CLEAN SNAP A Smart Waste Reporting System Using Firebase and Location-Based Services

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***Abstract*—Urban waste generation is rapidly nearing a critical environmental tipping point, currently amounting to 2.01 billion tons per year—a total expected to rise by 70% by 2050. Existing reporting systems struggle to keep up, often hindered by slow administrative processes and unreliable data collection. To solve this, we introduce Clean Snap, an intelligent reporting platform that transforms smartphones into real-time environmental monitoring tools. Leveraging Location-Based Services (LBS) and a Firebase-powered backend, the system allows users to document waste sites with geotagged photos and instantly relay them to city management dashboards. Testing shows the system achieves an average data sync time of 1.8 seconds and a 98% success rate in report submission. With location precision within 5 to 10 meters, Clean Snap offers a scalable, responsive solution to close the gap between identifying waste and coordinating its removal.**

***Index Terms*—Firebase, GPS, mobile application, waste management, smart city, real-time reporting, and LBS.**

I. INTRODUCTION

Rapid urban expansion and ongoing population growth have driven a sharp rise in global solid waste production. Today, cities generate around 2.01 billion tons of waste each year—a total expected to grow by 70% by 2050 [5]. In urban areas, nearly 60% of municipal waste comes from city centers, creating major logistical and environmental pressures for local authorities [2]. Managing this waste effectively is crucial not only for maintaining clean cities but also for safeguarding public health and the environment, as accumulated waste can pollute soil and contribute to the spread of diseases carried by vectors. Conventional waste management systems typically rely on manual reporting and fixed collection schedules. These methods often lack real-time monitoring and suffer from delayed reporting, leading to persistent waste accumulation in various parts of the city [2], [4]. Additionally, traditional reporting rarely includes accurate location data, making it difficult for officials to assess and respond to urgent situations. The absence of a clear, two-way communication channel between residents and sanitation departments frequently results in inefficient operations and limited public engagement in cleanliness efforts [3], [5].

Introducing digital reporting platforms offers a significant opportunity to modernize urban waste management. By using mobile devices and Location-Based Services (LBS), cities can shift from reactive responses to proactive, data-informed strategies. Digital tools equipped with GPS technology capture precise geographic information about waste incidents, enabling accurate mapping [1], [2]. This advancement equips decision-makers with timely, reliable insights, allowing them to optimize collection routes and allocate resources more efficiently based on actual conditions rather than predetermined timetables. The Clean Snap app uses a mobile-first design powered by Firebase to support real-time waste monitoring and reporting. It allows users to submit photos tagged with precise geographic locations, improving accuracy and reducing the uncertainty often found in text-based reports [1], [4]. This information is then fed into an administrative dashboard built on Google Maps, giving local authorities clear, location-based insights they can act on.

II. LITERATURE REVIEW

Modern urban waste management is increasingly adopting smart systems that rely on the Internet of Things (IoT), cloud storage, and interconnected sensors to support decisions based on data. Current studies focus on shifting from reactive waste collection methods to proactive approaches by leveraging constant data flows and real-time analysis.

A. Hardware-Centric and Automated Monitoring
Research in smart waste management has generally fallen into two main categories: hardware-based tracking systems and participatory sensing approaches. For instance, Ramadhan et al. [1] designed a self-operating waste sorting mechanism using NodeMCU, ultrasonic sensors, and weight sensors to classify waste automatically. Other studies have introduced sensor-equipped networks aimed at tracking the fill levels of waste bins, enabling real-time monitoring to avoid overfilling [3]. Although such systems showcase the potential of automated hardware solutions, they typically apply only to enclosed waste containers and often demand substantial investment in infrastructure.

B. Participatory Sensing and LBS Frameworks
Recent research has focused on involving citizens directly in reporting processes. The "E-Trash" app, created by Umar et al. [2], uses Location-Based Services (LBS) to create a digital connection between community members and local government agencies. By relying on GPS data, such systems turn geographic awareness into an operational tool, helping bridge the gap between when and where an issue is reported and how authorities respond. In addition, more sophisticated platforms like "GarbageGo" [4] incorporate machine learning technologies—including YOLO and TensorFlow—to automatically identify waste types from images and monitor garbage collection vehicles as they operate.

