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Development of A Smart Waste Collection and Evacuation Protocol Using IOT and Cloud Computing

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ABSTRACT

Developing countries struggle with the management of solid waste and environmental health risks associated with unsanitary conditions. Solid waste management options are one of the major channels through which these harmful gases find their way into the atmosphere. Indiscriminate disposal of household and industrial waste remains an alternative means of waste disposal for cities that have no access to reliable refuse removal services. It is constantly a topical issue because improper waste disposal is capable of severely endangering public health and/or the environment. This work, therefore, developed a holistic system approach to waste management by harnessing the robustness of IoT technology, GPS, and Cloud computing. The proposed system involves the use of various sensing devices integrated with the Microsoft Azure cloud platform to monitor waste collection in real-time ensuring that waste buckets are emptied as and when due, curbing the littering and indiscriminate disposal of trash. This work also developed a mobile application interface (iTrash) to streamline the operations of waste management workers and to ensure policy compliance by the populace with the waste collection protocols using Owerri Imo state as a reference location.

INTRODUCTION

The manifestation of climate change in excessive flooding, heat waves, and wildfires has caused damages to multiple billion-dollar investments in rural, urban, and their natural environment (Wolff, 2014; Nnaji and Utsev, 2011). Governments all over the World have placed this phenomenon on the radar, with millions of dollars already spent on research, regulations, monitoring, and global sensitization. The weight of efforts of African nations to augment that of their foreign counterparts will be a topic of critical debate. It is undeniable that the most popular method of waste management in most African countries is by using it in landfills and/or by indiscriminate burning, both of which have significant levels of greenhouse emissions.

Improper waste disposal has continued to be a serious issue of concern in Nigeria due to its effect on sanitation and the general quality of urban life. Managing solid waste is progressively becoming a major challenge in many cities of developing nations because of rapid urbanization and the rise in population (Wolff, 2014). This can be described by indiscriminate dumping, ineffective collection methods, inadequate coverage of the collection, and processing system, and inappropriate disposal. According to Coleen, *et al* (2021), waste management accounts for 19% of greenhouse gas emissions in the island of Mauritius, right behind the energy sector which contributes about 77% of all emissions. Also, a 2009 report by the United States Environmental Protection Agency estimated that 42% of total greenhouse gas emissions in the US were associated with the management of waste materials (USEPA, 2009).

Despite long-established environmental sanitation laws, formal governmental structures, and campaigns addressing a cleaner environment, it is appalling that our people continue to dump household waste into gutters, canals, highways, street corners, and other available spaces. During the rainy season, people intensify the flooding challenge by disposing of their refuse into the flowing water bodies and channels. Major roads and streets become choked with filth not due to a lack of regulation codes but because of Nigerians' attitude of indiscriminate waste disposal.

The difficulty in allowing modernity and education to change the attitude of individuals toward orderliness has sadly made an unclean environment a normal syndrome in our national life. Owerri Municipal in Imo State is not an exception. This work developed a protocol for waste management strategy by harnessing the robustness of IoT technology and Cloud computing ranging from waste collection, gathering, and evacuation, ensuring that indiscriminate disposal of waste is curbed. It developed a mobile application interface (iTrash) to streamline the operations of waste management workers and to ensure policy compliance by the populace with the waste collection protocols. The robust and efficient waste collection/evacuation protocol system based on modern technological practices and principles, exploited the synergetic handshake of IoT and cloud computing using Owerri Imo state as a reference location.

SOLID WASTE MANAGEMENT IN URBAN CITIES

According to Buckle and Smith (2000), the management of solid waste encompasses all the activities that seek to minimize the health, environmental, and aesthetic impacts of the disposal of solid waste. Many urban cities in Nigeria are deficient in effective solid waste management systems and consequently, the major part of generated wastes is indiscriminately released into the environment. Indiscriminate dumping refers to the unlawful disposal of waste in undesignated spaces such as open or vacant land, sources of water, and other areas (Achi *et al.*, 2012; Okechukwu *et al*., 2012). Indiscriminate disposal of solid waste has become one of the most serious problems facing many urban cities of the world, especially in developing countries. It is a prevalent though risky practice, especially among developed and developing communities.

