EcoConnect-X: An Integrated Smart Waste Management System Using IoT, GIS, Machine Learning, And Satellite Data

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***Abstract*—Urbanization rates have been increasing unevenly with the growth in municipal solid waste (MSW) generation, resulting in difficulties in managing urban solid waste. Current methods face problems of overflowing bins, inefficient collection routes, no real-time data monitoring and limited recycling initiatives. This paper attempts to address these problems by proposing EcoConnect-X, a smart waste intelligence system which integrates Internet of Things (IoT), Geographic Information System (GIS), Machine Learning (ML) and satellite monitoring. This includes IoT-enabled smart bins with sensors to detect its level and weight, sending the information to a cloud-based data management and analysis system. GIS is used to plan route and visualise and machine learning is used to forecast the waste. Satellite data is also used to monitor landfill growth and dumping across the country. The system connects communities, collectors, recyclers and the government through a mobile app for effective coordination. A prototype has been developed using an ESP32 microcontroller, ultrasonic sensor and load cell for real-time monitoring, segregation and a virtual market. It is also multilingual. Finally, EcoConnect-X demonstrates how an integrated approach using multi-technologies can result in effective waste collection for urban areas, encourage recycling and support green urban growth.**

***Index Terms*—IoT, Smart Waste Collection, GIS, Machine Learning, Satellite, EcoConnect-X, Smart City**

I. INTRODUCTION

An increase in population and urbanisation has resulted in rapid growth in solid waste generation, and a lag in collection and disposal. The problem of overflowing bins, poor collection infrastructure, not monitoring waste in real time and not engaging the public in recycling initiatives have further complicated this issue of waste. Traditional waste management approaches are mostly responsive and thus tackle issues retrospectively. Hence, there are pollution, operational costs and human health implications.

As technology improves, we need to be more intelligent and informed to manage waste. The Internet of Things (IoT), Geographic Information System (GIS) and Machine learning (ML) are some technologies that can help turn the old into the new smart system. Internet of Things (IoT) can help you monitor the rubbish bins; Geographic Information System (GIS) can help you in route planning and spatial analysis and Machine Learning (ML) can assist you in planning smarter by predicting the amount of waste generated.

Mapping at a broader level via satellite can assist you in identifying illegal dumping spots and assess landfill growth. Combining these technologies can help design effective, transparent and sustainable waste management solutions.

Here, we present EcoConnect-X, a smart waste intelligence system that combines IoT smart bins, geographic information system (GIS) for smart routes, machine learning predictive modelling and satellite monitoring in one application to solve these problems. This system enables communication between stakeholders including citizens, collectors, recyclers and government in real time and enhances engagement.

Additionally, the system is multi-linguistic, enabling interactions with the system in the users' preferred language. This helps to increase user awareness and

interaction with the system to enable citizen engagement in waste management.
The goal of this study is to design and develop an efficient and scalable smart waste management system that will enhance performance, promote recycling and enable eco-development.

II. LITERATURE SURVEY

Urgent waste management issues are being faced as a result of increasing population, associated waste and inefficiency of traditional waste management solutions. To address these challenges, a number of studies have proposed technology-driven solutions to improve waste management, collection and sustainability.
Many studies have examined smart waste management systems based on the Internet of Things (IoT) technologies that use sensors placed in bins to measure their fill level and transmit the data to the authorities in real-time. Generally, these involve ultrasonic sensors, GSM (Global System for Mobile Communications) module and online platforms for real-time monitoring and efficient collection [1][3][6][7][9][10]. These approaches help avoid wastes spilling over and increase efficiency. But this type of approach usually only offers real-time monitoring, without predictive analysis and intelligence.
Apart from IoT systems, Geographic Information Systems (GIS) have also been extensively deployed for route-planning and geo-analysis. Research indicates that the use of GIS-based approaches can reduce distance, time and fuel consumption through route optimisation [11][12][13][14]. These systems help make logistics more efficient but rely on static information and don't use smart monitoring data.
And machine learning approaches have been used to predict waste and improve scheduling. These include predicting waste collection considering population and period in the day using neural networks and regression analysis [16][17][18]. While these techniques may be applied to create better resource planning and scheduling, they are often used in a stand-alone fashion, not tightly integrated with real-time, IoT-based monitoring.
Furthermore, satellite and remote sensing have been used to monitor environmental factors. Studies have shown that satellite images and thermal data can be applied for monitoring the expansion of landfill, temperature variations and illegal dumping [19][20][21][22]. Even though these approaches provide valuable information at the regional scale, it is generally not linked to local waste management strategies.
From the above analysis, it is evident that the existing method only uses individual technologies including IoT, GIS, machine learning or remote sensing methods. However, there is a need for an integrated approach using these technologies to develop a whole system approach to waste management.
The EcoConnect-X platform proposed in this study integrates IoT monitoring, GIS route planning, machine learning prediction and remote sensing technologies. This will enhance efficiency, predict future decision making and drive sustainability practices in urban environments.

