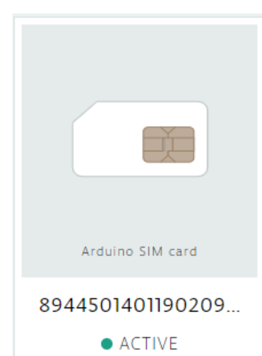

Figure 7. Arduino SIM card

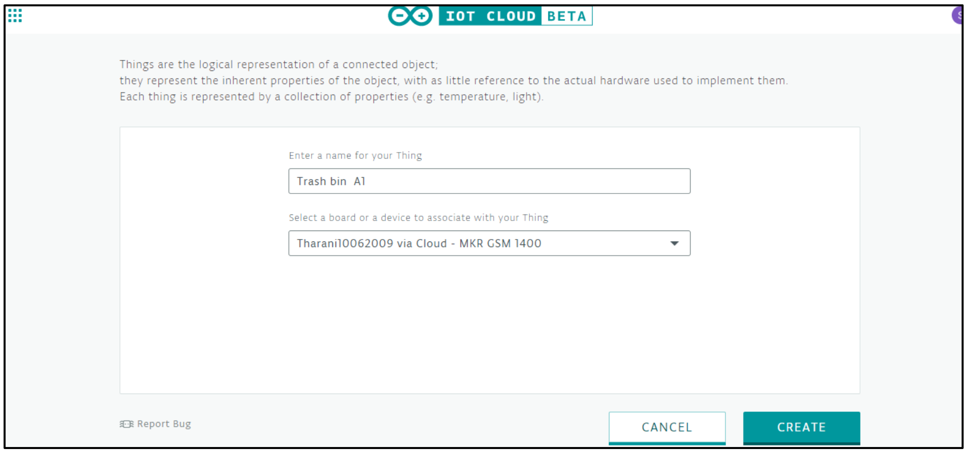

Figure 8. Association with trash bin A1 and MKR GSM 1400 board

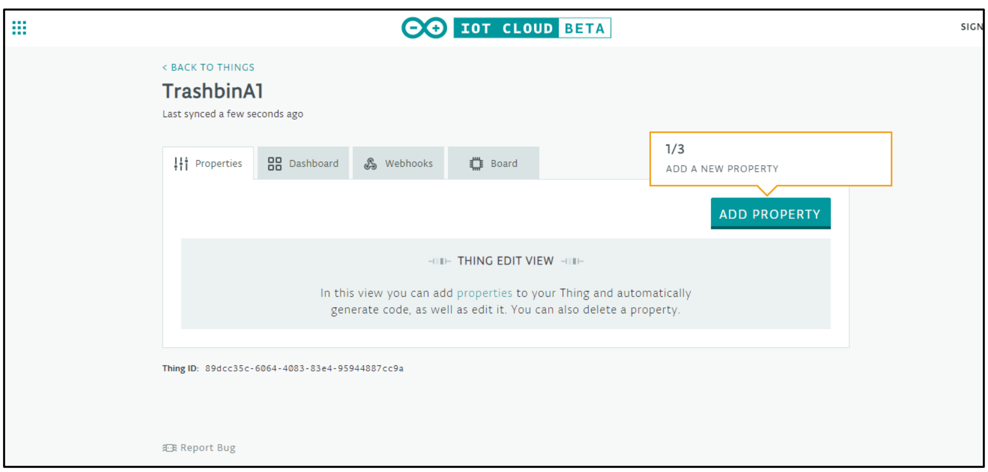

Figure 9. Adding and editing properties of trash bin A1

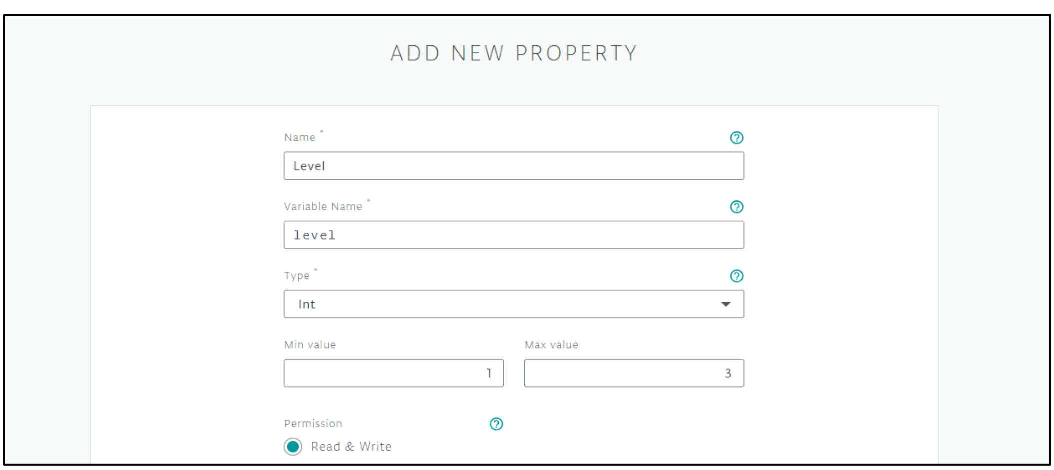

Figure 10. Adding new property of trash bin A1

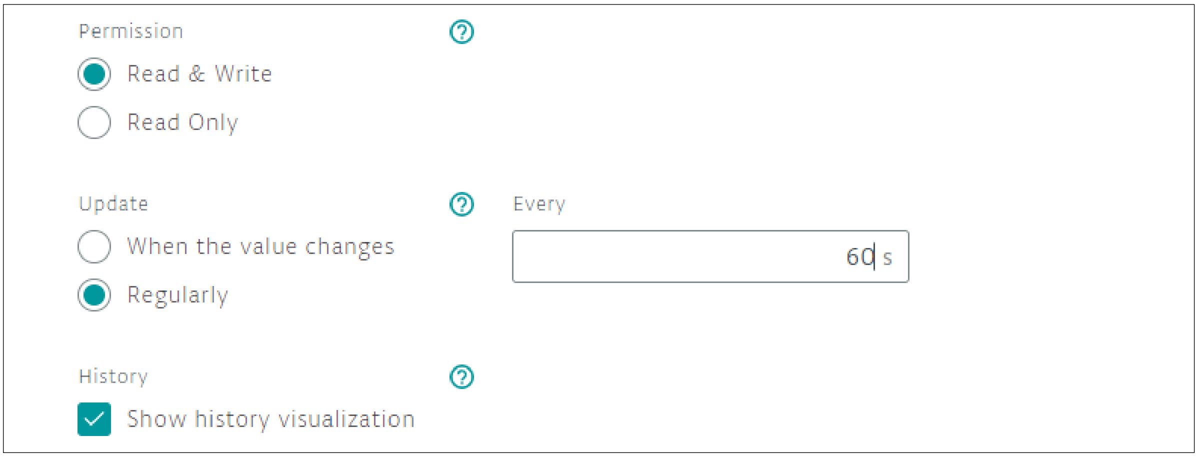

Figure 11. Providing accessibility to the property of trash bin A1

Data collected from the garbage bins attached with RFID tag shows the levels of garbage collected in various parts of the city. The dataset collected over a period makes historical dataset for the analysis. This dataset may contain different variables such as Bin Id, Sector, date, time, day and level. The real time data is compared with historical data using predictive analytics and the route map for the Garbage truck will be prepared accordingly. The levels of the waste bin range from 1 to 3. Level 1 means less than 50% filled, level2 means almost filled and Level3 means filled fully. The rate of filling of dustbin is measured periodically and compared with the historical data. If the bin is filled earlier than usual timings continuously then the notifications and alerts will be sent to the concerned authorities. Table 1 shows the synthetic data of garbage levels of bins at different timings of the day. K means clustering has been applied to produce three clustering for three levels of garbage in bins. At each level of time different clusters have been formed to decide the route of the collection truck. Let us assume the garbage cleaning truck will clean the bins when its value is "3" only. Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18 show the scatter plot of clusters for levels of bins at time 1, time 2, time 3, time 4, time 5, time 6, time 7 respectively. From these scatter plot at different time level, the path of the garbage cleaning truck can be determined as A1, A1-A5, A1-A5, A1-A5, A1-A2-A4-A5-B1, A1-A2-A4-A5-B1, A1-A2-A3-A4-A5-B1-B2-B4-B5 at time 1, time 2, time 3, time 4, time 5, time 6, time 7 respectively. K-means clustering algorithm helps to determine the path of garbage cleaning truck. In the sample dataset, only 10 bins are considered. When in real life, number of bins will be more, determining garbage cleaning path manually will become challenging where this predictive analysis will help to determine garbage cleaning path for the truck very efficiently.

Similarly, for sewage pipes, liquid garbage levels at different times of the days are collected and monitored. Finally implementing above method, cleaning path is determined for sewage pipe.