According to Regassa *et al* (2011) and Adeniran *et al* (2014), 68% of the solid waste generated by communities was indiscriminately dumped, 20.8% was disposed of through appropriate landfill sites and 10.7% was burnt in Nigeria. However, Aurah (2013) points out that at most 10% (≤100 tons) of the total daily waste generated of approximately 1000 tons was collected by the local authority in Nairobi. The remaining 9900 tons of generated waste is unaccounted for. Indiscriminate disposal accrues solid waste which creates health problems, such as pollution, global warming, and climate change due to the release of greenhouse gases, increased disease incidence such as malaria, cholera, diarrhea, dysentery, respiratory tract infection, and other filth–related diseases (Ogwueka, 2009; Nwankwo, 2008). Other problems associated with solid waste accruement are blockage of roads and drainage systems, flood occurrences, accidents, and environmental degradation. It is evident from these studies that indiscriminate dumping of waste remains the main approach used for the final disposal of municipal and hazardous wastes in most developing economies and will continue to be a challenge (Oyoo, Leemans, and Mol, 2010). According to a report, experts predicted that due to climate change, the stability of the ice sheets will be placed in jeopardy resulting in long-term sea-level rise, arctic sea-ice loss and warming, coral reefs, more intense tropical storms with increasing warming, and likelihood of positive feedbacks amplifying warming due to the release of methane hydrates from the sea bed, which would add methane to the atmosphere, increasing the warming (Hare, *et al.*, 2011). There appear to be daring consequences if prompt actions are not taken to curb the rate of ozone layer depletion, which according to scientists is behind this disproportionate rise in temperature of the earth's atmosphere.

Fig 1: Indiscriminate Refuse dump site in Owerri Municipal

IoT AND SOLID WASTE MANAGEMENT

Undiscerning illegal disposals of waste, lack of waste management systems, and inept waste management policies have resulted in severe health and environmental challenges. The conventional waste management process begins with waste being generated by residents in cities and disposed of in trash bins at the point of creation. At a predetermined schedule, municipal department trucks gather the garbage and transport it to the recycling centers. Municipalities and corporations struggle to keep up with the outdoor bins to determine when to clean them or whether they are filled or not. One of the most pressing issues of our time is the prevention, tracking, and treatment of these wastes (Maria *et al.*, 2020). The conventional method of manually inspecting waste in bins is a time-consuming procedure that requires more human labor, time, and money which can be eliminated with today's technology (Venkiteela, 2020).

For this war against the consequences of indiscriminate waste disposal and poor SWM to succeed, man must expend the entire technological arsenal at his disposal. Understanding the integration of several empowering technologies in a system (such as data acquisition and network transmission) offers an improved insight into the meaning of each functionality within the context of the Internet of Things technology (IoT). In this work, the authors sought to exploit the ubiquitous capabilities of the IoT to tackle waste management, drastically reducing greenhouse emissions and consequently decelerating global warming. The rapid development of IoT-based smart technologies has legalized a slew of new capabilities in numerous areas of life. IoT intends to offer plug-and-play technologies for easy operation, remote access control, and configurability. The IoT paradigm (Ramson and Moni, 2017) integrates application solutions and communication technologies such as identification and tracking, sensor networks, wired and wireless actuators, better communication protocols, and distributed intelligence for objects. RFID tags, sensors, actuators, wireless sensor networks, near-field communications, and GPS are used in waste management to annotate and communicate information. Improvements in IoT have enhanced the present waste management system. IoT-based waste management models play an important role in illuminating human existence by enhancing energy efficiency, improving governance, and lowering costs. The communication distance between the garbage collection location and the collector's location is crucial in determining the system's efficacy.

METHODOLOGY

Reference location

The reference location is Owerri Municipal of Imo State in south-eastern Nigeria located within longitude 7° 02' E and latitude 5° 29' N. In the city of Owerri, poor governance has encumbered the solid waste management sector for many years. The government has at one time initiated a notable public sector reform Clean and Green Initiative to recreate Owerri, through improved solid waste management and beautification, to become a Garden City.

