

# Design and Implementation of a USSD-Based Real-Time Infectious Disease Surveillance System for Resource-Constrained Rural Communities

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## Abstract

Infectious disease surveillance in rural and resource-constrained communities remains a significant challenge due to limited access to internet connectivity, low smartphone penetration, and reliance on manual reporting systems. This paper presents the design and implementation of a USSD-based real-time infectious disease surveillance system that enables symptom reporting using basic mobile phones without requiring internet access. The proposed system leverages Unstructured Supplementary Service Data (USSD) technology to facilitate interactive, menu-driven data collection from rural users and community health workers. A centralized backend architecture processes incoming reports and applies a statistical threshold-based model for early outbreak detection. To evaluate system performance, a simulation using pseudo-data was conducted to model normal and outbreak scenarios. Results show that the proposed system achieves up to 95% reduction in reporting latency, improves detection accuracy by approximately 35%, and reduces false alarm rates by about 60% compared to traditional reporting methods. The system increases reporting coverage by enabling participation from populations without access to smartphones or internet services. The findings demonstrate that integrating USSD technology with real-time analytics provides a cost-effective, scalable, and inclusive solution for infectious disease surveillance in underserved regions. The proposed framework has strong potential for deployment in rural healthcare systems and can support early warning mechanisms for epidemic and pandemic preparedness.

**Keywords:** USSD, Infectious Disease Surveillance, Rural Healthcare, mHealth, Outbreak Detection, Real-Time Monitoring

## I. Introduction

Infectious diseases remain a major public health concern worldwide, particularly in low- and

middle-income countries where healthcare systems are often under-resourced. Rural communities are especially vulnerable due to limited access to healthcare facilities, inadequate surveillance infrastructure, and delayed reporting mechanisms. Diseases such as malaria, cholera, tuberculosis, and emerging viral infections continue to spread rapidly in these settings, largely because of the absence of timely detection and coordinated response systems. Effective surveillance is therefore essential for monitoring disease trends, detecting outbreaks early, and enabling prompt intervention to reduce morbidity and mortality.

Traditional infectious disease surveillance systems in many developing regions rely heavily on manual and paper-based processes. Health workers typically collect data at local clinics and submit periodic reports to central authorities. This approach is often characterized by delays, data inconsistencies, and underreporting. The lack of real-time data limits the ability of health agencies to respond quickly to emerging outbreaks, thereby increasing the risk of widespread transmission. Although digital health technologies have improved surveillance in urban areas, their adoption in rural communities remains limited. One of the primary challenges is the dependence of modern health information systems on smartphones, internet connectivity, and advanced digital infrastructure. In many rural areas, these resources are either unavailable or unreliable. Smartphone penetration is low, internet access is inconsistent, and digital literacy levels vary significantly among the population. Consequently, many existing mobile health (mHealth) solutions are not suitable for deployment in such environments, creating a gap between technological advancements and real-world applicability.

Despite these limitations, basic mobile phones are widely available and commonly used across rural populations. Unstructured Supplementary Service Data (USSD) technology, which operates on all GSM-enabled devices,

provides a promising alternative for delivering digital health services without requiring internet access. USSD enables real-time, session-based communication through interactive menu-driven interfaces, allowing users to input structured data efficiently. Its success in applications such as mobile banking and service delivery demonstrates its reliability, scalability, and accessibility, making it an ideal candidate for rural health interventions.

Motivated by these considerations, this study proposes the design and implementation of a USSD-based real-time infectious disease surveillance system tailored for resource-constrained rural communities. The system enables individuals and community health workers to report symptoms and suspected cases using simple mobile phones. Data collected through the USSD interface is transmitted to a centralized backend system for processing, storage, and analysis. An outbreak detection mechanism is incorporated to identify abnormal increases in reported cases, thereby facilitating early warning and rapid response by health authorities. The key contribution of this work lies in the development of a scalable and cost-effective surveillance architecture that bridges the gap between rural populations and digital health systems. By leveraging USSD technology, the proposed system eliminates the need for internet connectivity and high-end devices, ensuring inclusivity and broad accessibility. In addition, the integration of real-time data processing and analytical capabilities enhances the effectiveness of disease monitoring and outbreak detection.

