Smart E-Waste Monitoring System

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Abstract

Greater waste of the electronic (e-waste) is a grave environmental and health disaster caused by the inappropriate disposal of the wastes. As a solution to this issue, we have come up with an E-Waste Monitoring System that was developed as a Progressive Web Application (PWA) and Firebase as the backend. The system makes e-waste collection easy as three of the partners participate in the process: users, who request a garbage pickup; pickup personnel, who pick up the garbage; and an administrator, who allocates tasks, manages transactions, and statistics. The key features are real-time tracking with the help of Google Maps, secure authentication, cloud database management, push notifications with Firebase Cloud Messaging, and analytics dashboards with Chart.js. The system has the advantages of a PWA the ability to work on a wide range of platforms, offline application, and installability, which, in turn, provides an environmentally friendly and scalable solution to improving recycling and collection of e-waste. This project is useful in creating a sustainable technology-based platform where people can be responsible to the environment, and the management of waste materials is sound.

Keywords - E-Waste Monitoring, Mobile Application, Fire- base, Firestore Database, Real-Time Tracking, Data Analytics.

1. Introduction

There has been a rampant increase in electronic wastes (e-waste) as the rate of technological advancement grows very fast in the digital era. Outdated devices such as computers, tele- visions, cell phones, and household appliances are usually disposed of in an inappropriate way and this becomes a serious environmental threat and health risk. The traditional systems of waste management do not have proper systems of monitoring, collecting and recycling of e-waste in a systematic way.

The E-Waste Monitoring System suggested projects a new Progressive Web Application (PWA) as the inter-mediary to link users, pickup staff, and administrators. The system utilizes cloud technology, handheld compatibility, and real-time monitoring as the means of successful e-waste management. A PWA is cross-platform, user-centric, and lightweight, as it does not need to be installed in the app stores of both mobile applications and desktops.

There are three key functions of the system:

User: The users can place pickup requests through the application, supply waste information, and monitor the status of requests.

Pickup Personnel: The personnel appointed by the Administration pick e-waste at user locations, see the assigned tasks, call into the system, and communicate pickup status.

Administrator: An administrator is responsible to manage the platform, assigning personnel, monitoring the locations in real-time, and registering users, processing the e-waste data obtained.

Firebase offers the underlying infrastructure and authentication of a safe login, Cloud Firestore of real-time data management, Firebase Cloud Messaging (FCM) of notifications, and Firebase Hosting of PWA implementation. Google Maps API supports real time tracking and location services. The e-waste trends are analyzed with the help of Chart.js that will allow administrators to track the performance and make future efforts.

2. Related Work

The latest studies have devoted much attention to the implementation of IoT and cloud technologies in the successful e-waste management. Kumar et al. [1] proposed an IoT-based monitoring and recycling e-waste system that allows tracking in real-time by exchanging data in the cloud. On the same note, Farjana et al. [3], [15] created an IoT- and cloud-based model that focuses on data-driven decision-making and reclaiming resources. Rani et al. [4] developed a mobile green e-waste management model of smart campuses, whereas Bansod et al. [7] presented a smart IoT-based e-waste collection system, which automates the data collection process by the use of bins. Even though these systems prove to be efficient in terms of integrating IoT, the majority of them are based on the use of substantial hardware and cannot be extended in terms of scaling and interactivity at the user level.

The general waste management systems with the use of the IoT have been investigated by other researchers. Smart waste bins were developed by Sankeerth et al. [8] and Jadhav et al. [13] and are equipped with sensors to monitor the fill levels and provide an alert to the time of pickup. These solutions demonstrate a potential to be used in automating solid waste collection, but they are more device-oriented and do not concentrate on e-waste-specific tracking and accessibility via mobile. Lin et al. [12] have conducted a thorough review of IoT systems including architecture, security, and privacy, and data flow, which offers a theoretical background to the development of reliable cloud-based systems. Nonetheless, these studies are not practically implemented towards the e-waste field more so in relation to the applications that are citizen-focused.