Materials

The work utilized the following materials, services, and technologies to effectively actualize the expected result: Google Cloud Platform (GCP), Google Play Store, Virtual machine instance, Ubuntu Linux OS (version 20.0 LTS), MySQL server (version 8.0.2), Java Programming LANGUAGE (JDK 17), Kotlin programming language (version 1.9.10), Springboot Framework (version 3.2), Android Studio IDE, Room Database, Retrofit REST Client, IntelliJ Idea IDE, Google Firebase Messaging, Git version control system, Github, Core i5 laptop running Windows 10 OS, A Smartphone running Android OS.

The system developed in this work is structured in a Client/Server model. The server side has the role of carrying out core business logic functions as well as database management. On the client side, a native mobile application is developed for the Android Operating system. The minimum Android version supported by the Mobile app is Android 8.0.

Methods

a. The Backend Application

The back-end application is structured to follow the single dependency principle, giving priority to security, scalability, testability, and code maintainability. This involved separating the client-facing controller classes from the business logic of the service classes and also the database-facing repository interfaces. More so, the model classes are hidden behind Data Transfer Objects (DTO).

The entity classes represent the database tables, each entity corresponding to a table. The fields of the entities translate to columns on the tables, while each object of the entity constructed forms a row in the table. The entities in the source code of this web-based application include Customer, Agent, Admin, Bin, Disposal Request, Bin Request, and Token.

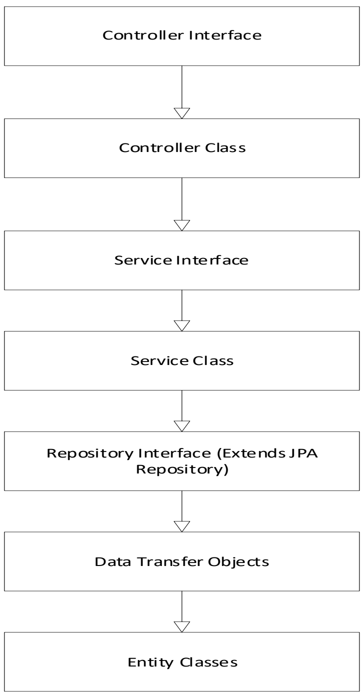


Fig 2: Structure of the API source code

b. Security Policy of the Proposed System

Security is a paramount issue in every digital system. Security in this domain includes Authentication, Authorization, and Accounting (AAA). ***JSON Web Token (JWT)*** authentication system was used for managing user authentication. JWT issues an authenticated user a token usually referred to as ***Bearer Token.*** Authorization controls the access level of different users based on their position or responsibilities in an organization. In authorization, a user can be granted privileges to access certain areas of an application, to access certain information, and to perform certain actions, especially administrative or technical support activities. An access level control mechanism was put in place by enforcing a role-based access level control policy.

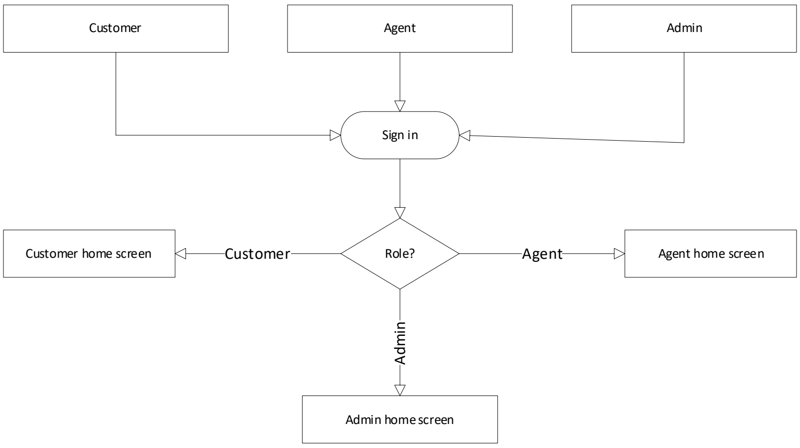


Fig 3: Client-side Access Control Policy

c. Mobile Application

The selected OS for this work is the Android OS. The choice of Android is a result of certain factors which include user-base and technical know-how. Android OS still enjoys a very large percentage of the mobile operating system ecosystem. Kotlin programming language as the official language for building modern Android applications was chosen to build a native Android application. To communicate with the web service (the backend of the system), the Retrofit library was used. The need for accurate location sensing in developing a smart waste management system prompted the interface with Google Location Service (GLS). GLS represents Google's commitment to improving location accuracy, battery efficiency, and user experience across a wide range of applications, including mapping, navigation, geo-fencing, and location-aware applications.