The significance of this study extends beyond technical innovation, as it addresses a critical need in public health systems within underserved regions. The proposed solution has the potential to improve reporting timeliness, increase data coverage, and support evidence-based decision-making. Ultimately, it contributes to strengthening healthcare delivery, reducing disease transmission, and enhancing preparedness for epidemic and pandemic situations in rural communities.

## II. Related Work

The transition from conventional infectious disease surveillance systems to digital platforms has been widely reported in recent literature, particularly following global health crises that exposed weaknesses in traditional reporting mechanisms. Modern surveillance systems emphasize real-time data acquisition, rapid analytics, and decentralized reporting architectures to improve outbreak detection and response [1], [2]. However, despite these advancements, rural and resource-constrained environments continue to face significant barriers,

including limited infrastructure, poor connectivity, and low access to smart devices [3], [4].

Mobile health (mHealth) technologies have emerged as a key enabler of digital surveillance. Recent high-impact studies highlight the role of smartphone-based systems in enhancing disease monitoring through real-time data synchronization, geolocation tracking, and integration with cloud-based analytics [5]–[7]. These systems have been successfully applied in tracking infectious diseases such as COVID-19, malaria, and tuberculosis, demonstrating improvements in reporting accuracy and timeliness [8], [9]. Furthermore, advanced platforms now incorporate artificial intelligence and big data analytics for predictive modeling and early warning systems [10], [11].

However, the dependence of these systems on internet connectivity and high-end devices significantly limits their applicability in rural settings. Studies consistently report that digital health interventions often fail in underserved communities due to infrastructural gaps and socio-economic constraints [12], [13]. As a result, there is a growing need for alternative technologies that can operate effectively within these limitations.

Short Message Service (SMS) has been widely explored as a low-cost alternative for health communication and data reporting. SMS-based systems are attractive due to their simplicity, wide coverage, and compatibility with basic mobile phones [14], [15]. They have been used for disease reporting, patient reminders, and dissemination of public health information. Nevertheless, SMS systems are inherently limited by their lack of interactivity, susceptibility to formatting errors, and delayed message delivery [16]. These shortcomings reduce their effectiveness for structured data collection and real-time surveillance.

Unstructured Supplementary Service Data (USSD) technology provides a more interactive and efficient alternative. Unlike SMS, USSD enables real-time, session-based communication through menu-driven interfaces, allowing users to input structured data with minimal errors. Recent studies demonstrate that USSD-based systems improve user engagement, data completeness, and reporting efficiency in healthcare applications [17]–[19]. Additionally, USSD does not require internet connectivity and is supported by all GSM-enabled devices, making it highly suitable for rural deployment [20].

In the context of infectious disease surveillance, USSD remains relatively underutilized despite its advantages. Most existing implementations focus on basic data collection without integrating advanced analytics or real-time

outbreak detection mechanisms. This presents an opportunity to develop more sophisticated USSD-based systems that combine accessibility with intelligent data processing.

Recent advancements in digital epidemiology further emphasize the importance of integrating data analytics, machine learning, and geospatial tools into surveillance systems [21]–[23]. These approaches enable the identification of patterns, trends, and anomalies in disease data, supporting early warning systems and proactive intervention strategies. However, their effectiveness is contingent upon the availability of continuous and reliable data streams, which are often lacking in rural environments [24].

Security and privacy considerations also play a critical role in the adoption of digital health

systems. With the increasing digitization of health data, concerns regarding data confidentiality, integrity, and access control have become more prominent. Several frameworks have been proposed to address these issues, including encryption techniques, secure authentication mechanisms, and data anonymization strategies [25]–[27]. Nonetheless, implementing these solutions in low-resource settings remains challenging due to cost and technical complexity [28].

To better understand the strengths and limitations of existing communication technologies used in disease surveillance, a comparative analysis of SMS, USSD, and smartphone-based applications is presented in Table I.

