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AI – powered Interactive Sign Language Learning Assistant

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Abstract:
Effective communication between hearing individuals and the Deaf community requires accessible and practical methods for learning Indian Sign Language (ISL). However, many existing learning resources rely on static materials and lack interactive support, making it difficult for beginners to understand the structure, movement, and grammar of sign language. These limitations reduce engagement and slow down the learning process. This paper proposes a smart and interactive Sign Language Learning Assistant that leverages modern technologies to improve ISL education. The system allows users to provide input via both speech and text, enabling natural, flexible interaction. Spoken input is converted into text using real-time speech recognition, after which a language processing module transforms the content into ISL-compatible grammatical structure. This ensures that learners receive meaningful and linguistically accurate outputs. To support skill development, the system generates detailed voice-based instructions describing how signs are performed, including hand positioning and movement flow. The platform also includes features such as progress tracking, practice modules, and learning resources to enhance user engagement and retention. By combining speech processing, natural language understanding, and audio guidance on a unified platform, the proposed system offers a user- friendly, scalable solution for ISL learning. The approach aims to simplify the learning experience, improve comprehension, and encourage wider adoption of sign language, thereby contributing to more inclusive communication.

KEYWORDS: Indian Sign Language (ISL), Speech Recognition, Natural Language Processing (NLP), Assistive Learning Systems, Human-Computer Interaction

I. INTRODUCTION:

Communication is essential for interaction and social inclusion, yet it remains challenging when people use different modes of language. Indian Sign Language (ISL) is widely used within the Deaf community for everyday communication, but its understanding among hearing individuals is still limited. This gap is mainly due to the absence of effective learning systems that can teach ISL in a simple, engaging, and practical way.

Conventional learning methods, such as books, charts and video tutorials, provide only basic knowledge and often fail to explain the dynamic nature of sign language. Sign language involves hand movements, spatial positioning, and specific grammatical structures that are difficult to grasp through static resources. As a result, learners often struggle to build confidence and apply their knowledge in real-life situations. With the rapid growth of digital technologies, new opportunities have emerged to improve language learning experiences. Intelligent systems can now offer interactive platforms that allow users to learn through real-time input, guided instructions, and continuous practice. These systems make learning more engaging and help users better understand the relationship between spoken language and sign language.

This work presents a smart learning platform designed to assist users in learning ISL more effectively. The system accepts both voice and text input, allowing users to interact naturally. Spoken input is converted into text and then processed to match the structure of ISL, enabling users to understand how sentences are formed in sign language. This approach enhances both clarity and learning efficiency. To support practical learning, the platform provides detailed audio-based guidance that explains how signs are performed, including movement, positioning, and transitions. This helps learners practice accurately without relying only on visual materials. Additional features such as progress monitoring and learning support tools encourage regular practice and improvement.
In summary, the proposed system aims to create an accessible and user-friendly learning environment for ISL. By combining modern technologies with an intuitive design, it helps reduce communication barriers and promotes inclusive interaction between hearing individuals and the Deaf community.

II. RELATED WORK:

Recent progress in sign language recognition has been largely driven by advancements in artificial intelligence and computer vision. Early approaches focused on identifying hand gestures using machine learning to convert signs into text or speech. Convolutional Neural Networks (CNNs) have proven effective in extracting visual features and recognising basic gestures with high accuracy [1]. To handle dynamic gestures, CNNs are often combined with Long Short-Term Memory (LSTM) networks to capture temporal patterns. Some models also use attention mechanisms to focus on important gesture movements and improve performance [2]. Real-time systems now integrate deep learning with hand-tracking technologies for practical communication support. Hand landmark detection frameworks further enhance gesture tracking and classification accuracy [3]. Recent research explores end-to-end systems that combine gesture recognition with natural language processing for sentence-level translation . Transformer-based models are also being studied to improve linguistic understanding and output quality [4]. However, challenges such as limited datasets, lack of sentence-level support, and absence of interactive learning features still remain [5].

III. PROPOSED SYSTEM:

A. Overview of Proposed System:

The proposed system is an intelligent platform designed to support the learning of Indian Sign Language (ISL) through interactive and technology-driven methods. It allows users to provide input using either speech or text, making the system flexible and easy to use. Speech input is converted into text using a recognition module, after which the content is transformed to match the ISL grammatical structure. This ensures that users are not only learning individual signs but also understanding the correct sentence formation used in sign language. The system then provides detailed voice-based instructions that explain how signs are performed, including hand movements, orientation, and positioning.

