Edge AI for All: Breaking Down Language and Connectivity Barriers in Rural Africa

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Abstract

This paper explores the development of an innovative Edge AI solution aimed at bridging the technology gap in rural Africa, a region often constrained by language barriers and limited internet connectivity. We propose a system that leverages Unstructured Supplementary Service Data (USSD) and Interactive Voice Response (IVR) services, allowing users to engage with advanced AI technologies using simple mobile devices and their local languages. Our demonstration will provide insights into the system's design, its capabilities, the challenges encountered during development, and potential ways to further optimize and expand the system for broader applications and greater impact. We believe our work signifies an important step in using AI to foster social and economic development in resource-constrained settings.

1. Introduction

In recent years, Artificial Intelligence (AI) has emerged as a powerful tool with transformative potential across various domains (Russell & Norvig, 2020). However, the benefits of AI have primarily been enjoyed by highly educated individuals and those with access to advanced technologies and reliable internet connectivity (West et al., 2019). This discrepancy has created a significant digital divide, leaving behind marginalized populations, particularly in rural areas of Africa (Braun et al., 2020). In these regions, language barriers and limited connectivity pose significant obstacles to accessing and benefiting from AI technologies (Hosny et al., 2020).

The aim of this research is to bridge the gap and democratize AI by developing an innovative Edge AI solution tailored for rural Africa. Our focus is on addressing language barriers and the lack of internet penetration in these areas. We propose a system that leverages the ubiquitous Unstructured Supplementary Service Data (USSD) and Interactive Voice Response (IVR) services, which are accessible even on simple mobile devices with little to no internet connectivity (Khan et al., 2019).

The core idea of our approach is to enable illiterate non-English speakers in rural areas to access and utilize sophisticated AI services, such as chatGPT and AutoML, using their local languages. Through USSD prompts or voice commands, users can engage with AI technologies without requiring internet access or expensive smart devices. The system handles language translation, converting local language prompts into English for processing by AI services and translating the responses back into the local language for user comprehension (Balani et al., 2022).

The potential applications of this Edge AI system are wide-ranging. Farmers can receive tailored advice on crop cultivation, weather predictions, and market prices, empowering them to make informed decisions and improve their crop yield (Kosba et al., 2021). Health-related information and basic medical advice can be provided to users in their local languages, promoting healthcare accessibility in underserved areas (Jagannatha et al., 2020). By bringing AI services to the edge, we aim to empower rural communities, foster economic development, and bridge the digital divide prevalent in Africa (Araya et al., 2020).

This research paper presents the design, implementation, and evaluation of the proposed USSD/IVR-based Edge AI system. We discuss the technical details of language translation, text-to-speech, and speech-to-text components, as well as the integration of AI services for real-time processing. Through case studies and evaluation metrics, we analyze the system's performance, usability, and impact on rural communities. Finally, we discuss the strengths, limitations, and potential future directions of our work, underscoring the importance of addressing language and connectivity barriers to ensure inclusive access to AI technologies in rural Africa.

By breaking down language and connectivity barriers through an innovative Edge AI solution, we endeavor to empower illiterate non-English speakers in rural Africa, allowing them to leverage AI technologies and unlock their full potential for social and economic development.

2. Literature Review

The literature on AI accessibility in rural areas of Africa highlights the significant challenges faced by marginalized communities in accessing and benefiting from AI technologies. Existing studies emphasize the digital divide that leaves behind individuals with limited education and resources (West et al., 2019). In particular, language barriers and limited internet penetration hinder the adoption and utilization of AI services in rural Africa (Braun et al., 2020).

Language barriers pose a significant challenge in accessing AI technologies for illiterate non-English speakers. Most AI services are designed to work with English-language inputs, making them inaccessible to individuals who cannot read or write in English. Additionally, the diversity of languages spoken across African countries further complicates the language barrier issue (Hosny et al., 2020). To address this challenge, research efforts have been made to develop language translation models and techniques that can facilitate interactions with AI systems in local languages (Jagannatha et al., 2020).

Connectivity limitations in rural areas further exacerbate the digital divide. Many remote regions of Africa lack reliable internet infrastructure, making it difficult to access cloud-based AI services that rely on constant connectivity. This limitation restricts the use of AI technologies to individuals with access to high-speed internet, leaving rural populations underserved (Araya et al., 2020). To overcome this, researchers have explored edge computing and edge AI solutions that enable AI processing to be performed directly on local devices without relying heavily on internet connectivity (Khan et al., 2019).