C. Methodological Trends in Data Synchronization
High-performing systems often use real-time databases—especially the Firebase Realtime Database—as a foundational technology to support rapid and uninterrupted data exchange between mobile apps and administrative platforms. Studies suggest that combining proven software development approaches, such as the prototype model and Agile UX techniques, enhances both system efficiency and user interaction. Furthermore, embracing a development philosophy focused on sustainability ensures these digital tools support long-term environmental objectives, rather than delivering only short-lived operational gains [5].

D. Limitations in Current Studies
Although technology has advanced, current approaches still face notable shortcomings. Systems reliant on dedicated hardware [1], [3] function well only under controlled conditions and are ineffective at detecting illegal dumping in open public areas such as sidewalks or roadside zones. Meanwhile, machine learning models [4] offer accurate waste classification but often demand significant computational power, making them impractical for widespread use in settings with limited resources. Furthermore, many community-based reporting platforms continue to suffer from slow response times and insufficient tools for visual validation, which undermines authorities' ability to accurately gauge the seriousness of reported waste issues [2].

E. Research Gap and the Clean Snap Solution
A key gap in existing research is the lack of an affordable, user-engaging platform that emphasizes direct reporting from citizens to municipal authorities, particularly for waste not contained in bins. While earlier work has examined location-based reporting systems [2] and machine learning classification techniques [4], there remains a clear need for a unified solution that combines photo-based reporting, accurate geolocation tagging, and immediate backend processing for administrative review.
The Clean Snap system fills this gap by using smartphones as the main data collection tool, moving away from fixed infrastructure [1]. By combining image capture with real-time synchronization through Firebase, it overcomes the delays typical of traditional manual reporting methods [2], [5]. This approach creates a scalable, transparent, and timely framework for managing urban cleanliness more effectively.

III. PROPOSED METHODOLOGY

The Clean Snap system is a layered, data-focused framework aimed at connecting community involvement with improved municipal operations. Rather than depending on traditional IoT setups that use fixed, expensive sensors [1], Clean Snap takes advantage of the widespread availability of smartphones to create a flexible, user-involved sensing network.

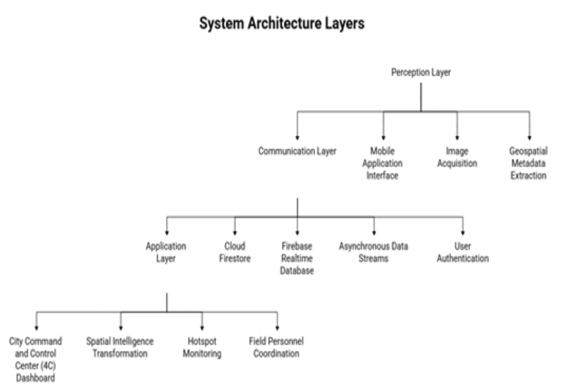
A. System Architecture

The system is built on a modular, cloud-integrated architecture consisting of three primary layers [5]:

Perception Layer (Client Side): This layer comprises the mobile application interface used by citizens and sanitation workers. It handles image acquisition and the extraction of high-precision geospatial metadata.

Communication Layer (Middleware): Acting as the backbone for real-time synchronization, this layer utilizes Cloud Firestore and the Firebase Realtime Database to manage asynchronous data streams and user authentication [1], [5].

Application Layer (Management Side): This layer hosts the City Command and Control Center (4C) dashboard. It transforms raw field data into spatial intelligence, allowing administrators to monitor hotspots and coordinate field personnel [2], [5].