B. System Architecture:

The architecture consists of six core modules:

- Input Module
- Speech-to-Text Module
- Criminal Database Management
- Public Reporting & Image Upload
- Real-Time Alerts & Notifications
- Maps & Location Tracking

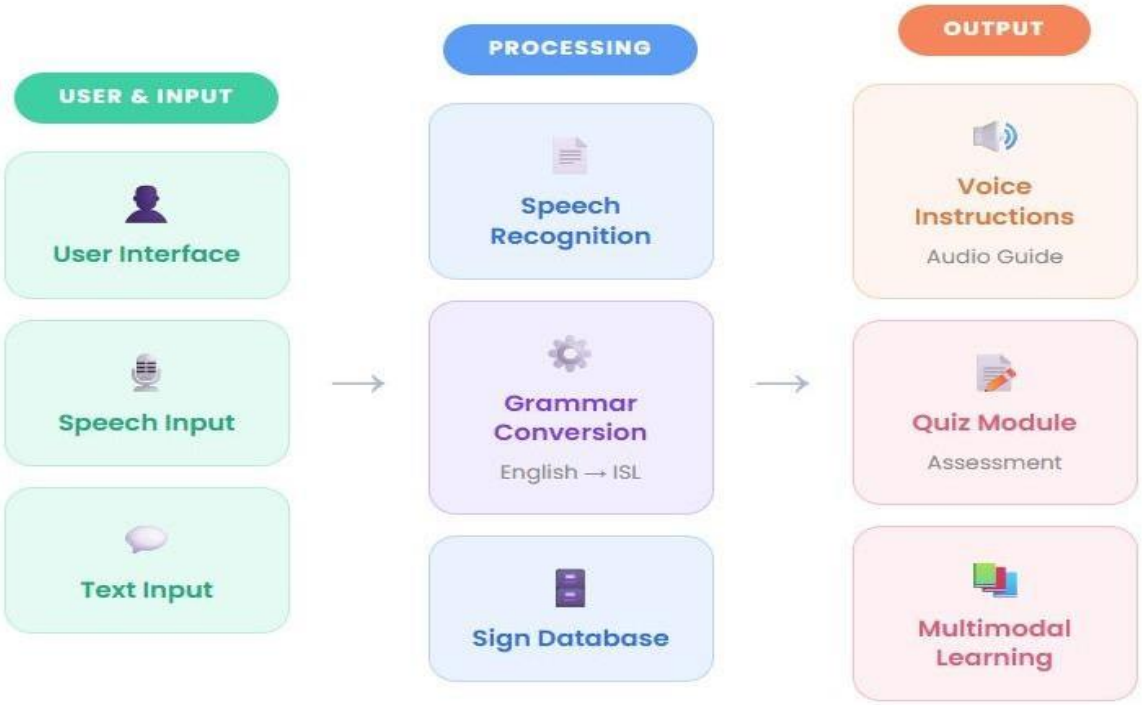


Figure 1: System Architecture for AI-Powered Interactive Sign Language Learning Assistant

1. Input Module
This module serves as the entry point of the system. It allows users to provide input either by typing text or speaking through a microphone. The flexibility of input methods improves usability and accessibility for different users.

2. Speech-to-Text Module
This component processes voice input and converts it into written text. It ensures that spoken words are accurately captured so they can be further analyzed by the system.

3. Language Processing Module
This module analyses the input text and prepares it for transformation. It identifies important words and structures the sentence in a way that can be adapted to sign language format.

4. Grammar Conversion Module
This module modifies the processed text to follow Indian Sign Language (ISL) grammar rules. It ensures that the output is meaningful and reflects the correct structure of sign language rather than direct translation.

5. Data Storage Module
This component maintains a collection of sign-related information, including descriptions and usage details. It retrieves relevant data whenever required by the system.

6. Instruction Generation Module
This module produces audio-based explanations that guide users on how to perform each sign. It describes movements, positioning, and transitions in a clear manner.

7. Evaluation Module
This module checks the learner's understanding by providing questions or activities. It helps users measure their progress and identify areas for improvement.

8. Support Module
This module offers additional learning materials and resources to enhance the learning process. It allows users to explore beyond the basic system functionality.

IV. IMPLEMENTATION DETAILS:

A. System Development Overview

The Sign Language Learning Assistant is implemented as a web-based platform designed to provide an interactive learning experience. The system follows a modular architecture where each component performs a specific function while maintaining smooth coordination with other modules. The implementation focuses on real-time processing, accuracy, and user-friendly interaction.

