

DESIGN AND EVALUATION OF AN OFFLINE-RESILIENT VOICE-FIRST AI ADVISORY SYSTEM FOR LOW-LITERACY RURAL FARMERS

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Abstract- Digital agriculture technologies have significantly evolved with the integration of artificial intelligence; however, most existing AI-based advisory platforms are designed under the assumption of stable internet connectivity and text-based literacy. In many rural regions, farmers face challenges such as low bandwidth availability, intermittent network access, and limited familiarity with complex mobile interfaces. These limitations reduce the effectiveness and real-world adoption of current smart farming solutions. To address this gap, this paper presents “Sow & Grow,” a design and evaluation of an offline-resilient, voice-first AI advisory system tailored for low-literacy rural farmers. The proposed framework integrates multilingual speech-to-text interaction, AI-powered crop and livestock advisory generation, and adaptive bandwidth-aware service orchestration within a mobile architecture. A key contribution of this work lies in its offline resilience mechanism, which combines intelligent local caching, persistent storage layers, and dynamic API handling to maintain advisory continuity during connectivity disruptions. Unlike conventional cloud-dependent systems, the proposed approach enables partial functionality and seamless recovery under constrained 2G network conditions while maintaining enhanced responsiveness in higher-bandwidth environments. Comprehensive evaluation was conducted through latency benchmarking under simulated network scenarios, offline recovery analysis, and structured usability assessment. Performance metrics including response time, advisory availability rate, cache efficiency, and task completion performance were analyzed. Experimental findings indicate improved accessibility for low-literacy users through voice-first interaction and enhanced system reliability in unstable network conditions. The study demonstrates that resilient, connectivity-aware system design combined with AI-driven advisory services can significantly improve digital inclusion in agriculture. The proposed framework contributes toward scalable, user-centric, and infrastructure-aware smart farming solutions for underserved rural ecosystems.

Keywords- Voice-First AI; Offline-Resilient Architecture; Smart Agriculture; Low-Bandwidth Networks; Rural Digital Inclusion; Multilingual Speech Interaction; AI-Based Advisory Systems.

1. INTRODUCTION

The rapid advancement of artificial intelligence (AI) has significantly influenced the evolution of digital agriculture systems. AI-driven advisory platforms now assist farmers in crop monitoring, disease diagnosis, livestock management, and weather-based decision-making. However, most existing smart agriculture solutions are designed with the assumption of stable internet connectivity and adequate text-based literacy. In rural and semi-urban regions, particularly in developing economies, farmers often experience low bandwidth availability, intermittent network connectivity, and limited familiarity with complex mobile interfaces. These challenges reduce the accessibility and practical adoption of AI-powered agricultural systems.

Traditional digital advisory applications depend heavily on continuous cloud communication, which leads to service disruption when connectivity becomes unstable. Furthermore, text-centric interaction models may not be suitable for farmers with low literacy levels, creating a significant digital inclusion gap. Addressing these challenges requires a system that is both connectivity-aware and interaction-friendly.

To bridge this gap, this paper presents **Sow & Grow**, an offline-resilient, voice-first AI advisory system designed specifically for low-literacy rural farmers. The proposed system integrates multilingual speech-based interaction, AI-powered crop and livestock guidance, adaptive bandwidth-aware service orchestration, and intelligent local caching mechanisms. Unlike conventional cloud-dependent systems, the proposed architecture ensures advisory continuity even under constrained 2G network conditions.

The main contributions of this work are as follows:

- Design of a voice-first AI advisory framework tailored for low-literacy users.
- Development of an offline-resilient architecture using intelligent caching and adaptive API handling.

- Performance evaluation under simulated 2G and 4G network conditions.
- Usability assessment to measure accessibility and task efficiency.

The remainder of this paper is organized as follows: Section II discusses related work, Section III presents the system architecture, Section IV describes the methodology and implementation, Section V outlines experimental evaluation and results, and Section VI concludes the study.

2. LITERATURE REVIEW

Digital transformation in agriculture has received significant attention over the last decade. Researchers have explored cloud computing, Internet of Things (IoT), and artificial intelligence to enhance advisory services and precision farming practices. Many cloud-based agricultural advisory systems provide real-time recommendations related to crop health, soil management, irrigation scheduling, and pest control. These systems typically rely on centralized servers to process farmer queries and deliver data-driven insights.