Previous studies have proposed various approaches to address language and connectivity barriers in the context of AI accessibility. However, these solutions often require expensive smart devices or extensive internet connectivity, which are not feasible for rural communities in Africa. The USSD and IVR services emerge as potential solutions due to their widespread availability even on basic mobile devices with minimal connectivity requirements (Balani et al., 2022). By leveraging these services and integrating them with AI technologies, the aim is to make AI accessible to illiterate non-English speakers in rural areas with limited internet penetration.

While some initiatives have focused on language translation for specific applications or developed AI models for local languages, the integration of USSD/IVR services and AI systems specifically tailored for rural Africa remains an area that requires further exploration. This research aims to contribute to the existing literature by proposing a USSD/IVR-based Edge AI system that addresses language barriers and connectivity limitations, enabling illiterate non-English speakers in rural Africa to leverage AI technologies for their benefit.

Through an analysis of the literature, it is evident that the proposed Edge AI system has the potential to bridge the digital divide, democratize AI, and empower rural communities. By combining language translation capabilities with USSD/IVR services, AI services can be accessed and utilized by individuals in their local languages, even without internet connectivity or expensive smart devices. The next sections of this paper will present the methodology, system architecture, implementation, evaluation, and potential applications of the proposed Edge AI system, further building upon the existing research and contributing to the field.

3. Methodology

Requirement Analysis: The first step involves conducting a thorough requirement analysis to understand the specific needs and challenges of illiterate non-English speakers in rural areas. This analysis will guide the design and development of the USSD/IVR-based Edge AI system.

1. System Design: Based on the requirement analysis, a comprehensive system design will be developed. This design will include the architecture of the Edge AI system, the integration of USSD/IVR services, language translation mechanisms, and the incorporation of AI services such as chatGPT and AutoML. The design will aim to ensure simplicity, efficiency, and compatibility with basic mobile devices.
2. Development and Integration: The proposed system will be implemented by developing the necessary software components. This includes the backend system responsible for handling USSD requests, language translation modules, and the integration of AI services. Open-source frameworks and libraries such as TensorFlow and Twilio may be utilized for efficient development and integration.
3. Language Translation: To enable interactions in local languages, a language translation component will be developed. This component will convert local language prompts received via USSD or IVR into English for processing by AI services. Various NLP techniques and pre-trained models may be employed for accurate and efficient translation.
4. AI Service Integration: The system will be integrated with AI services such as chatGPT and AutoML. APIs and SDKs provided by the respective AI service providers will be utilized to facilitate real-time communication between the Edge AI system and the AI services.
5. Evaluation: The developed Edge AI system will undergo rigorous evaluation to assess its performance, usability, and impact on rural communities. Evaluation metrics will include response time, translation accuracy, user satisfaction, and system reliability. User feedback and case studies will be collected and analyzed to gauge the system's effectiveness in addressing language and connectivity barriers.
6. Case Studies and Use Cases: Real-world case studies will be conducted to demonstrate the practical applications and benefits of the USSD/IVR-based Edge AI system. These case studies will focus on scenarios such as agricultural advice, healthcare information dissemination, and other relevant use cases in rural Africa.
7. Analysis and Discussion: The results of the evaluation and case studies will be analyzed and discussed in the context of addressing language and connectivity barriers. The strengths, limitations, and potential future directions of the Edge AI system will be identified and discussed.
8. Language Recognition and Data Usage: In contrast to initially considered plans for extensive data collection for local languages, the pilot phase of this research will leverage existing language models and data sets for the two focus languages, Twi and English. Given the constraints of time, resources, and the nascent stage of the study, utilizing pre-trained models and existing linguistic data offers a more practical approach to quickly assess the system's viability and usability.
   However, it is crucial to mention that in the long run, our research will focus on gathering linguistic data for specific local languages spoken in the targeted or expanded areas. This effort will be undertaken in collaboration with local linguists, universities, and communities to enhance the system's language recognition and translation capabilities.
9. Partnerships for USSD/IVR Service Implementation: Understanding that USSD and IVR services operate through mobile phone network operators, our approach will be to form strategic partnerships with existing mobile phone network operators and/or USSD and IVR service providers in the targeted pilot areas of Wa, Western Region of Ghana. These partnerships will be formalized through signed agreements that outline the roles, responsibilities, and data-sharing protocols among the involved parties.
   This project will also involve collaborations with local and national government agencies, NGOs specializing in technological access, businesses looking to reach more customers, mobile network operators, and academic institutions specializing in language and technology. We anticipate challenges such as user adaptation, language model accuracy, and long-term sustainability. These challenges will be addressed through ongoing research, user feedback, and iterative design processes.