RESULTS

The results obtained are presented with a focus on the development and deployment of the web-based REST API and the mobile application developed as part of a holistic smart waste collection and management system aimed at reducing the impact of climate change on our planet.

1. Web-Based Rest API Results

Google Cloud Platform (GCP) which provides a high service level agreement of up to 99.99% uptime per annum was chosen based on its high level of availability, and adequate analytic tools for monitoring the health and performance of the deployed application.

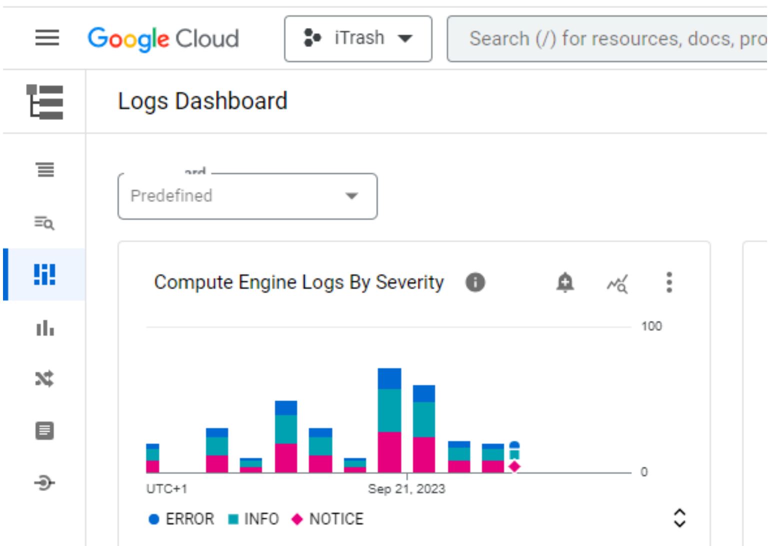


Fig 4: Section of the GCP logs dashboard of the web-based application

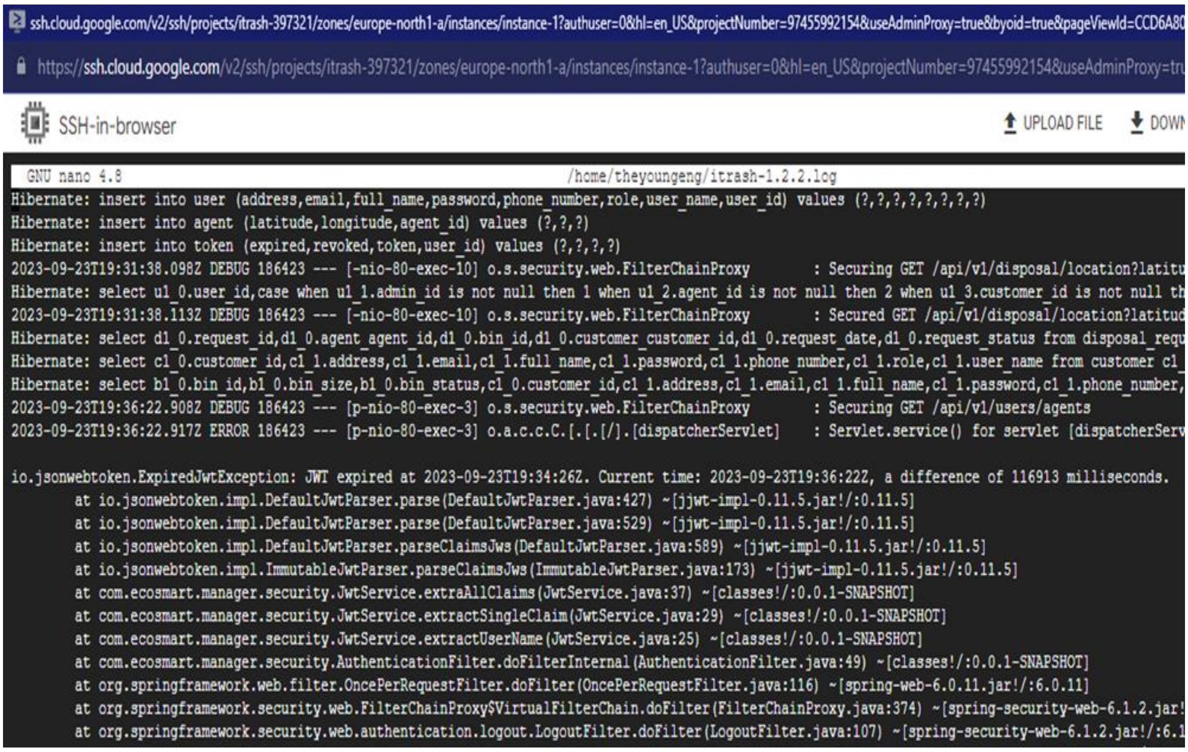


Fig 5: Application logs showing failed API request

Figure 5 depicts the application logs showing an API request attempt with an expired authentication token. The cloud infrastructure was carefully provisioned within the nearest zone to the end users of the application and to that effect, the round-trip latency rate stayed far below 500 milliseconds since deployment. The implication is that the mobile application offers a smooth user experience to the end user, as though all the data being accessed are stored locally on the local device. Figure 4 shows the network latency of the web application for 30 days. The highest latency from the figure shows that the highest latency within the reference period was 240.2 milliseconds.

All monitoring and analytics information presented in Figure 6 indicates that the web application is performing far above the benchmark. This implies that the core functionality of the system is highly reliable. This gives credit to the actualization of a smart waste management system that leverages the reliability of cloud computing technology.

Fig 6: Network latency graph for August 31 to September 30, 2023.