B. Frontend Development

The user interface is developed using React.js along with HTML, CSS, and JavaScript. This combination enables the creation of a responsive and dynamic interface that supports seamless user interaction. The frontend handles user inputs, displays outputs, and ensures smooth navigation across different modules such as learning, quiz, and resources.

C. Backend Development

The backend is built using Node.js and Express.js, which manage application logic and handle communication between the frontend and **the** database. RESTful APIs are used to process user requests, perform data operations, and return appropriate responses. This ensures efficient data flow and system reliability.

D. Speech Recognition Implementation

The system integrates the Web Speech API to capture and process voice input. It converts spoken language into text in real time, allowing users to interact naturally. The implementation supports different accents and speaking styles, improving accessibility and usability.

E. Grammar Conversion Module

This module processes the input text and restructures it according to Indian Sign Language grammar. It uses Natural Language Processing techniques to analyse sentence structure and generate meaningful ISL-based output. This step ensures that the translated content reflects proper linguistic format rather than direct translation.

F. Database Implementation

MongoDB is used to store all relevant data, including sign descriptions, instructional content, quiz data, and user interaction records. The database is designed with a flexible structure to allow quick retrieval and efficient data management.

G. Voice Instruction Module

The system uses text-to-speech technology to generate audio instructions. This module provides clear explanations of sign formation, including hand movements and positioning. The voice output acts as a guide, helping users understand how to perform each sign correctly

H. Quiz and Evaluation Module

An interactive quiz module is implemented to assess user understanding. It generates questions based on learned content, evaluates responses, and provides feedback.

I. Integration of Modules

All modules are connected through APIs to ensure smooth communication and data exchange. The system processes user input step-by-step, from input capture to output generation, without interruption. This integration ensures a consistent and efficient workflow.

J. System Testing and Execution

The implemented system is tested under different conditions to verify its performance and accuracy. It ensures proper functioning of all modules, quick response time, and error-free execution. The final system provides a reliable and effective learning experience.

V. ALGORITHM:

Inputs: User text input, User speech input (audio), ISL grammar rules, Sign database, User interaction history.

Outputs: Converted ISL grammatical text, Voice-based instructional guidance, Quiz results, Learning

feedback.
BEGIN
INITIALIZE Speech_Module, NLP_Module, TTS_Module, Database LOAD ISL_RULES, SIGN_DATA
READ user_input
IF user_input = speech THEN
audio ← CAPTURE_AUDIO()
text ← SPEECH_TO_TEXT(audio) ELSE
text ← user_input END IF
IF text = NULL OR text = "" THEN DISPLAY "Invalid Input" STOP
END IF
clean_text ← REMOVE_SPECIAL_CHARACTERS(text) clean_text ← REMOVE_EXTRA_SPACES(clean_text) normalized_text ← TO_LOWERCASE(clean_text)
tokens ← SPLIT(normalized_text) filtered_tokens ← EMPTY
FOR each token IN tokens DO
IF token NOT IN STOPWORDS THEN
ADD token TO filtered_tokens END IF
END FOR
keywords ← filtered_tokens
structure ← ANALYZE_STRUCTURE(keywords) isl_text ← CONVERT_TO_ISL(structure) sign_list ← EMPTY
FOR each word IN isl_text DO
IF word EXISTS IN SIGN_DATA THEN
sign ← FETCH(word) ELSE
sign ← SPELL_ALPHABETS(word) END IF
ADD sign TO sign_list END FOR
instruction_set ← EMPTY

FOR each sign IN sign_list DO
movement ← GET_MOVEMENT(sign) position ← GET_POSITION(sign) orientation ← GET_ORIENTATION(sign)
instruction ← COMBINE(movement, position, orientation) ADD instruction TO instruction_set
END FOR
voice_output ← TEXT_TO_SPEECH(instruction_set) DISPLAY isl_text
DISPLAY sign_list PLAY voice_output READ user_choice
IF user_choice = "quiz" THEN
questions ← GENERATE_QUESTIONS(sign_list) score ← 0
FOR each question IN questions DO response ← GET_RESPONSE()
IF response = correct_answer THEN score ← score + 1
END IF END FOR
DISPLAY score END IF
STORE user_input STORE isl_text STORE score READ next_action
IF next_action = "continue" THEN GO TO READ user_input
ELSE
EXIT END IF END

VI. RESULTS:

The Sign Language Learning Assistant was implemented successfully and performed efficiently across all modules. The system accurately converts speech and text input into ISL-structured output using

grammar adaptation. The voice instruction feature provides clear guidance, helping users understand sign formation easily. The interface is responsive and supports smooth interaction, while the quiz module effectively evaluates user learning. Overall, the system delivers a fast, reliable, and user-friendly platform for learning Indian Sign Language.