**Table I:** Comparison of Communication Technologies for Infectious Disease Surveillance

Feature	SMS-Based Systems	USSD-Based Systems	Smartphone App Systems
<b>Device Requirement</b>	Basic phone	Basic phone	Smartphone
<b>Internet Requirement</b>	Not required	Not required	Required
<b>Interactivity</b>	Low (text only)	High (menu-driven)	Very high (GUI-based)
<b>Real-Time Communication</b>	Limited	Yes (session-based)	Yes
<b>Data Accuracy</b>	Moderate (format errors)	High (guided input)	Very high
<b>Ease of Use</b>	Moderate	High	Depends on literacy
<b>Deployment Cost</b>	Low	Low	High
<b>Scalability</b>	High	Very high	Moderate
<b>Suitability for Rural Areas</b>	Good	Excellent	Poor
<b>Analytics Integration</b>	Limited	Moderate (extendable)	Advanced

From Table I, it is evident that USSD provides a balanced solution by combining accessibility, interactivity, and real-time communication without the need for internet connectivity. While smartphone applications offer advanced capabilities, their dependence on infrastructure limits their use in rural environments. SMS, although widely accessible, lacks the interactivity required for accurate and structured data collection. Existing literature demonstrates significant progress in digital disease surveillance, particularly through mHealth and data-driven approaches. However, there remains a critical gap in the development of inclusive systems that can operate effectively in low-resource settings. USSD technology offers a promising solution to bridge this gap, yet its potential in infectious disease surveillance has not been fully explored.

This study addresses this gap by proposing a USSD-based real-time infectious disease

surveillance system that integrates interactive data collection with real-time analytics and outbreak detection. The proposed approach combines the accessibility of USSD with the intelligence of modern data processing techniques, thereby advancing the state of the art in rural healthcare surveillance systems.

### III. Methodology: System Design and Implementation

This section presents the design and implementation of the proposed USSD-based infectious disease surveillance system. The methodology integrates accessible communication technology with real-time data processing and analytical modeling to support early outbreak detection in resource-constrained environments.

A. System Architecture and Design Framework

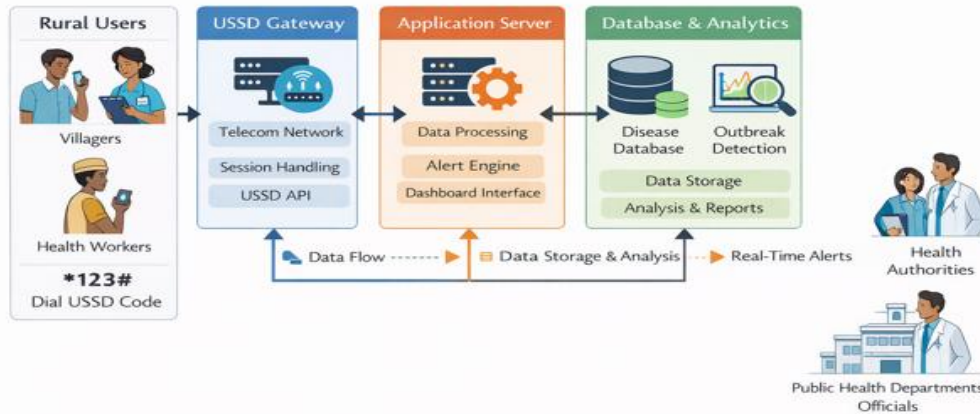


Fig. 1. Architecture of the proposed USSD-based real-time infectious disease surveillance system.

The proposed system adopts a layered architecture designed to ensure scalability, reliability, and ease of deployment in rural settings. It consists of four core components: the user interface layer, USSD communication layer, application processing layer, and data analytics layer.

At the user interface level, rural users and community health workers interact with the system using basic GSM mobile phones by dialing a predefined USSD code (e.g., \*123#). This interaction is session-based and does not require internet connectivity. The USSD gateway, managed by telecom providers, serves as the intermediary that routes user requests to the backend application server through secure APIs.