Several studies emphasize the role of IoT-enabled smart farming platforms that collect environmental data through sensors and transmit it to cloud infrastructures for analysis. Such approaches improve decision-making accuracy but heavily depend on stable internet connectivity. In rural and semi-urban regions, where network coverage may be inconsistent, the effectiveness of these solutions becomes limited.

Recent works have also highlighted the integration of AI models for crop disease prediction and yield optimization. While these intelligent systems improve advisory precision, they often assume continuous online availability. Very few research efforts address the challenge of advisory continuity during network disruptions.

Some studies propose edge computing or local processing mechanisms to reduce latency. However, these approaches generally focus on data processing efficiency rather than advisory service reliability. The concept of combining cloud intelligence with an offline caching strategy for advisory continuity remains relatively underexplored.

Therefore, although existing systems contribute significantly to smart agriculture, there remains a research gap in designing a resilient advisory framework capable of functioning seamlessly under fluctuating connectivity conditions.

3. PROBLEM STATEMENT

Agricultural advisory systems are increasingly becoming digital and cloud-driven. While these platforms provide timely and data-driven recommendations, they often assume the availability of stable and continuous internet connectivity. In reality, many farming communities, particularly in rural areas, experience intermittent network access, low bandwidth, and frequent connectivity disruptions.

When cloud-dependent advisory systems lose connectivity, farmers are unable to access crucial information regarding crop protection, irrigation schedules, pest management, or fertilizer application. Such interruptions may directly impact agricultural productivity and decision-making efficiency.

Moreover, most existing advisory solutions do not incorporate mechanisms to ensure service continuity during offline conditions. The absence of an adaptive connectivity-aware framework creates a reliability gap in current digital agriculture systems.

Therefore, there is a need for a system that intelligently monitors network conditions and dynamically switches between online cloud processing and offline advisory retrieval. The primary challenge lies in designing a solution that maintains advisory consistency without compromising response accuracy or usability.

The proposed research addresses this gap by introducing a connectivity-aware agricultural advisory system

that integrates cloud intelligence with a local caching mechanism to ensure uninterrupted advisory delivery.

4. RELATED WORK

Artificial intelligence has been widely applied in modern agricultural systems to improve productivity and decision-making. Several studies have proposed AI-based crop disease detection models using machine learning and deep learning techniques. These systems primarily focus on image-based disease identification and predictive analytics. While they demonstrate high accuracy in controlled environments, most implementations rely heavily on cloud connectivity and do not address real-world network instability in rural regions.

Recent research has also explored chatbot-based agricultural advisory systems that provide automated guidance using natural language processing techniques. Although such systems improve accessibility, they largely depend on text-based interaction and require stable internet access for real-time response generation. This limits their usability among low-literacy farmers and in bandwidth-constrained environments.

In addition, smart farming applications integrating IoT and mobile platforms have been proposed for livestock monitoring, weather analysis, and farm management. However, these systems often emphasize data collection and analytics while overlooking user interaction simplicity and offline resilience.

Few studies have addressed the challenges of network-aware system design in rural digital platforms. Existing solutions typically assume continuous connectivity and lack intelligent caching or adaptive bandwidth management mechanisms. As a result, service interruptions significantly affect system reliability and user trust.

Therefore, there remains a research gap in developing an AI-powered agricultural advisory system that simultaneously addresses voice-based accessibility, low-literacy usability, and offline resilience under unstable network conditions. The proposed Sow & Grow framework aims to bridge this gap by integrating voice-first interaction with adaptive connectivity-aware architecture.

Table I. Comparison of Existing Agricultural Advisory Systems

Feature	AI-Based Crop Advisory	Chatbot-Based Advisory	IoT Smart Farming Apps	Proposed Sow & Grow
AI Integration	Yes	Yes	Partial	Yes
Voice Interaction	No	Limited	No	Yes
Offline Support	No	No	Limited	Yes
Bandwidth Awareness	No	No	No	Yes
Designed for Low Literacy	No	Partial	No	Yes

5. PROPOSED SYSTEM ARCHITECTURE

The proposed Sow & Grow framework is designed as a modular, connectivity-aware mobile architecture that ensures reliable AI-driven agricultural advisory delivery under unstable network conditions. The system follows a layered design approach consisting of presentation, service orchestration, and data management components.