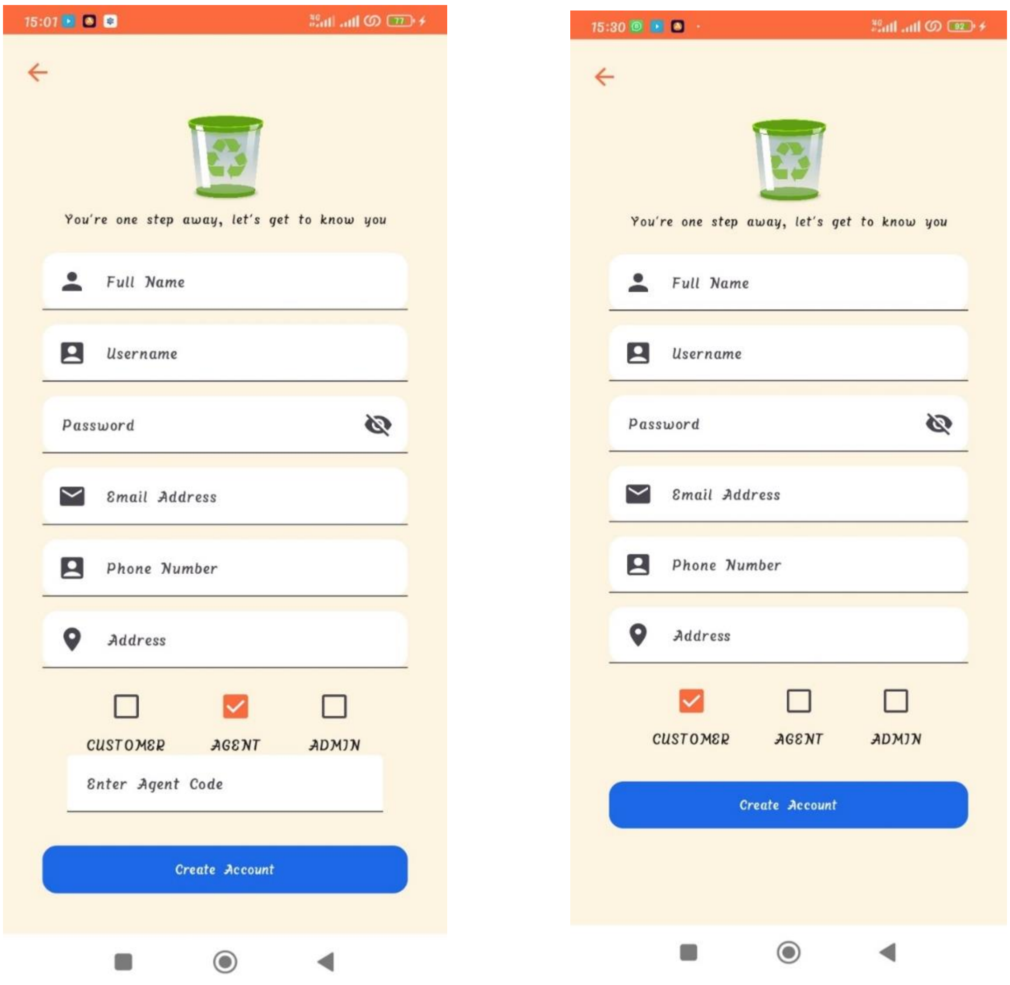
2. iTRASH

The Mobile application, iTRASH serves as the client-side and the sole user-facing component of the smart waste management system. It is designed to enable Customers, Agents, and Admins alike, to carry out all tasks involved in the process of account creation, trash can request and issuance, waste disposal request, tracking and evacuation, and account management, in addition to all other administrative tasks.

a. Account Creation

There are three categories of users on this iTRASH – the Customers, the Agents, and the Admins. During the account creation process, the user selects a suitable category by clicking the corresponding checkbox.

If a user checks the agent box or the admin box, a secret code will be required to proceed. This is to ensure that only licensed users can sign up as Agents or Admins. Only the Admins can deactivate or delete any account that violates the user policy. The information required for creating a user account includes username, password, full name, email address, phone number, and address. The geo-location data is automatically captured by the app. These supplied data are securely transmitted to the database running on Google Cloud where they are stored.



(a) Agent *(b) Customer*

Fig 7: Sign-up screen

(b) The Customer

The customer sits at the bottom of the layers of the active players in the smart waste management system. The customer which comprises the populace, needs to acknowledge that illicit waste disposal negatively impacts the environment, causing environmental pollution, releases harmful gasses into the atmosphere, and could cause several forms of health hazards.

Fig 8: Customer home screen