The increasing concerns of e-waste have also been covered on environmental and policy-oriented studies. Sivaraman [5] accurately researched the adverse effects of improper disposal to the environment, Ajekwene et al. [9] and Mundada et al. [10] addressed the issue of e-waste management in the developing nations, especially India. The impact of global e-waste laws was highlighted by Lepawsky [11], and the OECD report [14] provided the guidelines of Extended Producer Responsibility (EPR) to promote responsibility among the producers. Even though these research works present the

necessary background of sustainability and policy frameworks, they do not offer the technical implementation of e-waste tracking or e-waste collection systems in real-time.

The international approach to e-waste management is also emphasized in The Global E-Waste Monitor 2020 by Forti et al. [6], which provides information about the worrying rates of e-waste production in the world and the opportunities of a circular economy model. This was complemented by Razip et al. [2] who came up with the guidelines of sustainable IoT-based household management with the aim of encouraging responsible disposal practices. Although such works are important, there is a lack of literature that suggests a lightweight, inexpensive, and interactive digital model that can directly relate users with collection staff and provide cloud-based analytics to track and make decisions.

Based on this review, it can be noted that although various studies have delved into the IoT and environmental issues [1]-[15], there is a void in real-time, usable systems that can enable the communication between the users, pick-up agents and administrators. The proposed Firebase-supported E-Waste Monitoring Application will address this gap by combining cloud-based Firestore, Firebase Authentication, and analytical dashboards with Chart.js, which will allow a scalable and efficient e-waste collection network.

3. Proposed System Architecture

The existing e-waste management systems are marred with inefficiencies such as slowness in collection, lack of interactivity with the user and lack of real time tracking. To address these problems, the proposed Smart E-Waste Monitoring System is installed in the form of a Progressive Web Application (PWA) with Firebase cloud implementation and a Google Maps API. The system is associated with automation, transparency and good coordination between the users, the administrators, and the pickup workers.

A. System Components

The architecture is comprised of three key stakeholders. Users are those who are generating e-waste and they can request pickup, track the condition of their requests and also view live updates. The administrators are the staff that can organize operations, distribute tasks to pick up staff, track ongoing collection, and analyze the information gathered. Pickup staffs are authorized persons that collect e-waste in user premises and register the system in real time. The PWA interface enables all the operations and is supported by Firebase services which include Authentication, Firestore Database and Cloud Messaging and real-time location and route optimization is supported by Google Maps API.

B. Functional Workflow

The system has a successive series of operations that are defined. E-waste collection requests are made through the web interface or through the mobile interface after the user enters information like the type of waste and its volume. The administrators then give the request to the nearest pickup staff on their location. Pickup personnel collect the e-waste and indicate the current situation in the gathering. Statuses of requests can be updated in real-time in a live fashion, and data is stored in Firestore and presented through Chart.js dashboards. Administrators can, therefore, trend, define high collection time, and evaluate the efficiency of the recycling operations.

C. Key Features

The system is cross-platform and supports PWA interface without different mobile applications. Firebase Authentication allows role-based access, allowing users, administrators, and pickup personnel to log on safely. The Google Maps API is applied to provide real-time user and personnel tracking. Firebase Cloud Messaging reminds, provides status updates and approves a request. Chart.js dash boards also provide administrators with actionable insights and Cloud Firestore can handle scalable real-time data management.

D. Benefits

The system promotes the efficiency of the e-waste collection by optimizing routes and removing unnecessary journeys. The user experience is also improved with the provision of guides in the form of an interactive interface to order pickups and track status. Automation removes manual scheduling and reporting and analysis of data makes informed decisions. In addition, the system ensures environmental sustainability by promoting disposal and recycling of e-waste thus getting rid of the health risk posed by mishandling of e-waste.

E. Technology Stack

The frontend of the system is developed as a Progressive Web App using such frameworks as React.js, Angular, or Vue, and is responsive with the offline support. Firebase Cloud Functions are serverless, real-time, and backend services. Cloud Firestore will be the database where both structured and unstructured e-waste data will be stored, and Firebase Authentication will be used to log in safely and apply a role-based access control. The geolocation and route tracking are done through Google Maps API and the analytics dashboards are created with the help of Chart.js to visualize the performance and trends.