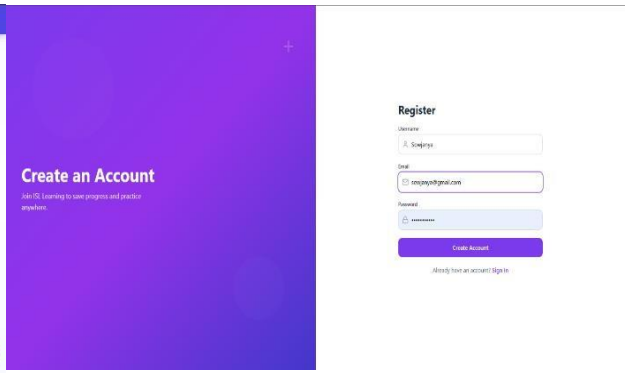
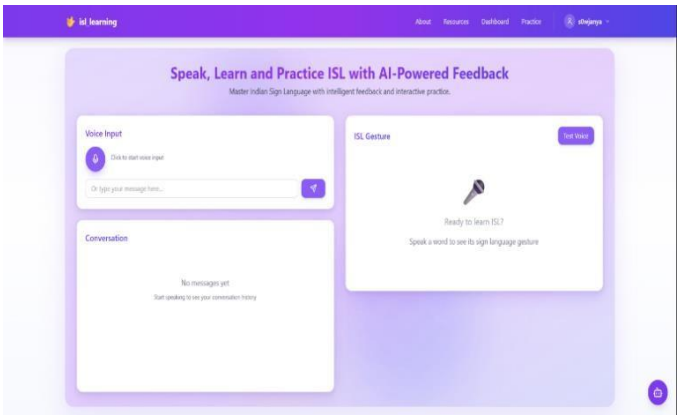


Fig 1: Sign Language Learning Assistant (Home Page) Fig 2: User Registration Interface



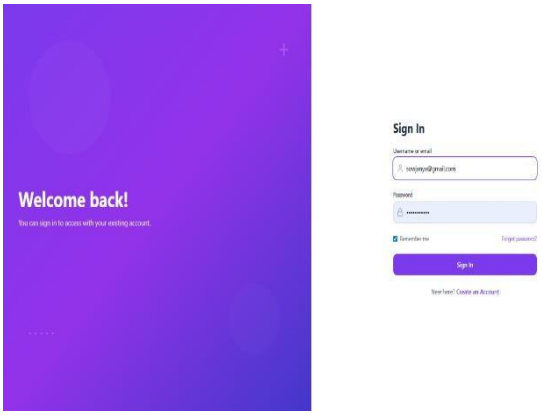
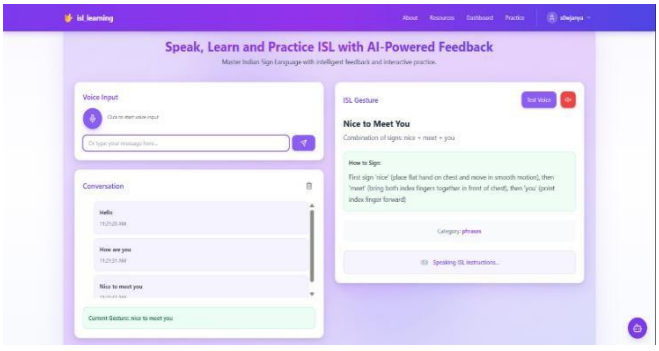


Fig 3: Sign Language Learning Assistant (Main Dashboard) Fig 4: User Login Interface



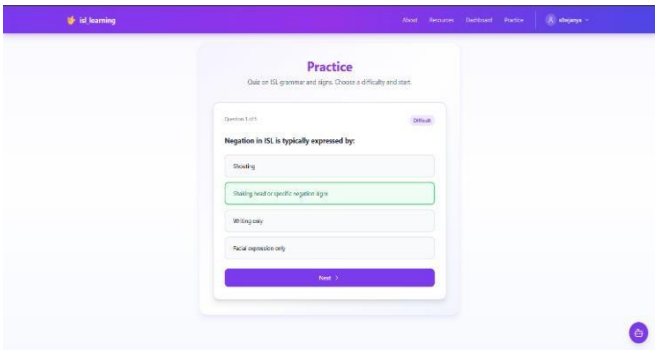


Fig 5: Input Processing and ISL Voice Instruction Output Fig 6: Quiz Module - Correct Answer Feedback