In this research, different categories of trash bins were introduced, ranging from those that are suitable for domestic use to those for industrial use, and to those suitable for public use. The basic functions of the customer on the iTrash mobile application are requisition of a suitable category of trash bin based on the customer's needs, requisition for trash evacuation by the agents, and payment of subscription fee for sanitation.

(c) The Agent

The Agent is an important factor in the smart waste management system, which is saddled with the responsibility of delivering trash bins to the users as well as evacuating filled bins on request for disposal. The agent is an employee of the Admin and is patterned to log all disposal requests from locations not farther than the benchmark distance, within his real-time location. At each log-in, real-time geo-location of the Agent is captured, sent to the server, and used to filter the requests that are displayed on the dashboard.

Fig 9: List of pending disposal requests on the agent's dashboard

To respond to any requests, the Agent clicks on it to see the details of the request and then assigns the request to himself by clicking the “Assign request” button. The information contained in each request which is visible to the agent includes the request ID, the name of the requesting customer, the address of the trash bin, and a link to view the location of the trash bin under reference on the Google map.

After an agent assigns a request to himself, the status of the request changes from **RECEIVED** to **PROCESSING** and it disappears on the dashboard of other agents. After successfully responding to evacuating the trash, the agent is expected to mark the request as TREATED and the request will automatically moved to the list of completed requests for the agent. The number of completed requests by an agent can be viewed by an admin for administrative purposes.