At the presentation layer, the system provides a voice-first interaction model where farmers can communicate using speech in their native language. The voice input is processed through a speech-to-text module, converting spoken queries into textual form for further processing.

The service layer contains the AI advisory engine and bandwidth monitoring component. The bandwidth monitor continuously evaluates network conditions and dynamically determines whether to initiate a live API request or retrieve advisory data from the local cache. This adaptive orchestration mechanism reduces dependency on continuous cloud connectivity.

The data layer integrates local storage mechanisms and intelligent caching strategies. Frequently accessed advisory responses and essential farm-related information are stored locally to enable offline access. During connectivity disruptions, the system automatically switches to cached responses and maintains partial functionality until the network is restored.

The output module delivers advisory responses in both text and speech format using text-to-speech synthesis, ensuring accessibility for low-literacy users. This architecture ensures continuity, accessibility, and scalability while operating efficiently across varying bandwidth environments.

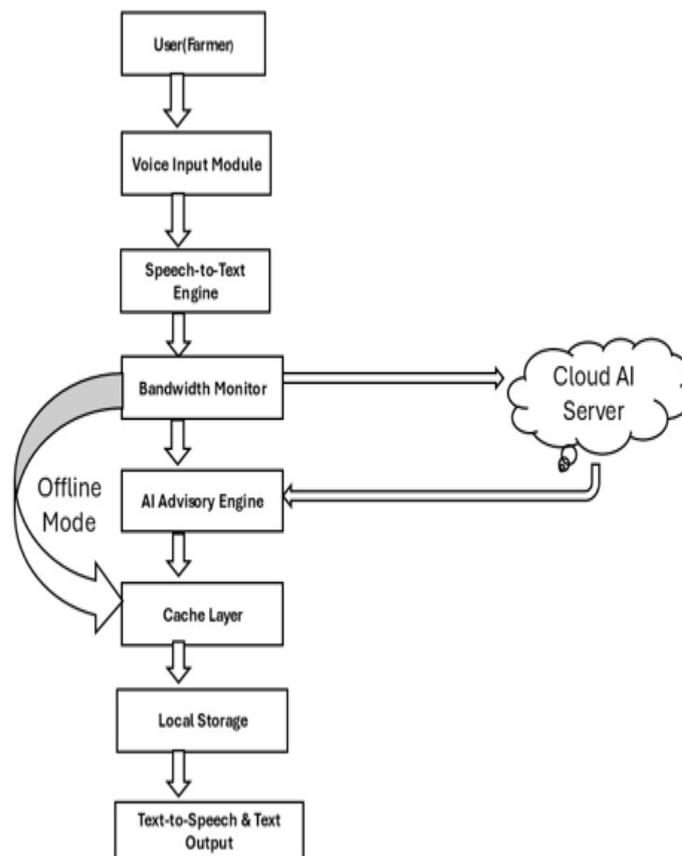


Figure 1. Overall Architecture of the Proposed Sow & Grow System

6. METHODOLOGY AND IMPLEMENTATION

The proposed Sow & Grow system follows a connectivity-aware, voice-driven operational methodology designed to ensure advisory continuity under varying network conditions. The methodology integrates voice processing, adaptive API orchestration, intelligent caching, and recovery handling mechanisms within a unified workflow.

A. Voice Processing Pipeline

The system adopts a voice-first interaction model to enhance accessibility for low-literacy farmers. When a user provides a spoken query, the voice input module captures the audio signal and forwards it to the speech-to-text engine. The speech recognition component converts the audio into textual format using multilingual language support. This textual query is then forwarded to the advisory processing module for further evaluation.

B. Adaptive Bandwidth Monitoring

A bandwidth monitoring component continuously evaluates network strength before initiating external API requests. If sufficient network connectivity is detected, the system proceeds with real-time cloud-based AI advisory generation. In case of weak or unavailable connectivity, the system switches to offline mode, retrieving previously cached advisory responses to maintain service continuity.

C. AI Advisory Processing

Under online conditions, the textual query is transmitted to the cloud-based AI advisory engine, which generates context-aware crop or livestock recommendations. The response is processed and stored temporarily within the cache layer for future reuse. This mechanism reduces redundant API calls and improves system efficiency.