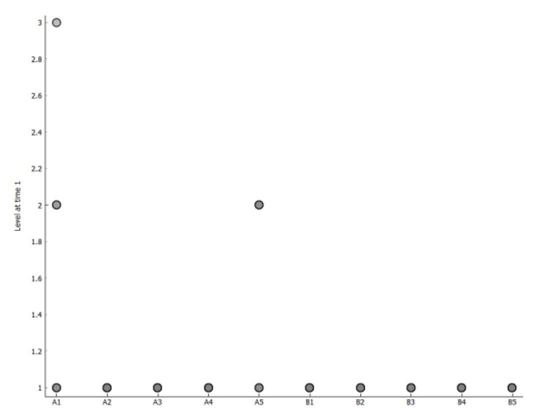

Figure 12. Scatter plot of clusters for levels of bins at time 1

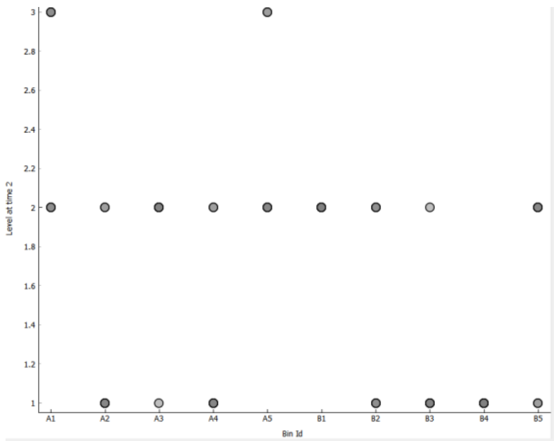

Figure 13. Scatter plot of clusters for levels of bins at time 2

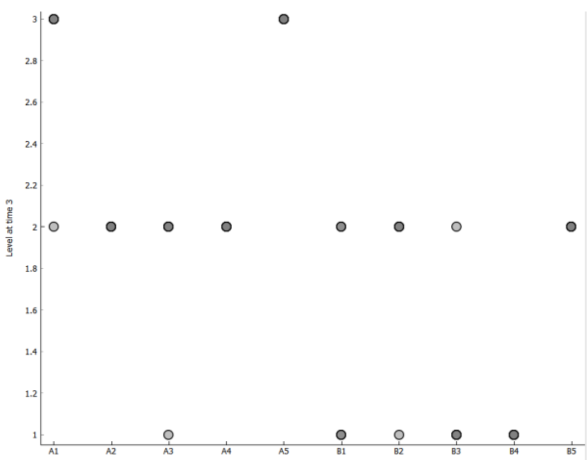

Figure 14. Scatter plot of clusters for levels of bins at time 3

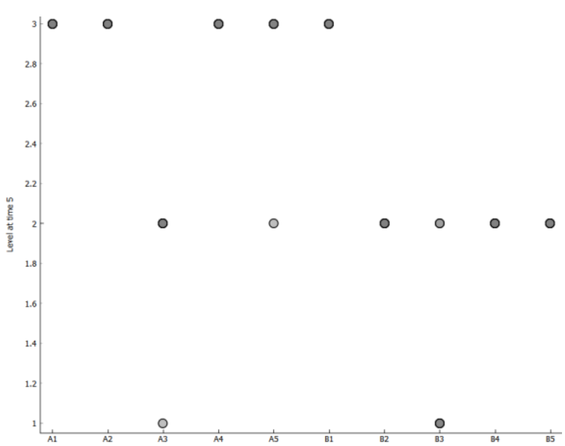

Figure 15. Scatter plot of clusters for levels of bins at time 4

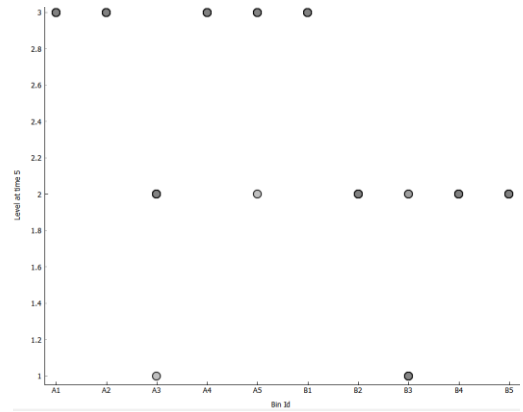

Figure 16. Scatter plot of clusters for levels of bins at time 5

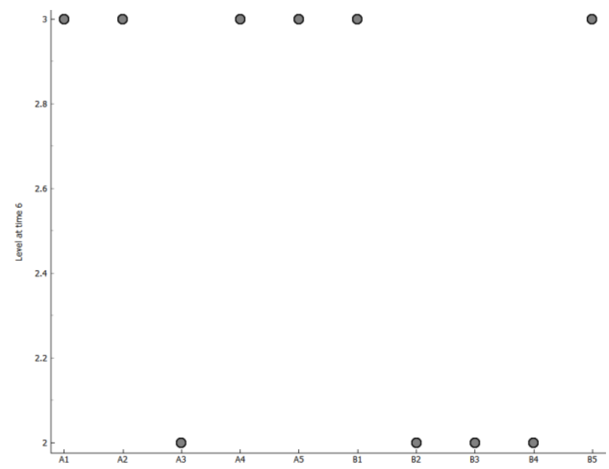

Figure 17. Scatter plot of clusters for levels of bins at time 6

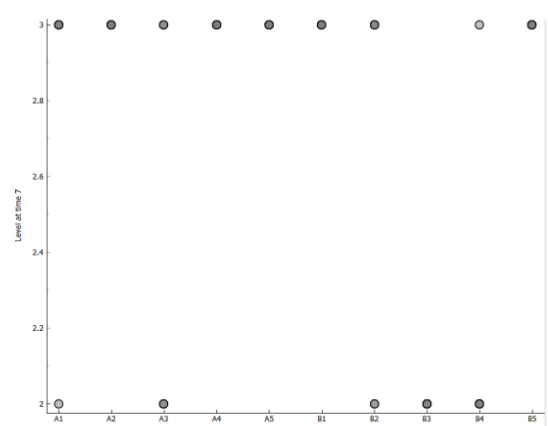

Figure 18. Scatter plot of clusters for levels of bins at time 7

8. Conclusion

This paper is targeted to design a clean smart city by developing predictive analysis-based garbage cleaning system. It has been shown how RFID system will capture the levels of bins and same will be communicated to the server. Analysis will take place in the server based on the received data at each level of pre-defined time. Path of garbage cleaning truck will be determined based on that. For analysis purpose synthetic data is considered where levels for garbage cleaning bins at different time are represented with different numbers. In future, if the analysis is done with real life data, where the data size is too big to handle manually, this predictive analysis can help in improving the efficiency substantially.

