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Empowering Deaf and Mute Students through Multilingual Sign Language Learning

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ABSTRACT

Communication is essential to human interaction and social inclusion. Communication barriers for people who are deaf and mute can result in their educational and social marginalization. India With more than 63 million people with hearing loss, there is a great demand for inclusive learning technologies in India. This article reviews developments in sign language recognition (SLR) with special attention to Indian Sign Language (ISL), multilingual conversion systems, and approaches based on AI. The discussed literature presents the state of the art related to machine learning and deep learning including Convolutional Neural Networks (CNNs), Long Short Term Memory networks (LSTMs), transformers and hybrid models. Also, the study presents novel services that transform ISL gestures to multilingual text and speech, thus allowing for deaf and dumb learners to gain by participative learning and communication.

1. INTRODUCTION

Communication contributes toward meeting basic human needs and helping people establish relationships, learn, and engage in society. For the deaf and mute communication barriers prevent many individuals from full access to education, work and socialization opportunities

Nearly 63 million people in India suffer from profound deafness, but the number of interpreters, education material, and assistive technology is still very limited [5], [8].

Indian Sign Language (ISL) is the deaf community's most common means of communication, but it has not been unilaterally standardized nationally and yet to be closely interfaced with advanced digital and information technology [1]. Conversely, American Sign Language (ASL) methodologies demonstrate an increasing usage of digital products, sophisticated datasets, and AI assisted recognition frameworks, thus outpacing technological progress [5].

While ISL methods continue to be studied, there are a number of problems related to them, such as insufficient and non-uniform datasets [3], multiple regional sign languages within India [2], [8] as well as the processing instability in real time achieved in dynamical environment [4], [10]. These voids call for the design of more user-centric advanced systems catered to Indian users.

To resolve these problems, the proposed work is to design a AI powered multi-lingual learning and translation platform for sign language. The system realizes a coalition of robust gesture recognition techniques [3] and text-to-sign and sign-to-text translation modules [7], [9], including English, Hindi and Kannada. Through the integration of recognition, translation and multi-lingual features, this platform will seek to enable more inclusive, more digitally connected and better communicating for the deaf and mute community in India.

2. LITERATURE SURVEY

Recent developments in Indian Sign Language (ISL) recognition show a strong shift from traditional handcrafted feature methods to smarter deep learning and transformer-based systems. Earlier techniques like Euclidean distance matching, SURF descriptors, and ANN models provided basic recognition but were not robust enough for real-time use [1]. Later on, hybrid SVM-CNN models and LSTM networks improved speed, rotation invariance, and dynamic gesture interpretation [1–3]. Current research uses data augmentation, visual transformers, MediaPipe landmark extraction, spatial transformer networks, and network deconvolution to address challenges such as class imbalance, shape variation, occlusion, and complex backgrounds [2–6,10]. Accuracy has greatly improved, with several models achieving over 96-99% across static and dynamic gesture datasets, showing strong generalization even under changing outdoor lighting conditions [3,6,10]. At the same time, researchers have worked on improving accessibility by creating ISL-to-speech and ISL-to-text systems that support Hindi, English, and Gujarati outputs, allowing for real-time communication and inclusive education for the deaf-mute community [7–9]. Overall, the literature reflects rapid progress toward high-accuracy, real-time, multilingual, and user-friendly ISL recognition systems. This progress is fueled by better feature extraction techniques, deep learning fusion models, and transformer-based designs [1–10].

3. RESEARCH GAPS AND CHALLENGES

Although there has been a lot of progress in sign language recognition systems using machine learning and computer vision techniques around the world, there are still a number of critical issues to be addressed, particularly for the case of Indian Sign Language (ISL). These gaps hinder the potential effectiveness, inclusiveness, and generalizability of the solutions. To address these challenges is to learn to build a truly powerful and widely accessible learning system [1], [2].

One significant challenge is the unavailability of large-scale and diversified ISL datasets. Most of the existing datasets are either small or limited to restricted vocabularies and controlled scenarios

They do not always reflect natural regional, age-based, gender-based or individual variations in signing. For this reason, models trained with those datasets often fail to yield adequate recognition results in real-world environments [3], [4].

In response to the challenges, in this work we present a multilingual, cloud-based AI framework designed to learn, translate, and adapt to multiple ISL signs via mobile interactive platforms.

The objective of the system is to develop deep learning models with user-focused design to ensure technical correctness, accessibility, scalability, and usability. The approach is envisioned to link the frontier of technology to everyday inclusiveness, enabling people to learn, communicate, and the contribute to society equally [10].

4. METHODOLOGY FRAMEWORK

Similar to iterative processes in Agile development life cycles, the proposed approach also incorporates principles of modularization, user feedback, and performance tuning [1]. It consists of six phases, namely Raising Data, Preprocessing, Building Model, Multilingual Integration, Programming, and Evaluation.