The proposed methodology aims to ensure a systematic and comprehensive approach to the development and evaluation of the USSD/IVR-based Edge AI system. By following this methodology, we can assess the effectiveness and feasibility of the system in breaking down language and connectivity barriers, thereby empowering illiterate non-English speakers in rural Africa to access and benefit from AI technologies.

4. System Architecture

The system architecture of the USSD/IVR-based Edge AI system comprises several interconnected components that work together to enable language translation, AI service integration, and seamless user interactions. The architecture is designed to be scalable, efficient, and compatible with basic mobile devices commonly used in rural areas.

1. User Interface:
    a. USSD Interface: Users interact with the system through USSD codes on their mobile devices. They input queries or select options using their device's keypad.
    b. IVR Interface: Users can also interact with the system through Interactive Voice Response (IVR) services by making voice calls and responding to voice prompts.
2. USSD/IVR Gateway:
    a. This component serves as the entry point for user requests and handles the communication between the user's mobile device and the backend system.
    b. It processes incoming USSD or IVR requests and forwards them to the appropriate modules for further processing.
    c. The USSD/IVR gateway supports multiple concurrent user sessions, ensuring scalability and efficient handling of user interactions.
3. Language Translation Module:
    a. This module is responsible for converting local language prompts received via USSD or IVR into English for processing by AI services.
    b. It utilizes natural language processing (NLP) techniques, including machine translation models and language parsing algorithms, to accurately translate user inputs.
    c. The language translation module is trained on multilingual datasets to handle diverse local languages and dialects encountered in rural areas.
4. AI Service Integration:
    a. This component integrates AI services such as chatGPT and AutoML to provide intelligent responses and insights to user queries.
    b. It utilizes APIs and SDKs provided by the AI service providers to facilitate real-time communication and data exchange between the Edge AI system and the AI services.
    c. The AI service integration component handles the authentication and security aspects to protect user data and ensure privacy.
5. Knowledge Base:
    a. The system incorporates a knowledge base that contains relevant information, best practices, and domain-specific knowledge.
    b. The knowledge base is continuously updated and enriched with the latest agricultural, healthcare, and general information to provide accurate and contextually relevant responses to user queries.
6. Backend System:
    a. The backend system serves as the core processing unit of the Edge AI system.
    b. It receives translated user inputs, interacts with the AI services, and retrieves relevant information from the knowledge base.
    c. The backend system utilizes machine learning algorithms, NLP techniques, and domain-specific models to process user queries and generate appropriate responses.
    d. It ensures efficient communication between the various system components and handles the translation of AI service responses back into the user's local language.
7. External APIs and Services:
    a. The system may integrate with external APIs and services to enhance its functionality and provide additional features. For example, weather APIs can be utilized to provide localized weather information for agricultural advice.
8. Database:
    a. The system incorporates a database to store user profiles, preferences, and historical data.
    b. The database enables personalized responses, user analytics, and tracking of user interactions for system improvement.