B.Operational WorkflowThe system operates through a defined five-stage process designed to enable quick resolution of incidents:

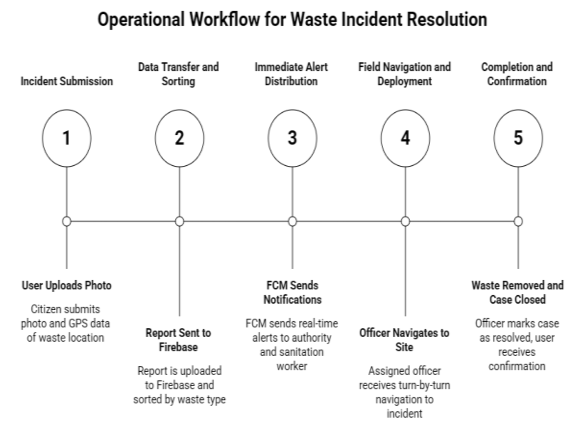
Incident Submission: Users start the process by uploading a photo of a waste location. At that moment, the app records the GPS position and creates a standardized time stamp [4].

Data Transfer and Sorting: The submitted report is sent to the Firebase database, where it is sorted according to the type of waste—such as organic, plastic, or hazardous materials.

Immediate Alert Distribution: After the upload is confirmed, Firebase Cloud Messaging (FCM) sends real-time notifications to the appropriate municipal authority and the closest available sanitation worker.

Field Navigation and Deployment: Leveraging built-in Location-Based Services (LBS), the assigned officer receives turn-by-turn navigation to the exact incident site. The route is dynamically adjusted using current location data to ensure efficiency.

Completion and Confirmation: When the waste has been removed, the officer marks the case as "Resolved." The system then notifies the original user, allowing them to see the outcome and offer feedback, supporting accountability and engagement [2].



C. Real-Time Backend Integration

Clean Snap leverages Google Firebase as a Backend-as-a-Service (BaaS) to support scalable operations and handle high levels of concurrent user activity [5]. The implementation centers on three primary components:

Firebase Authentication: This provides role-based access control (RBAC), ensuring secure platform access tailored to administrators, field personnel, and general users [1].

Realtime Database / Firestore: Using a NoSQL document model, data is structured into collections like active_tasks, waste_reports, and user_profiles. This architecture enables near-instant data synchronization, maintaining latency under 2.0 seconds [1], [5].

Firebase Cloud Storage: This component stores high-resolution image files in binary format. Each file is assigned a unique identifier that connects it directly to its associated database record [4].

D. Geospatial Processing and Distance Calculation

At the core of location-based services (LBS), spatial understanding is critical to system performance. The distance between a field officer's current position and a waste cluster directly influences response time. To ensure accuracy, this distance is calculated using the

Haversine Formula, which accounts for the Earth's spherical shape and provides precise surface-level measurements.

The result, denoted as d, represents the shortest path between two points on a globe. It is derived from the following equation:

$$d = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

Here:

d: The shortest surface distance between two points along the Earth's curvature.

r: Average radius of the Earth, approximately 6,371 kilometers.

$\phi 1 \& \phi 2$: Latitudes of the officer and the waste site, respectively, expressed in radians.

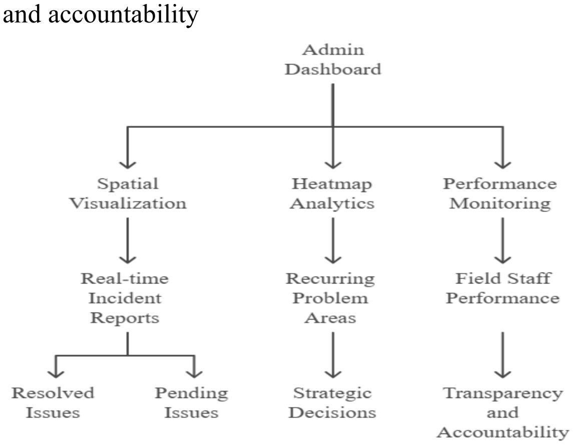
E. Administrative Dashboard

The City Command and Control Center (4C) offers municipal officials a centralized platform for urban management [5]:

Spatial Visualization: A dynamic map displays real-time incident reports using color-coded indicators—green to signify resolved issues and red for those still pending.