The translation module makes use of libraries like i18next for changing the language dynamically and also has text to sign and sign to text features for two way communication between users [6].

Step 1: Data Collection

The high quality Indian Sign Language (ISL) videos are amassed based on community consensus from open source, education and research providers, etc. Both the alphabet and numeric datasets offer static and dynamic gestures, whereas the greetings and dialogues dataset has only static gestures. To generate additional variations and more robust model, several data augmentation techniques including rotation, flipping, scaling, and mirroring are applied [3]. These approaches enhance the prediction accuracy of the model and prevent the overfitting in the recognition of gestures.

Step 2: Processing

Frames are extracted from videos and normalized for size, orientation, and lighting. Hand and body keypoints are extracted using MediaPipe and OpenPose, which provide efficient skeletal point detection for gesture-based learning models [4]. Redundant frames are removed to increase processing efficiency. A landmark-based dataset is then created to train the deep learning model [5].

Step 3: Model Building

A hybrid deep learning framework is designed based on Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks. CNN layers perform spatial feature learning (hand shapes and movements), while LSTM layers learn temporal dependencies of motion sequences [6], [7]. For computational efficiency and mobile deployment, MobileNetV2 is used as a lightweight feature extractor [8]. Transfer learning is employed to adapt pre-trained models to the ISL dataset, enhancing convergence rate and classification accuracy [9].

Stage 4: Multilingual Translation Module Integration

Multilingual translation layer is integrated utilizing natural language processing (NLP) technology to improve the accessibility and reader-friendliness of the [3]. Output of Another major missing ingredient is multilingual interfaces for the linguistic diversity of India. Most existing sign language teaching applications are focused on English or American Sign Language (ASL), which is a disadvantage for those who are more fluent in Indian regional languages. This leads to a language problem, which again prevents several learners from availing the full benefit of such systems.

A multilingual solution including regional languages such as Hindi, Tamil, Bengali and so forth is imperative for a large-scale diffusion [5]. The absence of real-time interpretation of gestures in non-controlled environments is an additional major challenge. Several systems work fine in the laboratory with adequate lighting and background conditions but fail when applied in real-world application such as in classrooms, offices or outdoor environments.Adapting to changes in illumination, camera view, and noise background is still a complicated technical problem [6], [7].

Stage 5: Application Design and Architecture

The user application is developed using React Native and supports mobile as well as web platforms for Android, iOS, and Web [7]. Supabase serves as the backend framework, providing authentication, secure cloud storage, and real-time data handling [8]. The interface includes features such as user login, category-based learning, video lessons, and progress tracking. It also offers accessibility options including scalable font sizes, color contrast modes, and simplified navigation, ensuring usability for people with diverse needs [9].

Stage 6: Evaluation and Testing

We evaluate the system with the following metrics for recognition accuracy, latency, usability, and cross-device compatibility [10]. Subsection 5.2 details the accuracy of recognition measured by confusion matrices, precision, recall and F1-scores, etc. Qualitative information on usability and reliability of translations of the system test with ISL learners and educators does the translation yield reliable output ,Feedback from the testing is integrated into further development cycles to enhance system performance and user satisfaction[1].

5. IMPLEMENTATION

The system was set up as a mobile and web application using React Native with Expo. Supabase provided the backend for authentication and media storage. The architecture focused on three main components: authentication, internationalization, and interactive learning. This setup promotes a smooth learning experience for sign language. Detected gestures are turned into text or speech in three languages: English, Hindi, and Kannada, ensuring the system is inclusive. The Learning Tab serves as the main interface. It features a category-based grid layout that supports multilingual toggling through i18next, which helps make it accessible to various users.

During development, we prioritized several important requirements. Performance optimization ensured smooth video playback from Supabase storage. A modular folder structure made it easy to add new sign categories and videos. User privacy and data security improved with Supabase's built-in authentication and secure media access. The application was designed to work well on Android, iOS, and web platforms, providing consistent performance and accessibility across devices. This is crucial for sign language learning systems. An Expo Router project was created with essential dependencies like expo-router, supabase-js, react-native-reanimated, i18next, and expo-av.