III. PROPOSED SYSTEM

EcoConnect-X system architecture is a layered system architecture which allows data gathering, communication and information sharing between stakeholders.
It has four layers: IoT layer, communication layer, application layer and analytics layer. The IoT layer comprises of smart bins that use sensors (e.g., ultrasonic) to measure the waste level in the bin. Data is collected from sensors which observe the state of the bin.
The communication layer (e.g., Wi-Fi, GSM) is used for data transfer between smart bins and server. This internet of things (IoT) allows the hardware and software to communicate in real time.
The application layer provides mobile (app) and web interfaces. The layer provides interfaces for a variety of users including collectors, recyclers and the government. It allows for bin status, notifications, complaints and waste transactions.
The analytics layer is responsible for data processing and uses machine learning and GIS. The machine learning algorithms are used to predict waste generation and route collection, while the GIS is used to route planning and mapping waste.
The system integrates this with a cloud computing system that has services for data storage, scalability and maintenance. This data is visualised in dashboards for reporting.

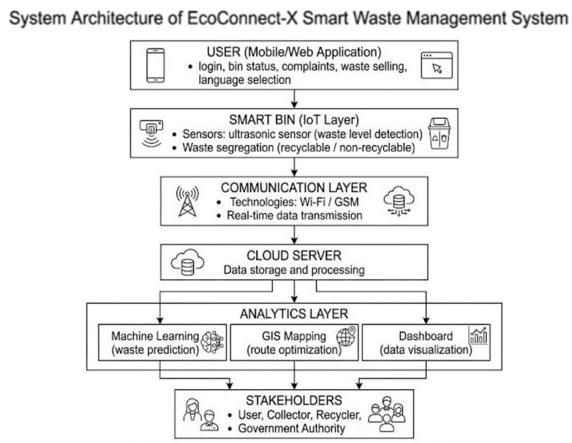

Fig. 1. Overall System Architecture of EcoConnect-X

The following diagram illustrates the entire process - from smart bins and data collection to the cloud, machine learning predictions, GIS mapping and stakeholder interaction.

IV. PROTOTYPE IMPLEMENTATION

An IoT-based smart waste bin and a multi-purpose application has been prototyped to test and implement the EcoConnect-X system. It demonstrates integrating hardware and software components for waste management.
The smart bin is a dual-separate wet and dry bin to separate waste into two different streams. Waste level and data is monitored through sensors. The smart bin system consists of sensor components and electrical wiring to monitor its status and generate data.

Hardware Components Used
We rely on IoT components to keep track of the waste level and bin weight of EcoConnect-X. They consist of:

- ESP32 Microcontroller:

The main microcontroller. It's connected to sensors, that it communicates data to the cloud - allowing us to monitor the bin in real-time.

- Ultrasonic Sensor (HC-SR04):

This sensor offers a method of measuring the level of waste in the bin by calculating the distance to the waste. The sensor can also be used to detect when the bin is full.

- Load Cell with HX711 Amplifier:

Load cell will be used to measure the weight of the waste in the bin. The HX711 amplifier will meter out the amplified output from load cell and this information will be used by the ESP32 to calculate weight.

- Prototype Board and Jumper Wire:

These are used to connect the ESP32, sensors and other modules.

- Power Source (Battery / USB).

Provides power to the ESP32 and sensors.

- Bi-sided Smart Bin:

Smart bin consists of two bins for segregation of waste into recyclables and non-recyclables.
The external design of the smart waste bin is depicted in Fig. 2 and is marked to separate waste items. This facilitates its easy operation and emphasizes waste segregation.
Fig. 3 is a typical internal hardware configuration of the smart bin with sensors and other electronic components required for monitoring the waste bin.

Fig. 2. Prototype Smart Waste Bin (EcoConnect-X)

Fig. 3. Internal Sensor and Hardware Setup

A user-friendly application has been developed for stakeholder interaction along with the hardware prototype. It allows users to check the status, reporting issues and selling waste. Bin collectors can be informed when waste bins are overflowing, and the recyclers can buy the waste.

It has a multi-lingual capability that allows users to use different languages. This improves user experience by allowing users from different parts of the world to access the system. The system prototype developed illustrates real-time monitoring, segregation and communication with stakeholders, validating the system.

Fig. 4 is the user interface to sell recyclables, where the user can enter details of waste type, quantity and price. Fig. 5 depicts the collector dashboard that provides real-time information about the status of bins such as urgent, medium and normal bins. Fig. 6 depicts the analytics dashboard, which provides visual analytics such as waste distribution and effectiveness of the system. These interfaces support effective system interaction and communication.

EcoConnect-X user interface is easily accessible. Fig. 4 shows the user interface for users to sell recyclable waste by entering waste type, amount and price. Fig. 5 shows the collector dashboard, which visualises the status of bins. Fig. 6 shows the analytics user interface, showing the waste graph and system efficiency.