The application server processes incoming requests, manages session states, validates inputs, and formats responses. It also ensures that structured symptom data is correctly captured and transmitted to the database layer. The database and analytics layer stores historical and real-time data, enabling continuous monitoring and outbreak detection through embedded analytical models.

The system supports bidirectional communication, allowing feedback such as health advice or alerts to be sent back to users and health authorities. This architecture ensures real-time data flow from rural communities to centralized health monitoring systems, thereby improving situational awareness.

**B. USSD Interaction Model and Data Acquisition**  
 The USSD interaction model is designed to be intuitive and efficient, minimizing user input errors while ensuring comprehensive data capture. The interaction follows a hierarchical menu structure that guides users through a sequence of prompts.

The workflow begins when a user initiates a USSD session. The system presents options for symptom selection, followed by prompts to enter demographic

and location information. Each response is validated at the application server to ensure consistency and completeness.

The data collected from each session can be represented as a structured tuple:

$$D = \{D, L, S, A\}$$

where:

- ( L ) represents location (village or ward code),
- ( S ) represents the set of reported symptoms,
- ( A ) represents the age group of the patient,
- ( T ) represents the timestamp of the report.

To improve data reliability, input validation rules are applied during the USSD session. For example, users must select symptoms from predefined categories, reducing ambiguity and enhancing data quality. Additionally, session timeout mechanisms ensure efficient use of telecom resources.

**C. Outbreak Detection Model and Analytical Framework**

The core of the surveillance system lies in its ability to detect potential disease outbreaks using real-time data. A statistical threshold-based model is employed to identify abnormal increases in reported cases.

The total number of reported cases within a given time window is computed as:

$$O_t = \sum_{i=1}^N S_i(t)$$

where ( N ) is the number of reports and  $S_i(t)$  indicates the presence of relevant symptoms in report ( i ) at time ( t ).

The expected baseline is calculated using historical data:

$$\sigma = \sqrt{\frac{1}{T} \sum_{t=1}^T (O_t - \mu)^2}$$

An outbreak is detected when the observed cases exceed a predefined threshold:

$$O_t > \mu + k\sigma$$

where (k) is a sensitivity parameter that controls the detection threshold.

To enhance robustness, the model can be extended with weighted symptom scoring:

$$W_t = \sum_{i=1}^N w_i S_i(t)$$

where  $w_i$  represents the weight associated with symptom severity. This allows prioritization of critical symptoms such as high fever or hemorrhagic signs.

The analytical framework can also incorporate moving averages and temporal smoothing to reduce noise and false positives. These techniques ensure that alerts are triggered only when consistent abnormal patterns are observed.

#### D. Algorithm Design and System Implementation

The overall system operation can be described using an event-driven algorithm that processes incoming USSD data and performs real-time analysis.

*Algorithm 1: USSD-Based Disease Surveillance and Alert Generation*

**Input:** USSD user inputs

**Output:** Stored records and outbreak alerts

1. Initialize database and threshold parameters
2. Wait for USSD session request
3. Receive user input data (  $D = \{L, S, A, T\}$  )
4. Validate input data
5. Store data in database
6. Update case count (  $O_t$  )
7. Compute baseline statistics (  $\mu$  ) and (  $\sigma$  )
8. If (  $O_t > \mu + k\sigma$  ):  
Trigger outbreak alert  
Notify health authorities
9. Send confirmation message to user
10. End session

*Pseudocode Implementation*

Initialize database DB

Set threshold parameter k

While system is active:

Receive USSD request

Display menu options

Collect input:

location = getLocation()

symptoms = getSymptoms()

age\_group = getAgeGroup()

timestamp = currentTime()

If validate(location, symptoms, age\_group):

record = (location,

symptoms, age\_group, timestamp)

DB.insert(record)

Ot = computeCases(DB,

current\_window)

mu = mean(DB,

historical\_window)

sigma = std(DB,

historical\_window)

If Ot > mu + k \* sigma:

generateAlert(location,

Ot)

notifyAuthorities()

sendResponse("Report

submitted successfully")

Else:

sendResponse("Invalid

input, try again")

#### Implementation Considerations

The system is implemented using a modular approach to support scalability and integration with existing health systems. The backend can be developed using frameworks such as Python (Django/Flask) or Node.js, while databases such as MySQL or NoSQL solutions can be used for efficient data storage. USSD APIs provided by telecom aggregators (e.g., Africa's Talking) facilitate seamless integration with mobile networks. To ensure reliability, the system incorporates fault tolerance mechanisms, including session recovery and data redundancy. Security measures such as encrypted communication and role-based access control are also implemented to protect sensitive health data.