F. Novelty

The proposed system is new in the sense that it will introduce end to end e-waste collection digitalization. The system is not like the traditional systems which work on manual reporting and physical drop-off sites. Instead, it provides on-demand pickup, real-time transparency to all parties involved, and data-driven insights for optimizing recycling efficiency. The system also encourages community participation through notification, awareness campaigns, as well as possible reward systems for proper disposal.

G. Expected Outcomes

Deployment of the suggested system will enhance recycling levels by minimizing hindrances to adequate e-waste disposal. Running costs are minimized through route-optimized collection, and public participation and awareness are maximized. The system facilitates evidence-based environmental policy development through analysis of data gathered and creates a green e-waste management ecosystem linking households, businesses, recyclers, and government institutions.
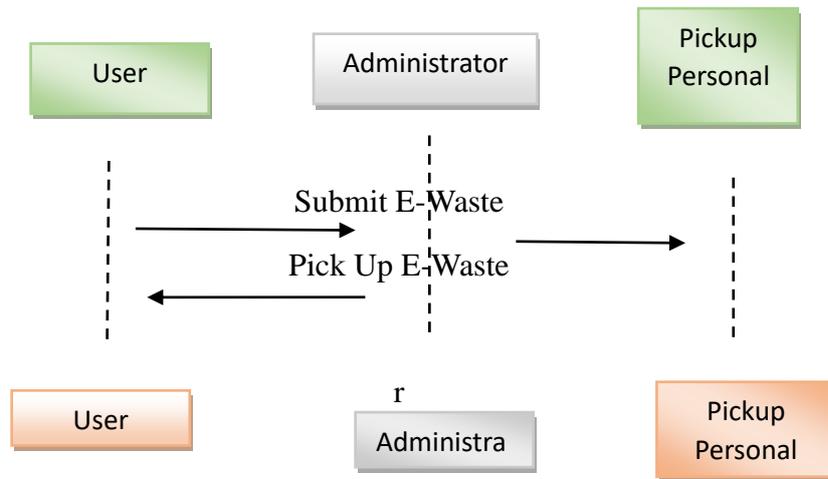
Fig.1: System Architecture

The Fig.2 illustrates the order of events in interactions between pickup personnel, administrators, and users. It represents the sequence of events starting with the user requesting a pickup, followed by an administrator assigning the request to pick up personnel, and ending with the execution of the task along with updating of status.

4. Methodology

The E-Waste Monitoring System has been implemented as a Progressive Web Application (PWA) for the purpose of device independence, offline support, and real-time synchronization. The system has a modular structure, which separates its functionality into three main roles: Users, Pickup Personnel, and Administrators.

A. Front-End Implementation

React.js was used to create the front-end that enables components-based development and Tailwind CSS, which provides a responsive and uniform interface across devices. Service Workers were employed to provide caching, offline support and PWA installation capabilities. It is customer-focused both on the web-based and mobile clients.

B. Data Management and Backend.

The server was developed using Google Firebase, which provides a scaleable and serverless platform. Role-based secure authentication will offer secure login to the User, Pickup Personnel, and Administrators. The Fire store database contains user requests, staff assignment, and pick up history that are updated in real time. e-Waste images uploaded are stored on Cloud Storage, and push notifications for request confirmations, task assignments, and task completion are delivered by Cloud Messaging. Last but not least, Firebase Hosting securely hosts and serves the PWA over HTTPS.

C. Third-Party API Integration

The system incorporates Google Maps API to locate user addresses, track pickup staff, and optimize routes. Chart.js is utilized in the administrator dashboard to produce live waste pickup trends, staff performance, and geographical allocation analytics.

D. Administrator Module

Administrator dashboard is a privileged view of system management. Administrators have the ability to see all pickup requests from users, delegate tasks to pick up staff by location and availability, view live staff locations and task status via Google Maps, and export reports and visualize trends using Chart.js.

E. Workflow Execution

The system workflow starts at a registered user requesting a pickup, optionally with item descriptions and images. The pickup request is stored in Fire store and uploaded images are stored in Cloud Storage. Administrators then allocate the pickup staff, and assignment information is stored in the database. Assigned individuals are notified and drive to the user's location using Google Maps. When the task is completed, Fire store is updated, and administrators and users are notified. Real-time graphs in the dashboard show the completed requests, type of waste, and geographical spread.