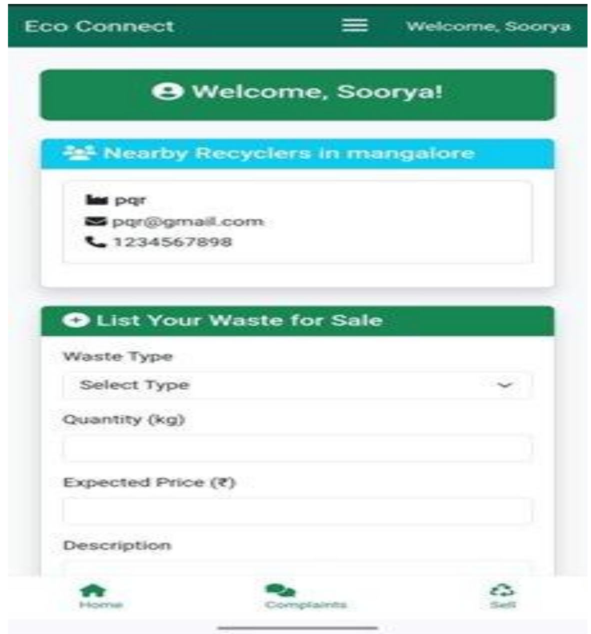

Fig. 4. User Interface for Waste Listing and Recycling

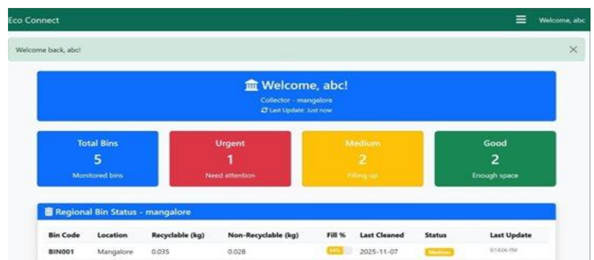

Fig. 5. Collector Dashboard Showing Bin Status

Fig. 6. Analytics Dashboard for Waste Monitoring

V. TECHNOLOGIES USED

In this paper we present EcoConnect-X, a combination of multiple emerging technologies for waste management.

A. Internet of Things (IoT)

For EcoConnect-X, we use IoT as the sensing technology. A smart bin is Council's smart bin that has a HC-SR04 ultrasonic sensor and a load cell to track the fill level and weight of the waste. Using its Wi-Fi module, data from the sensor is streamed to the cloud server which triggers notifications based on threshold, and displays the fill level in the dashboard used by the collector.

B. Geographic Information System (GIS)

GIS is used for map placement of the bins and route planning. This helps map the waste generation patterns and helps in optimal route planning to save time, money and fuel.

C. Machine Learning (ML)

EcoConnect-X applies ML to modelling historical data of bin-level waste. The predictions are integrated to determine dynamic routes, which provide on-demand resource allocation, as opposed to planning for waste collection.

D. Space Technology (Satellite Data)

Satellites are used to track landfill development and dumping. This gives an overall perspective on environmental pollutant, and assists waste management.

E. Information and Communication Technology (ICT)

ICT is used for interaction between components using mobile apps, websites and cloud computing. This ensures data exchange and interaction with waste collectors, recyclers and government.

VI. RESULTS AND DISCUSSION

We tested EcoConnect-X to see if it is effective in real-time monitoring and co-ordination of waste. The smart bin using IoT technology could measure its level using ultrasonic sensors and load using load cells. The ESP32 microcontroller transmitted the data to the cloud for monitoring in real time.

The system was able to raise an alarm when the bin was full for collection. The approach minimises the "no pick up" and overfill issues associated with the existing scheduling-based waste collection approach.

The multi-role app was tested with a number of users, including citizens, collectors, recyclers and governments. Users tracked bin status, reported problems and listed waste material. Collectors were provided with bin details in real-time to optimise collection. The recycling module enabled transactions between waste buyers and sellers to build a circular economy.

Using the data analytics dashboard, waste data and efficiency were visualised. Although the existing urban waste management system has plans for future integration of the GIS and machine learning modules, they are expected to address route optimisation and predictive problem solving, respectively.

Overall, the EcoConnect-X prototype suggests this system can potentially improve operational efficiency, reduce manual processes and promote recycling. The system can potentially be used in smart cities.

VII. CONCLUSION

The paper presents the design of a smart waste collection system EcoConnect-X to address the inefficiencies involved in the traditional practices of waste collection in densely populated areas. The system uses advanced technologies such as Internet of Things (IoT), Geographic Information System (GIS), Machine Learning (ML) and satellite monitoring to achieve a data-driven and efficient waste management system.

The prototype of the system is developed to demonstrate the concept with real-time monitoring of the waste bins with sensors such as ultrasonic and load cells. The ESP32 microcontroller allows communication among users through wireless networks and real-time refresh of data and coordination between stakeholders.

Not only does this system improve efficiency in waste picking, but it also promotes recycling via an online platform to connect users, waste pickers and recyclers. And its multilingual nature makes it inclusive and engaged.

In all, EcoConnect-X is an efficient, eco-friendly and cost-effective waste management system. The system can be implemented in smart cities to reduce environmental impact, improve resource efficiency and enable the shift towards a circular economy.

Further research could look at using advanced algorithms through machine learning, real-time heatmaps through GIS and more incorporation of satellite data for large-scale environmental monitoring.

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