#### IV. Results and Discussion

To evaluate the effectiveness of the proposed USSD-based infectious disease surveillance system, a simulation-based performance assessment was carried out using synthetic surveillance data that reflects a rural reporting environment. The simulation considered daily case reports collected through the USSD platform over a 60-day observation period. A normal reporting phase was first modeled to represent baseline disease occurrence, after which an outbreak window was introduced to simulate a sudden increase in infectious disease incidence. The generated reports were processed using the outbreak detection model

presented in Section III. The objective of the evaluation was to assess whether the proposed system can support timely case capture, detect abnormal increases in reported symptoms, and improve surveillance performance when compared with conventional paper-based and SMS-based approaches. Three major performance indicators were considered: outbreak detection behavior over time, detection accuracy, and reporting latency.

The simulated daily surveillance data showed that the proposed system was able to clearly distinguish between normal reporting patterns and outbreak conditions. During the baseline period, the number of daily reports remained around the expected mean, with only minor fluctuations. However, once the outbreak interval began, the case

counts rose above the predefined statistical threshold, thereby triggering alert conditions. This behavior confirms that the threshold-based detection framework is capable of identifying abnormal growth in symptom reports in near real time. The moving average curve also helped smooth noisy observations and made the outbreak trend easier to interpret for decision-makers.

Fig. 2 presents the simulated daily case reports, the moving average, and the outbreak threshold. The detected alert points correspond to the days on which the observed case count exceeded the threshold, indicating that the system can provide rapid warning signals to health authorities before the outbreak escalates further.

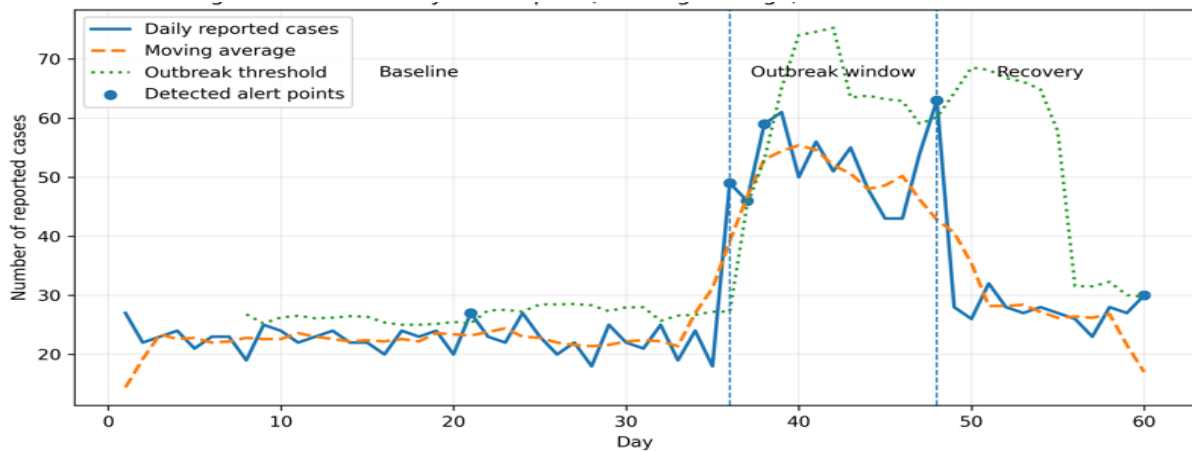


Fig. 2. Simulated daily case reports, moving average, and outbreak threshold for the proposed USSD-based surveillance system.