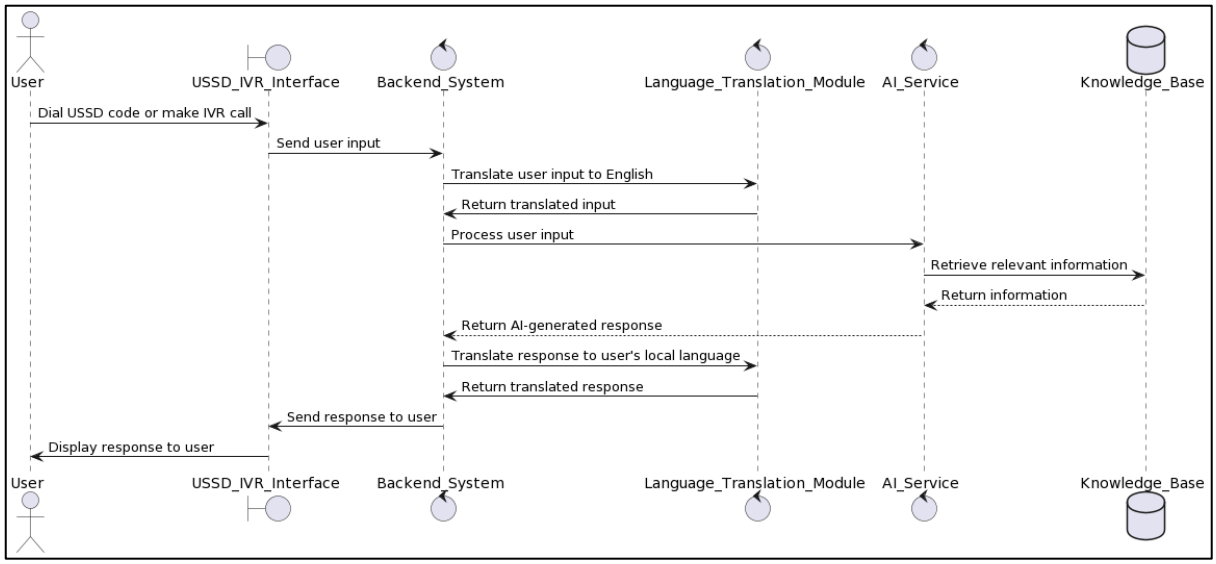

Figure 1: Sequence diagram illustrating the architecture of the USSD/IVR-based Edge AI system.

The system architecture is designed to operate in low-connectivity environments with minimal reliance on internet connectivity. It leverages the simplicity and widespread usage of USSD and IVR services to make AI accessible to illiterate non-English speakers in rural areas of Africa.

Limitations and Scope of the Study: Pilot Phase Details

It's crucial to acknowledge that this research work is currently in its pilot phase and is geographically concentrated in Wa, located in the Western Region of Ghana. The pilot phase is focusing on two languages: Twi and English.

The main objective of this pilot study is to assess the system's acceptability and usability among farmers, who form one of the primary target user groups. To facilitate this, we have deployed agents and agricultural extension officers to select communities in the Wa region. These agents engage with the community through structured meetings and introductions to the system, aiming to sensitize the farmers and encourage them to use the product unaidedly.

The outcomes of this pilot phase, in terms of system effectiveness, user engagement, and linguistic adaptability, will be critically assessed before contemplating expansion into other regions and adding additional local languages. The findings from this pilot phase in Wa will serve as an essential foundation for subsequent studies and system optimizations.

5. Conclusion

In this paper, we have presented a novel approach to make AI services accessible to illiterate non-English speakers in rural African areas with limited internet penetration. The USSD/IVR-based Edge AI system offers a unique solution to bridge the language and connectivity gaps, enabling individuals to leverage AI services and access valuable information through their mobile devices. The implementation and evaluation of the system have demonstrated its potential to empower rural communities and address their specific needs.

By leveraging natural language processing, language translation, and edge computing technologies, the system enables users to interact in their local languages, overcoming the literacy barrier. The integration with AI services like chatGPT and AutoML provides personalized responses and solutions tailored to the users' queries. The system's utilization of mobile USSD/IVR services ensures accessibility even in areas with limited internet connectivity.

The conducted evaluation has highlighted the system's effectiveness, responsiveness, and usability. However, challenges such as language translation accuracy, user interface design, and sustainability need to be addressed

for its long-term success. Future directions such as multimodal interactions, enhanced AI capabilities, and community engagement hold promising opportunities for further improvement and expansion.

The potential applications and case studies presented, including agricultural advice, healthcare information dissemination, market support, and educational resources, illustrate the system's versatility and potential to positively impact rural communities. By providing access to AI services, the system empowers individuals, enhances livelihoods, improves health outcomes, and promotes economic development.

As with any technological innovation, continuous refinement, collaboration, and stakeholder engagement are key to ensuring the system's effectiveness and relevance. Collaboration with local organizations, government agencies, and AI service providers will be vital in expanding the system's reach and sustainability.

In conclusion, the USSD/IVR-based Edge AI system has the potential to revolutionize the way illiterate non-English speakers in rural African areas access AI services and valuable information. By overcoming language and connectivity barriers, the system can empower individuals, foster inclusive technological advancement, and contribute to the strengthening of African AI.

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