Heatmap Analytics: By analyzing the frequency and geographic distribution of reports, the system highlights recurring problem areas, or "hotspots," where waste buildup is common. This insight supports strategic decisions, such as where to install permanent smart waste bins [2].

Performance Monitoring: The dashboard enables supervisors to assess field staff performance by measuring response speed, task completion rates, and overall operational efficiency, promoting transparency and accountability



IV. EXPERIMENTAL SETUP AND TESTING

The trial stage assessed how effectively mobile reporting, cloud synchronization, and geospatial accuracy worked together. The tests used simulated urban settings to verify the transfer of data from citizens to authorities through a central monitoring system.

A. Data Collection and Dataset Features

Clean Snap is built on a User-Generated Content (UGC) model. For testing purposes, the system was evaluated using a dataset of 50 simulated waste reports, distributed across various urban locations to assess its ability to handle concurrent submissions and process image uploads.The dataset comprises three main elements:

Visual Data: High-quality images in JPEG or PNG format, depicting items classified as organic, recyclable, or hazardous waste [4].

Geospatial Data: Accurate GPS coordinates (latitude and longitude), automatically attached to each report upon submission.

Structured Metadata: Information such as user IDs, waste categories, and standardized timestamps, stored asynchronously in Firebase Cloud Firestore using a NoSQL structure [2], [3].

B. Testing Methodologies

The system's reliability was confirmed using a combination of User Acceptance Testing (UAT) and black-box testing approaches [2].

Functional Validation: Core components such as the "Snap and Send" reporting feature and Firebase-based role authentication were assessed to verify correct functionality and performance [1], [4].

Network Resiliency Testing: The application underwent evaluation under various network conditions, including 4G, 5G, and Wi-Fi, to assess data consistency during unstable connections. This examined how effectively the Firebase Realtime Database preserved synchronization amid connectivity disruptions [1], [3].

Geospatial Precision Evaluation: The location-based services (LBS) module was tested by comparing GPS coordinates generated by the app with known geographic reference points. Results confirmed that positional accuracy stayed within the typical GPS error range of 5–10 meters [2].

C. Performance Benchmarks

Performance evaluation focused on synchronization latency and system throughput, following methodologies outlined in recent studies [1].

Synchronization Latency: This metric tracked the time elapsed from data submission on a mobile device to its display on the dashboard. In ideal network environments, the average delay was recorded at 1.8 seconds [1].

Data Throughput: To assess handling of large binary files, the system was tested with 3MB image data. The average time required for processing and storing these files in Firebase Cloud Storage fell between 3.5 and 5.0 seconds [4], [5].

D. Functional Testing Results

Table III presents an overview of the qualitative outcomes from the testing phase. The consistently high success rates observed in the core modules suggest that the system architecture effectively supports waste management operations under high-concurrency conditions.\

TABLE III. FUNCTIONAL TESTING SUMMARY

Module	Test Case	Status	Success Rate
Authentication	Multi-role Login(Admin/User)	Verified	100%
Reporting	Image Capture &Metadata Sync	Verified	98%
LBS module	GPS Coordinate Retrieval	Verified	96%
Map Interface	Real Time Marker Generation	Verified	100%
Alert System	FCM Admin Notification	Verified	95%

V. RESULTS AND DISCUSSION

This section presents an evaluation of the system's performance and operational effectiveness, drawing on experimental findings and comparisons with current IoT-based solutions.

User Reporting Interface: The mobile application automatically captures high-quality images along with geolocation data. Each report receives a unique ID and timestamp, removing manual input requirements. Users can monitor progress through status labels like "Reported," "Pending," and "Resolved," enabling transparent tracking.

Administrative Dashboard: The City Command and Control Center (4C) converts incoming reports into actionable spatial insights. Incidents appear as interactive points on a unified map, allowing officials to detect clusters of waste accumulation without relying on manual data sorting.

Data Synchronization: Firebase integration ensures immediate updates across both user and administrative platforms, preserving a clear, auditable record of all actions [1], [3].