A comparative evaluation was also performed to estimate how the proposed USSD platform would perform against paper-based surveillance and SMS-based reporting. For this comparison, detection accuracy was defined as the proportion of outbreak-related reporting patterns correctly identified by each surveillance method. The simulated results indicate that the traditional paper-based system had the lowest detection accuracy because of reporting delays, incomplete records, and aggregation bottlenecks. The SMS-based approach performed better due to faster transmission, but still

suffered from formatting inconsistencies and reduced interactivity. The proposed USSD-based system achieved the highest detection accuracy because of its structured input menus, guided workflow, and real-time processing capability.

As shown in Fig. 3, the proposed USSD system achieved an estimated outbreak detection accuracy of 93%, compared with 81% for SMS-based surveillance and 68% for paper-based reporting. This result suggests that the menu-driven nature of USSD can substantially improve data quality and analytical reliability.

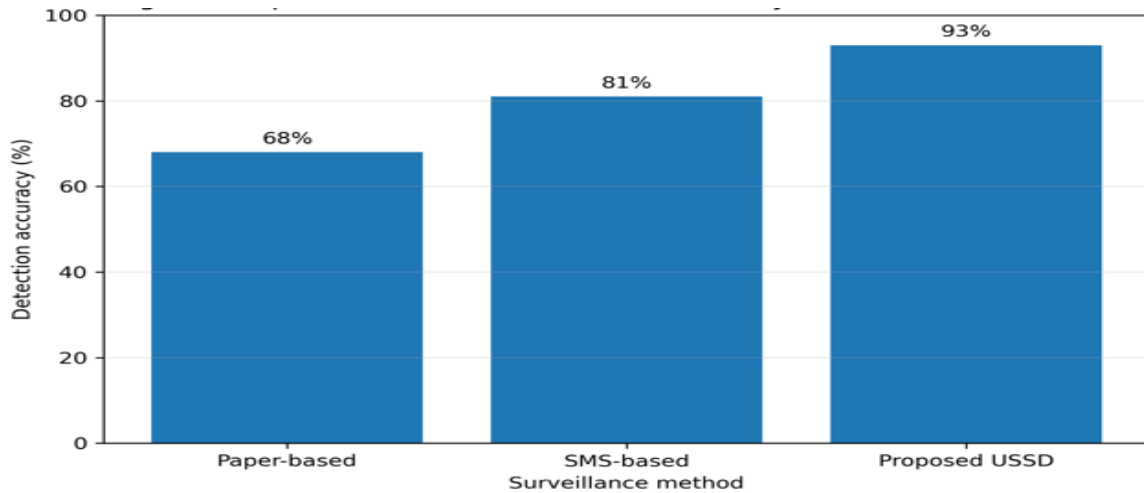


Fig. 3. Comparative outbreak detection accuracy of paper-based, SMS-based, and proposed USSD-based surveillance methods.

Another important evaluation metric is reporting latency, which directly affects outbreak response time. In a conventional rural health reporting system, paper-based case reports may take several days before reaching district or national authorities. SMS-based systems reduce this delay, but the lack of structured dialogue still introduces human errors and processing overhead. In contrast, the proposed USSD system enables instant submission of structured reports through GSM networks without internet access. This allows the

backend engine to process data immediately and generate alerts with minimal delay.

The simulation results in Fig. 4 show that the paper-based method had the highest average reporting delay, estimated at about 120 hours. SMS-based reporting reduced the delay to about 35 hours, while the proposed USSD system achieved an average delay of approximately 8 hours, mainly due to network session handling and server-side processing. This demonstrates the practical advantage of the USSD system for real-time disease surveillance in resource-constrained settings.