TABLE I. Synthetic Data of Garbage Levels of Bins

Bin Id	Date	a	b	c	d	e	f	g
A1	1/6/2019	2	3	3	3	3	3	3
A2	1/6/2019	1	1	2	2	3	3	3
A3	1/6/2019	1	1	1	1	1	2	2
A4	1/6/2019	1	1	2	2	3	3	3
A5	1/6/2019	2	3	3	3	3	3	3
B1	1/6/2019	1	2	1	2	3	3	3
B2	1/6/2019	1	1	1	2	2	2	2
B3	1/6/2019	1	1	1	1	1	2	2
B4	1/6/2019	1	1	1	2	2	2	2
B5	1/6/2019	1	2	2	2	2	3	3
A1	1/7/2019	2	3	3	3	3	3	3
A2	1/7/2019	1	1	2	2	3	3	3
A3	1/7/2019	1	2	2	2	2	2	3
A4	1/7/2019	1	1	2	2	3	3	3
A5	1/7/2019	2	3	3	3	3	3	3
B1	1/7/2019	1	2	2	2	3	3	3
B2	1/7/2019	1	1	2	2	2	2	3
B3	1/7/2019	1	1	1	1	1	2	2
B4	1/7/2019	1	1	1	1	2	2	2
B5	1/7/2019	1	1	2	2	2	3	3
A1	1/8/2019	1	2	3	3	3	3	3
A2	1/8/2019	1	2	2	2	3	3	3
A3	1/8/2019	1	2	2	2	2	2	2
A4	1/8/2019	1	2	2	2	3	3	3
A5	1/8/2019	1	2	3	3	3	3	3
B1	1/8/2019	1	2	1	2	3	3	3
B2	1/8/2019	1	2	2	2	2	2	2
B3	1/8/2019	1	1	1	2	2	2	2
B4	1/8/2019	1	1	1	2	2	2	2
B5	1/8/2019	1	2	2	2	2	3	3
A1	1/9/2019	2	3	3	3	3	3	3
A2	1/9/2019	1	1	2	2	3	3	3
A3	1/9/2019	1	2	2	2	2	2	3
A4	1/9/2019	1	1	2	2	3	3	3
A5	1/9/2019	2	3	3	3	3	3	3
B1	1/9/2019	1	2	2	2	3	3	3
B2	1/9/2019	1	1	2	2	2	2	3
B3	1/9/2019	1	1	1	1	1	2	2
B4	1/9/2019	1	1	1	1	2	2	2
B5	1/9/2019	1	1	2	2	2	3	3
A1	1/10/2019	1	2	3	3	3	3	3
A2	1/10/2019	1	2	2	2	3	3	3
A3	1/10/2019	1	2	2	2	2	2	2
A4	1/10/2019	1	2	2	2	3	3	3
A5	1/10/2019	1	2	3	3	3	3	3
B1	1/10/2019	1	2	1	2	3	3	3
B2	1/10/2019	1	2	2	2	2	2	3
B3	1/10/2019	1	2	2	2	2	2	2
B4	1/10/2019	1	1	1	2	2	2	3
B5	1/10/2019	1	2	2	2	2	3	3
A1	1/11/2019	1	2	3	3	3	3	3
A2	1/11/2019	1	1	2	2	3	3	3
A3	1/11/2019	1	2	2	2	2	2	3
A4	1/11/2019	1	1	2	2	3	3	3
A5	1/11/2019	1	2	3	3	3	3	3
B1	1/11/2019	1	2	2	2	3	3	3
B2	1/11/2019	1	2	2	2	2	2	3
B3	1/11/2019	1	1	1	1	1	2	2
B4	1/11/2019	1	1	1	1	2	2	2
B5	1/11/2019	1	2	2	2	2	3	3

a: Level at time 1
b: Level at time 2
c: Level at time 3
d: Level at time 4
e: Level at time 5
f: Level at time 6
g: Level at time 7

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