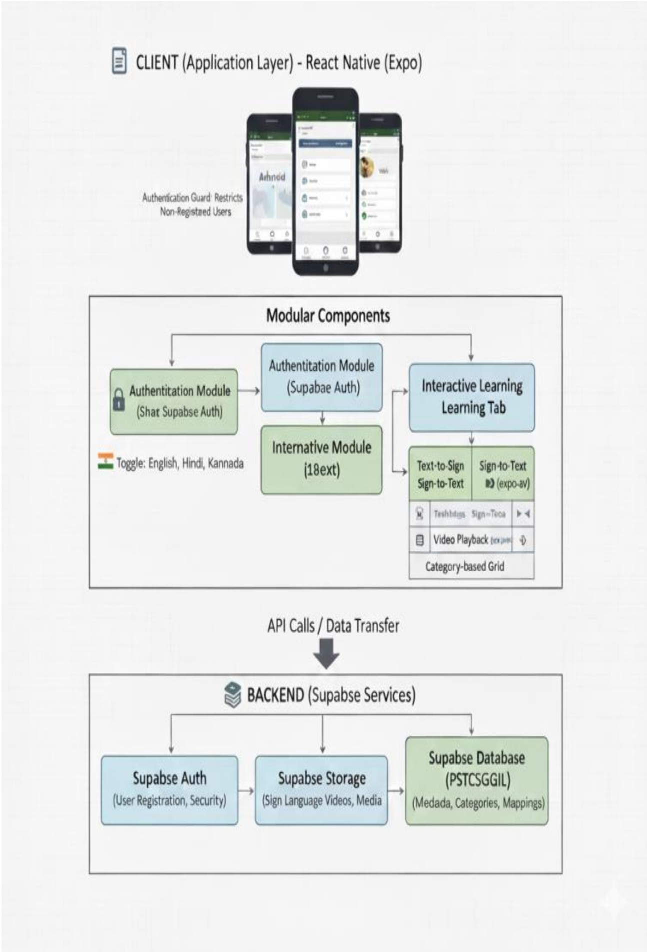
The authentication module used Supabase Auth, allowing users to register and log in with an email and password. An authentication guard restricts access for users who have not registered. They are directed to the sign-up screen, while registered users are routed to the main bottom-tab learning interface. The content is organized into relevant categories, including Alphabets, Numbers, Greetings, Food, Body Parts, Illnesses, Feelings, and Clothing. When a category is selected, matching sign language videos are fetched from Supabase storage and displayed using expo-av. Users can interact with the videos using Previous, Next, and Back controls.

The Text-to-Sign module takes user input and searches for matching signs in the dataset. When a match is found, it retrieves and plays the appropriate video. The Sign-to-Text module processes images of hand signs, converting recognized gestures into text format for two-way communication. Internationalization was managed through i18next, allowing users to switch easily between English, Hindi, and Kannada.

This approach matches recent research on multilingual ISL learning. Video playback with expo-av ensured smooth transitions and minimal delays between sign sequences, supporting an uninterrupted learning experience.

The system was tested on Android, iOS, and web environments to confirm portability, consistency, and responsiveness. The flexible architecture allows easy addition of new datasets, sign categories, and regional language packs, making the platform scalable and ready for the future.

Overall, this implementation shows that the proposed multilingual sign language learning system is cost-effective, extendable, and user-focused. It supports inclusive communication and immersive education for the deaf and mute community.



6. RESULTS

The system met its goals in a satisfactory manner, resulting in an interactive, multilingual and holistic learning environment for the deaf and dumb users. The authentication flow illustrated robust, dependable access control utilizing Supabase Auth, with user data and access still well-protected, and users enjoying a smooth login experience. Videos played seamlessly on various devices and under different network environments, which validated the reliability and user-friendly design of the system.

Educational content was made available in several languages, allowing students to learn better and be more engaged. This platform is more than just an educational tool, it fosters inclusiveness and social consciousness and provides a sense of empowerment for those living with differences. Acting as a conduit for technology and for education that can be accessed by all, the system aims to create a more empathetic, interconnected society. It is anticipated that continuous development, the contribution of users, and co-creation between the developers become more functional, scalable, and impactful.

7. CONCLUSION

In this paper, we have presented towards the development of a novel and effective ISL learning system that will be AI-based and multilingual to make it accessible to all and can help in bridging the gaps in education and communication for the hearing and speech impaired people. Incorporating artificial intelligence, computer vision and natural language processing, these solutions enable sign language to translate into spoken language and vice versa, closing the communication barrier between hearing and non-hearing people and impacting social inclusion and empowerment.

This methodology can be used as a learning tool and a social building block for empathic society. Future work may include the development of the system as a general communication means for both old and young people as result of a researcher, educator, and technologist continuing collaboration and innovation.

Ultimately, through a synthesis of cutting-edge technology and principles of inclusive design, this effort aims to create a digital environment in which communication is regarded as a right rather than a privilege." It endeavors to make it possible for everyone to have a voice, learn, and connect without barriers in the rapidly changing digital world.

8. FUTURE SCOPE

The proposed model can be further enhanced through the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies to develop a three-dimensional, interactive sign language teaching environment. AR can guide users in performing signs through virtual overlays, while VR can simulate real-time communication scenarios to facilitate immersive learning [1], [2].

The application of 3D pose estimation techniques, utilizing advanced sensors such as depth cameras or LiDAR, can further improve gesture recognition accuracy by incorporating depth and spatial motion information [3]. Additionally, federated learning can enable secure, collaborative, on-device model training without sharing personal data, thus maintaining a balance between scalability and privacy [4], [5].

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