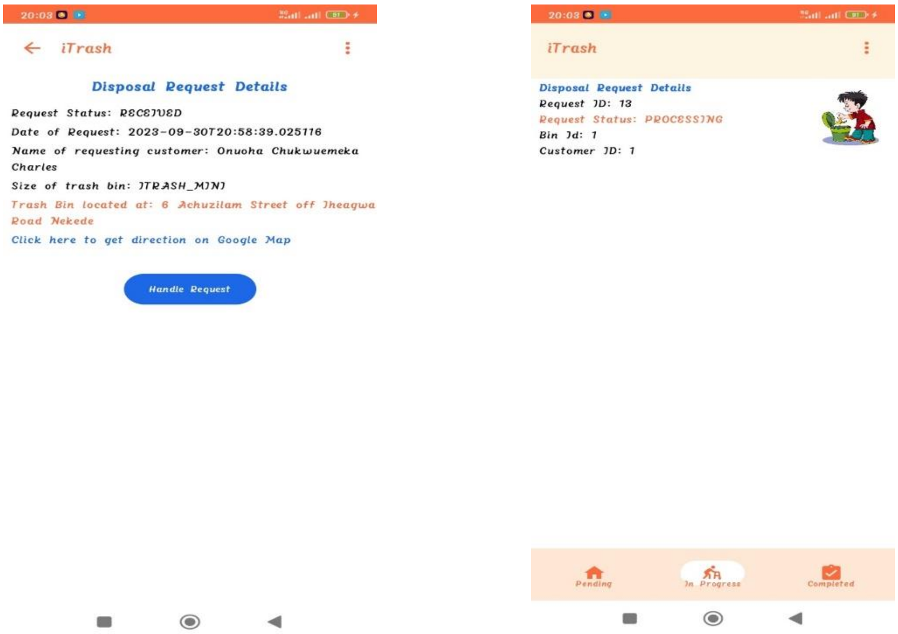


Fig 10: Disposal request assignment screen and list of requests in progress for an agent

(d) The Admin

At the top layer of the active players in the smart waste management system sits the admin. The admin performs all the administrative functions like approving or rejecting the request. At the approval of a request, the admin assigns an agent to deliver the trash bin to the requesting customer by providing every detail needed to get the trash bin delivered.

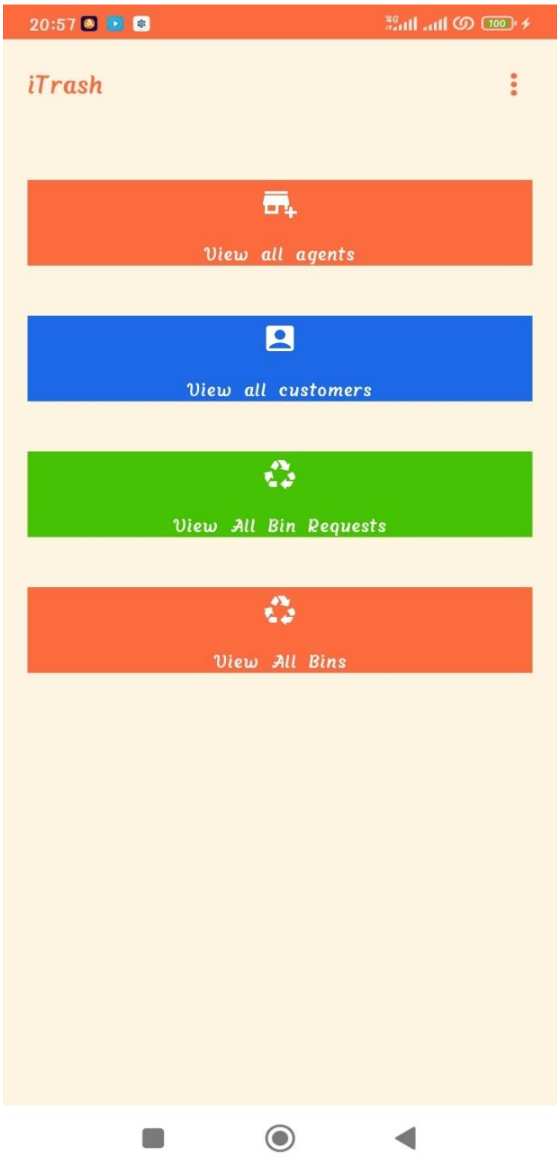


Fig 11: Admin home page screen

The admin is also saddled with the responsibility of monitoring the activities of agents, ensuring that disposal requests are promptly being attended to by agents. All complaints from customers are attended to by the admin.