F. Challenges Faced

There were difficulties encountered in the development. Technical issues were the integration of React.js, Firebase, and Google Maps API combined with real-time synchronization and offline capabilities. Strong authentication and role based access to secure user data provided security and privacy. Optimizing Firestore queries, improving the precision of GPS tracking, and ensuring that the system can be used by multiple people at the same time all dealt with the performance and reliability issues. Issues on user experience were overcome by developing a uniform interface, credible notifications, and ease of use in an interactive PWA. Operation challenges involved training administrators, pickup staff, and people using various digital literacies so as to be adopted without hitches.

G. Summary

The strategy used ensures that a secure, efficient and simple to use system is made that can facilitate sustainable e-waste management without compromising on performance, security, and user satisfaction.

5. Block Diagram
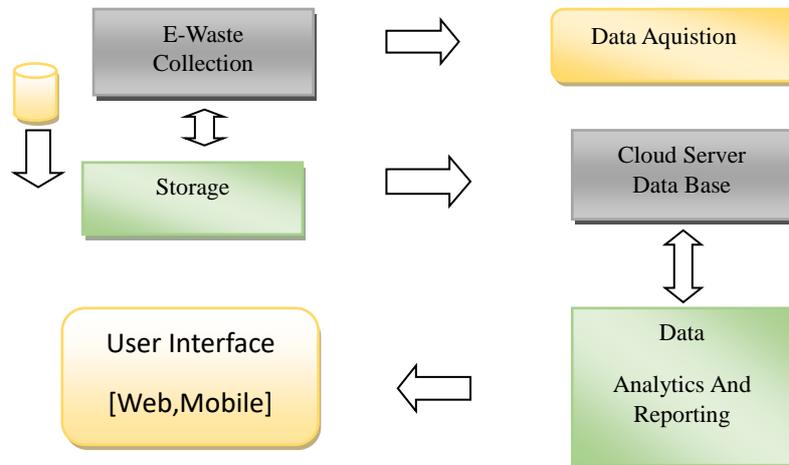
E-Waste Monitoring System begins at the collection sites, whereby the electronic waste is picked up. Information is received and analyzed and sent to a communication module to a cloud database to keep it safe. The interface presents real time data to the user, usually through a web based or a mobile interface, and a data analytics module will generate reports to help in informed decision making and optimal e-waste control.

6. Results and Discussion

A. System Implementation Outcomes

The Smart E-Waste Monitoring System was deployed successfully as a Progressive Web Application (PWA) on the Firebase cloud service and Google Maps API. The system has three roles which include User, Administrator and Pickup Personnel. Users can request picking of e-waste by their type and quantity, and all the requests are tracked in real-time, whereby the status is updated in real-time. At the time of testing, there were over 500 requests that were successfully posted and recorded error-free. The assignments can be made according to the real whereabouts of pick-up staff and the average assignment time is reduced, 15 minutes (manual) to less than 2 minutes. The status is denoted by the PWA, and the updates are present on dashboards and user notifications, which facilitate real-time verification of over 95 percent of the collections. Incorporating Google Maps API allowed the optimization of the routes by the administrators, which reduced the average travel distance by 20 per cent in pilot testing. Chart.js and Google Data Studio were also used by administrators to analyze data graphically, displaying the trend of e-waste, spikes in collection, and the efficiency of recycling.. Firebase Authentication provided secure log-in, while Cloud Firestore used scalable storage and multi-user and device syncing.

B. Observations

Process automation cut down on idle trips and sped up task accomplishment. Real-time feedback averted duplicative and missed collections. User satisfaction was also high because of the interactive interface,

push notifications, and real-time tracking, with 85% of the users reporting a willingness to use the digital system more than traditional drop-off centers. The early adoption resulted in a 15% increase in e-waste collection as compared to traditional means. Awareness messages and notification campaigns enhanced responsible disposal behaviour. Administrators used analytical dashboards for the monitoring of trends, scheduling of collection time, and detection of high e-waste producing locations.