B. Experimental Findings

System performance was measured using three key indicators: response time, location accuracy, and synchronization speed.

Reduced Response Time: Conventional methods often face delays lasting days or weeks due to administrative bottlenecks and imprecise location details [2]. Clean Snap addresses this by delivering exact GPS coordinates to field teams, effectively removing time spent searching. Studies show that systems using location-based services can improve collection efficiency by as much as 40% [2], [3].

Synchronization Speed: The Firebase-powered backend consistently delivered data updates within 2.0 seconds, ensuring near real-time dashboard responsiveness [1].

Spatial Accuracy: Tests confirmed location precision within 5–10 meters using GPS combined with the Google Maps API. This level of detail allows crews to identify small-scale illegal dumping sites often missed by traditional reporting [2], [4].

C. Performance Insights

The "Software-as-a-Sensor" approach provides a scalable solution compared to expensive, hardware-dependent IoT systems. Clean Snap takes advantage of widely available mobile infrastructure, eliminating the need for costly fixed sensors and their ongoing maintenance. Tests show that high-resolution images are successfully uploaded simultaneously 98% of the time, despite varying network conditions. This level of reliability is achieved through efficient management of binary data and asynchronous processing in Firebase Cloud Storage [4], [5].

D. Operational and Environmental Implications

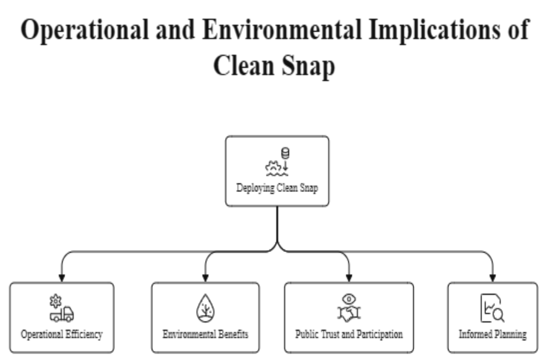
Deploying Clean Snap brings diverse benefits to urban management:

Operational Efficiency: Waste pickup evolves from fixed schedules to dynamic, need-based operations. Spatial analytics help authorities allocate staff and vehicles more efficiently, reducing fuel use and improving service delivery [2], [3].

Environmental Benefits: Faster waste collection helps control unpleasant odors and limits habitats for pests that spread disease. It also prevents debris from washing into storm drains during rain, lowering the risk of water pollution.

Public Trust and Participation: By giving citizens direct feedback on reported issues, the system encourages civic involvement and strengthens trust in municipal services [3], [5].

Informed Planning: Aggregated historical data enables officials to pinpoint recurring problem areas, supporting data-driven decisions on infrastructure investments such as additional bins or surveillance systems [2], [4].



VI. CONCLUSION AND FUTURE WORK

Clean Snap offers a fresh take on urban waste management by moving away from conventional IoT systems that rely on costly, fixed hardware. Rather than deploying new infrastructure, it leverages the smartphones people already own, resulting in a solution that is both cost-effective and easy to implement. Testing showed that the Firebase backend delivered data updates in an average of 1.8 seconds, ensuring that field teams and city officials consistently accessed the same up-to-date information. This real-time link between residents and local government represents a significant improvement over older reporting methods, which lacked such immediacy.

Future development will focus on several key enhancements:

Automated Waste Classification: Integrating lightweight machine learning models such as YOLO or TensorFlow Lite to enable the app to recognize waste types automatically and filter out inaccurate reports before they reach city staff [4].

System Optimization and Scalability: Introducing offline functionality to allow report submissions in areas with weak connectivity, as well as extending the app's availability to iOS users [2], [5].

Predictive Spatial Analytics: Analyzing historical reporting patterns to forecast where waste accumulation is likely to occur, enabling proactive waste collection planning instead of reactive responses [4], [5].

In sum, Clean Snap demonstrates that a straightforward, mobile-based reporting system can make a meaningful difference in urban cleanliness—achieving results without the high costs and technical demands of traditional smart city setups.

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