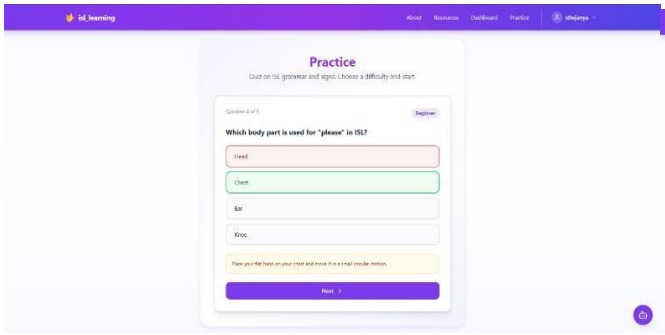


Fig 7: Quiz Module – Incorrect Answer Feedback

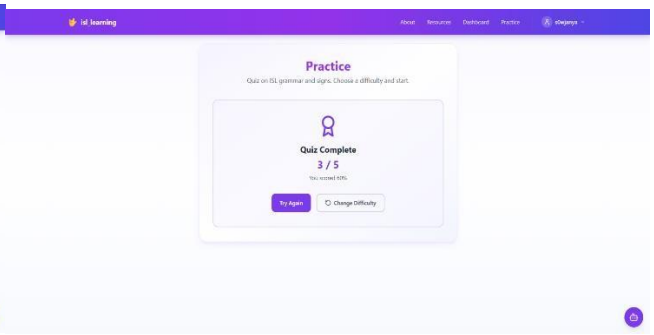


Fig 8: Quiz Results Screen

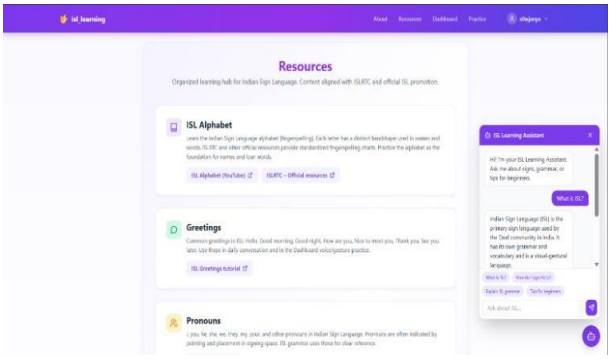


Fig 9: Resources Page with Chatbot Assistance

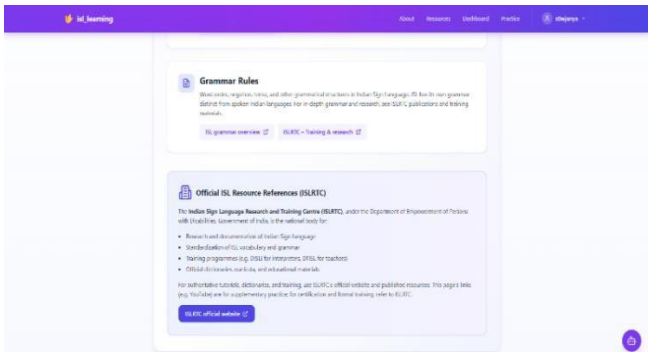


Fig 10: Resources Page with External Links

VII. DISCUSSION:

The results indicate that the proposed system significantly enhances the learning of Indian Sign Language through an interactive and intelligent approach. By converting user input into ISL grammatical structure and providing voice-based guidance, users can better understand and practice sign language effectively. The integration of speech recognition and natural language processing improves the overall learning experience. The system demonstrates improved accessibility and engagement by supporting both speech and text input
methods. Features such as quizzes and progress tracking further assist users in continuous learning and self- evaluation. However, challenges include the absence of visual gesture demonstrations and dependency on speech recognition accuracy, which may be affected by noise or pronunciation variations.

VIII. CONCLUSION:

The proposed system provides an effective solution for improving the learning of Indian Sign Language (ISL) through the use of modern technologies. By combining speech input, text processing, and intelligent language transformation, the system creates an interactive environment that makes learning more accessible and engaging. Unlike traditional methods, it allows users to interact naturally and receive clear guidance, which enhances understanding and confidence.The integration of voice-based instructions helps learners grasp the practical aspects of sign execution, including movement and positioning. In addition, features such as progress evaluation and learning resources support continuous practice and skill development. The modular design of the system ensures smooth operation and allows future enhancements to be easily incorporated.

Overall, the system contributes to reducing communication barriers by making ISL learning simpler and more efficient. It promotes inclusive communication by enabling more people to understand and use sign language effectively. This approach demonstrates how technology can be used to create meaningful solutions for real-world social challenges.

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