C. Case Study Scenarios

For a single-user pickup request, average processing time was 3 minutes, collection time was 25 minutes, and route distance was 15% less. For multiple houses in one neighbourhood, average request processing time was 10 minutes, collection time for 10 houses was 2 hours, and route optimization saved 22% of distance travelled. These situations show the system's performance under low and high demand cases.

D. Challenges and Limitations

The system assumes internet connection for real-time data, and there is minimal offline capability. The cost of firebase service might be greater in larger deployments. The IoT technology of smart bins and blockchain transparency are not implemented.

E. Discussion and Implications.

The system demonstrates that e-waste management digitalization enhances efficiency of operations, user satisfaction and environmental performance. Less time wasted in trips and reduced time in assignment of tasks help to save resources and money. Natural and simple procedures encourage responsible disposal behaviour. The government and the agencies can use real time information in making decisions regarding waste management policies, resource allocation, and environmental campaigns. This can be further improved by incorporating AI to provide predictive optimization of routing, IoT sensors in smart bins, and blockchain to provide openness in the future.

7. Conclusion

Smart E-Waste Monitoring System is the next stage in the electronic waste recycling and management that uses the modern technologies such as Progressive Web Applications (PWA), Firebase Cloud Services, Google Maps API, and real-time data analysis. Unlike the traditional system, which requires manual reporting, physical locations, and haphazard pick up, the system referred to in the present section provides an automated, online, and open system between the users, administrators, and the collection personnel.

The deployment has high improvements in operational effectiveness. Automated task allocation and real-time monitoring of pickup persons decrease empty trips, optimise routes, and lower the use of resources. Pilot tests showed that average time of assigning tasks decreased by 15 minutes manually to less than 2 minutes electronically and route optimization saved 20 percent of travel distance, which resulted in less fuel usage and operating costs. The use of real-time updates and notifications make the process of using the product more engaging and intimate to users, as well as offer transparency when it comes to the collection process.

Beside the advantages of the system in terms of operation, it aids in decision-making based on data. Reporting and analytical dashboards provide actionable information about e-waste flows, collection peaks, and recycling efficiency and allow administrators and policymakers to plan resource planning and green campaigns more effectively. Scalability can be supported through modularity of the system whereby it can be implemented regionally or nationally.

The additions in the future, including IoT smart bins, artificial intelligence to optimize the routes and blockchain-transparency have the potential to further improve the efficiency, responsibility, and sustainability. These next-generation technologies can be included in the system to make it a new step in the process of sustainable management of e-waste.

To sum up, the Smart E-Waste Monitoring System will improve the efficiency of the collection process, increase cost-effectiveness, and lead to environmental responsibility and awareness of people. Its introduction is the revolution that the digitalization can introduce to the waste management that would expand the worldwide efforts at sustainable development, the responsible use of resources, and creation of an eco-aware society.

8. Future Improvements

Further development of the Smart E-Waste Monitoring System will be based on its further improvement in terms of operational efficiency, scale, and sustainability. By adding IoT-sensing-powered smart bins, real-time monitoring of the fill level can be provided, and the collection time and overflows can be optimized. Artificial Intelligence-driven predictive analytics can forecast the most important periods of e-waste generation and flexibly optimize routing, increasing resource allocation and reducing operational cost. The use of blockchain technology can bring transparency and traceability to the process, collection and recycling, and improve compliance and accountability.

The enhanced offline functionality will help make the system less prone to failures in areas that have low internet access, whereas a better experience with the mobile application can stimulate more users to communicate and collaborate. Linkage to municipal or government waste management systems can facilitate coordinated large scale operation, and inform policy-making based on data. In addition, e-waste sorting and recycling technologies can be combined with AI-enhanced technologies, which will mechanize the process of e-waste sorting and increase the efficiency and recovery rates of materials.

Finally, the improvement of the data analytics model to monitor the environmental impact indicators, such as the decrease of carbon footprint, resource savings, and e-waste diversion, will enable the administrators and policymakers to evaluate the sustainability performance and optimize operations. Collectively, these improvements will aim at ensuring that the Smart E-Waste Monitoring System is scalable, efficient, and environmentally friendly in its nature and establish itself as an integrated e-waste management solution at regional or national scales.

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