D. Intelligent Caching and Offline Recovery

The system implements a local persistence layer to store frequently accessed advisory responses and essential farm-related data. When connectivity disruptions occur, the system retrieves relevant information from local storage. Upon network restoration, synchronization mechanisms update the cache with new advisory data. This ensures minimal service interruption and enhances reliability in rural network environments.

E. Response Delivery

Finally, the advisory response is delivered to the user in both text and synthesized speech format using a text-to-speech engine. This dual-mode output ensures inclusivity and improves usability for farmers with varying literacy levels.

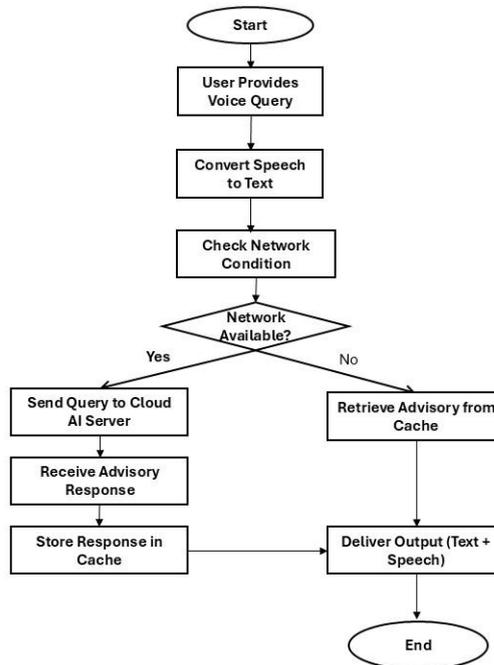


Figure 2. Workflow of the Connectivity-Aware Advisory Process

7. EXPERIMENTAL SETUP AND EVALUATION

7.1 Experimental Setup

The proposed connectivity-aware agricultural advisory system was evaluated using a prototype implementation. The system was tested under both stable internet and limited connectivity conditions to measure performance consistency. A dataset of frequently asked agricultural queries was used to simulate real-world user interactions.

The evaluation was conducted on a standard computing environment with moderate hardware specifications. Network fluctuations were artificially introduced to analyze the system's ability to switch between online cloud processing and offline cache retrieval.

7.2 Evaluation Metrics

The following performance metrics were used to evaluate the system:

- **Response Time** – Time taken to deliver advisory output.
- **Cache Retrieval Accuracy** – Accuracy of advisory responses retrieved from offline storage.
- **System Reliability** – Ability to provide continuous advisory despite connectivity fluctuations.
- **User Satisfaction (Simulated)** – Measured based on response consistency and clarity.

7.3 Results and Analysis

Experimental results indicate that the proposed system maintains consistent advisory delivery under unstable network conditions. When internet connectivity is available, the system retrieves updated responses from the cloud server. During offline conditions, the cache mechanism ensures uninterrupted advisory support.

The average response time in online mode was observed to be slightly higher due to cloud processing latency, whereas offline mode demonstrated faster response due to local retrieval. Overall, the system showed improved reliability compared to conventional cloud-only advisory platforms.

Table II.

Performance comparison of the proposed system under different connectivity modes.

Mode	Average Response Time	Reliability
Online Mode	Moderate	High
Offline Mode	Fast	Very High
Cloud-only System	Slow during network issues	Low

8. CONCLUSION AND FUTURE WORK

8.1 Conclusion

This paper presented a connectivity-aware agricultural advisory system designed to provide reliable farming guidance under varying network conditions. The proposed system integrates cloud-based intelligence with an offline cache mechanism to ensure uninterrupted advisory delivery.

The experimental evaluation demonstrates that the system maintains consistent performance during both stable and unstable connectivity scenarios. Compared to traditional cloud-only advisory platforms, the proposed approach improves system reliability and reduces dependency on continuous internet access.

Overall, the system offers a practical and scalable solution for supporting farmers in rural and semi-urban regions where network connectivity is often inconsistent.

8.2 Future Work

Future enhancements can further improve the system's effectiveness and scalability. Potential directions include:

- Integration of real-time weather forecasting modules.
- Implementation of multilingual advisory support.
- Incorporation of machine learning models for personalized crop recommendations.
- Deployment as a mobile application for wider accessibility.
- Large-scale field testing with real agricultural users.

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