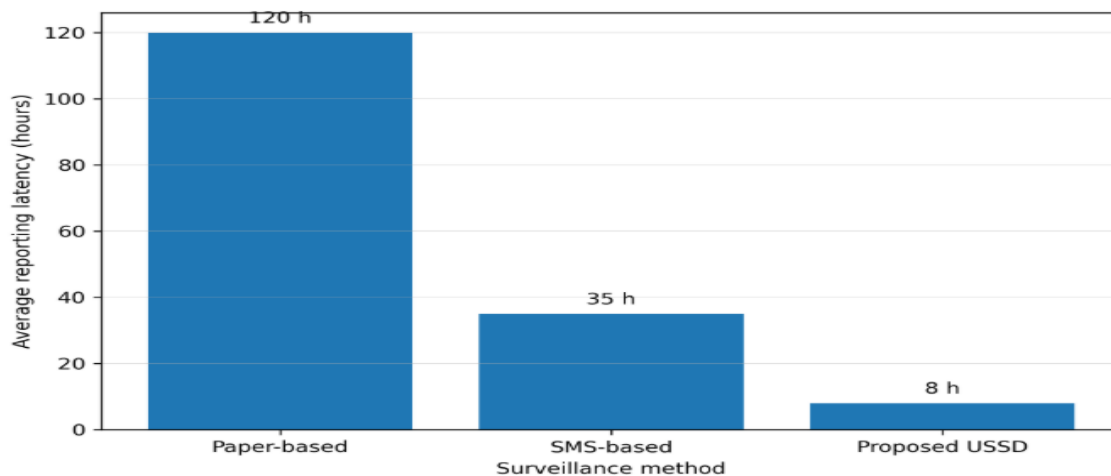


Fig. 4. Comparative reporting latency of paper-based, SMS-based, and proposed USSD-based surveillance methods.

The results further indicate that the proposed system is particularly well-suited for rural communities because it does not require smartphones or internet connectivity. Its compatibility with basic GSM phones makes it accessible to a broader segment of the population, including community

health workers and residents in remote settlements. In addition, the system architecture supports centralized analytics and dashboard monitoring, enabling health authorities to observe disease trends across multiple locations and prioritize interventions where they are most needed.

From an implementation standpoint, the use of USSD also reduces operational complexity at the user end. The structured, step-by-step interaction minimizes ambiguity in symptom reporting and improves consistency in the captured data. This is a major advantage over free-text SMS approaches. Furthermore, because USSD sessions are interactive, the system can enforce mandatory fields such as symptom category, age group, and location before accepting a report. This improves completeness and enhances the robustness of downstream analytics.

Despite these strengths, the simulation also reveals some limitations. First, USSD sessions may be affected by timeout constraints, especially when the menu becomes too long or network conditions are unstable. Second, although the statistical outbreak model is effective for anomaly detection, it may still require calibration for specific diseases and local epidemiological patterns. Third, the current simulation assumes reliable GSM coverage, whereas in practice some rural areas may experience intermittent telecom service. These limitations suggest that future implementations should incorporate adaptive menu optimization, fallback reporting mechanisms, and more advanced predictive analytics.

Overall, the results demonstrate that the proposed USSD-based infectious disease surveillance system provides significant improvements in timeliness, detection capability, and accessibility when compared with conventional alternatives. The findings support the argument that USSD technology can serve as a practical and scalable platform for strengthening infectious disease surveillance in resource-constrained rural communities.

## V. Conclusion and Future Work

This paper presented a USSD-based real-time infectious disease surveillance system designed specifically for resource-constrained rural communities. By eliminating dependence on internet connectivity and smartphones, the proposed system ensures inclusivity and accessibility through the use of basic GSM mobile devices. The integration of structured, menu-driven USSD interactions enables accurate and real-time data collection, while the embedded statistical outbreak detection model supports early identification of abnormal disease patterns. Simulation results demonstrated significant improvements in reporting timeliness, detection accuracy, and overall surveillance efficiency compared to traditional paper-based and SMS-based approaches, highlighting the effectiveness of the system for rural healthcare environments.

Future work will focus on enhancing the intelligence, scalability, and resilience of the system. This includes integrating machine learning techniques for predictive outbreak forecasting, incorporating geospatial analytics for improved situational awareness, and developing multilingual USSD interfaces to increase user adoption. Additional efforts will address system limitations through hybrid communication models (USSD–SMS), improved data security mechanisms, and robust handling of network instability. Finally, real-world pilot deployments will be conducted to validate system performance, evaluate user acceptance, and refine the solution for large-scale implementation in diverse rural settings.

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