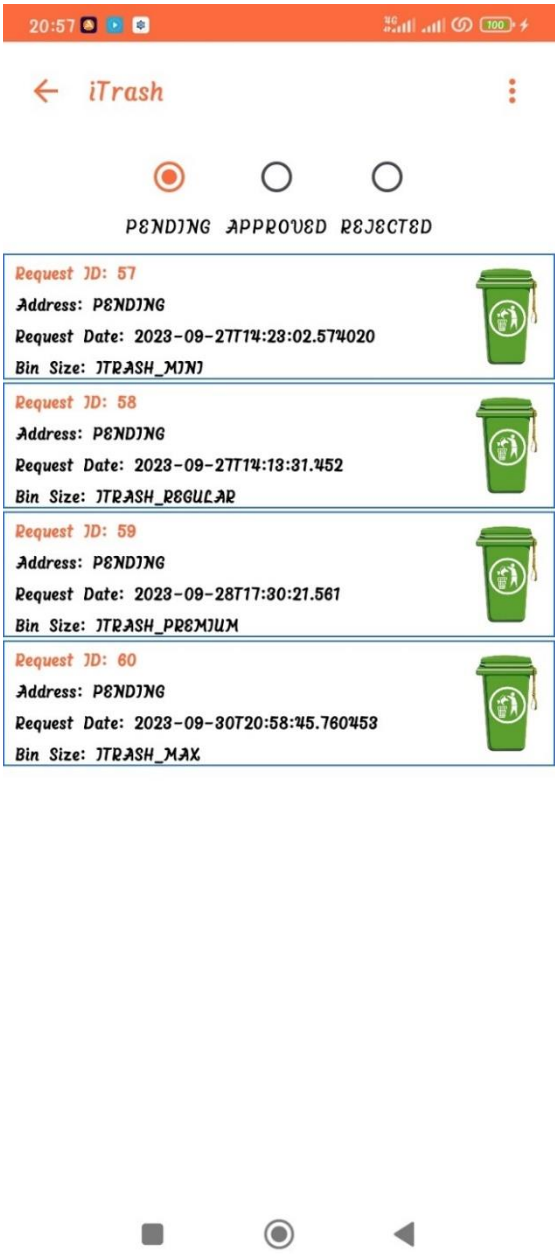


Fig 12: List of pending trash bin requests

The admin can suspend any agent or customer at any default in the protocol of operation in the case of the customer, or replicate consistent negligence of duty, in the case of agents. The admin also assists the customer in resolving any authentication issue that may arise. More so, if the need arises to replace any trash bin, the admin performs the swap for the customer.

The aggregation of responsibilities of the different players makes up a holistic smart waste management system, utilizing GPS and cloud computing technologies. The robustness of the system ensures that no waste is left indisposed, the result being a more pollution-free environment and safer ozone layer.

CONCLUSION

By developing a robust mobile application and a powerful server-side REST API hosted on Google Cloud, the project has demonstrated the potential of technology particularly in the context of waste management. The mobile application, iTrash addressed the critical issue of climate change through the innovative integration of Smart Waste Management System, GPS technology, and Cloud Computing.

The implementation of GPS technology provides robust navigation capabilities, enabling the precise location of filled trash bins. Through the efficient collection, transportation, and disposal of waste, the system optimizes resource utilization and minimizes environmental pollution. Additionally, the utilization of Cloud Computing technologies facilitated seamless data processing, storage, and analysis. The scalability and flexibility offered by cloud-based solutions ensure the system's adaptability to varying scales of operation, making it a sustainable and viable option for diverse communities.

This research project not only contributes to the optimization of waste management processes but also aligns with global efforts to combat climate change. By reducing carbon emissions associated with inefficient waste management practices, the implementation of iTrash paves the way for a greener, more sustainable future. Through collaborative efforts and the integration of cutting-edge technologies, we can strive towards a more environmentally conscious society. Furthermore, the project highlights the importance of technological innovation in addressing environmental challenges, emphasizing the need for continued research and development in this field.

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