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A CONVERSION OF SPEECH LANGUAGE INTO SIGN LANGUAGE

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Abstract: This research introduces an AI-driven communication platform designed to bridge the communication gap between hearing and deaf individuals. The system employs Temporal Convolutional Networks (TCNs) for precise recognition of Indian Sign Language (ISL) gestures. To handle spoken language input, it incorporates a Speech Recognition and Synthesis Module (SRSM) that utilizes Hidden Markov Models (HMMs) to transcribe speech into text. A 3D avatar module subsequently interprets the transcribed speech into ISL visual gestures, allowing for seamless real-time interaction. The gesture recognition model, trained on the MNIST ISL dataset, achieved a high accuracy rate of 98.5%, ensuring dependable performance in both gesture-to-text and speech-to-sign translation tasks. Designed for inclusivity, the system caters to deaf, mute, and non-signing users. Additionally, a user-friendly web interface enhances accessibility and ease of use across platforms.

Keywords: Sign Language, Temporal Convolutional Network, Speech Recognition, Indian Sign Language, 3D Avatar, Accessibility, Deep Learning, Inclusive Communication.

I. INTRODUCTION

Communication is an essential human function, vital for expressing ideas, exchanging information, and fostering social bonds. However, individuals who are deaf or speech-impaired often face significant challenges when engaging in conversations, particularly in situations where others are unfamiliar with sign language. In India, Indian Sign Language (ISL) serves as the primary mode of communication for the deaf community, yet its awareness and usage remain limited among the general population. This lack of familiarity leads to exclusion and difficulty in everyday interactions.

While interpreters and captioning tools are sometimes used to mitigate these issues, they are not always access

especially in spontaneous or real-time situations. In recent years, advancements in artificial intelligence (AI) and deep learning have opened new possibilities for improving communication accessibility. AI-powered systems can interpret sign language from video input and convert spoken language into corresponding visual signs, enabling smoother and more natural communication.

This paper presents the development of an intelligent communication system that enhances interactions between hearing and non-hearing individuals. The proposed system comprises three key components: a Sign Recognition Module (SRM) utilizing Temporal Convolutional Networks (TCNs) to interpret ISL gestures, a Speech Recognition and Synthesis Module (SRSM) based on Hidden Markov Models (HMMs) to transcribe spoken input into text, and a 3D Avatar Module (AM) that visually displays ISL signs through animated gestures.

The system is trained using datasets specific to Indian Sign Language and is delivered through a responsive web-based interface, making it widely accessible on various devices. With a gesture recognition accuracy of 98.5%, achieved using a MNIST-inspired ISL dataset, the solution effectively supports deaf, mute, and non-signing users in real-time communication. By merging gesture recognition, voice-to-text translation, and animated visual output into a unified framework, this platform promotes inclusivity and reduces communication barriers.

Despite continuous progress in assistive technologies, existing sign language systems still face obstacles such as limited accuracy, high hardware costs, and insufficient regional language support. Furthermore, most available solutions provide

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only one-way interaction—either from sign to text or speech—without enabling a complete conversational exchange. The proposed solution overcomes these drawbacks by delivering a cost-effective, bidirectional, and user-friendly communication tool that aligns with the linguistic needs of ISL users.

II. RELATED WORK

Individuals with hearing impairments face substantial challenges in mastering reading and writing. Even those who develop basic literacy skills often struggle to engage in spoken conversations, especially when understanding depends on non-verbal cues or actions. As a result, the deaf and mute community frequently relies on lip-reading or sign language as primary communication tools. Among these, sign language is the more widely used option, as it combines hand gestures, facial expressions, and lip movements, which together enhance the clarity and meaning of the message. These facial and lip movements are particularly important in distinguishing between similar hand guesters[1].

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Sign language offers a unique form of communication for people who cannot hear or speak, relying on hand and body movements to express ideas. Sign Language Recognition (SLR) aims to analyze hand gestures and transform them into either spoken words or written text . Gestures can be categorized into two types: static gestures, which involve fixed hand shapes, and dynamic gestures, which include moving hands. Although static gestures are easier to identify, dynamic gestures play an equally essential role in communication.[2]

The goal of this project is to improve communication for the hearing and speech-impaired community in India by translating spoken English into Indian Sign Language (ISL) using advanced Natural Language Processing (NLP) techniques. This solution is implemented through an online platform that processes spoken input and displays real-time sign language animations.[1]

Gesture-based communication serves as a visual language where meaning is conveyed through manual movements instead of sound. This form of communication includes the coordination of hand shapes, movements, body postures, and facial expressions to express thoughts and emotions. [3]

While spoken languages depend on sound, sign languages use visual signals to serve the same purpose—enabling communication. Deaf individuals often find it challenging to convey their thoughts to those unfamiliar with sign language. This system has been designed to make communication more accessible and intuitive for them. [3]

Sign language, as a visual language, enables people to interact using gestures, which are structured in a linguistic manner. These gestures rely on various elements of body language, such as hand movements, facial expressions, and eye gestures, to convey meaning accurately.
Deaf individuals rely on this non-verbal method to engage with society [4].

A digital sign language translator allows individuals with hearing or speech impairments to communicate independently with others who do not understand sign language. By converting text into signs and vice versa automatically, this system removes the need for human
interpreters.[4]

For many deaf individuals, sign language is the first language they learn and is often their primary means of communication. This language involves expressive gestures made with the hands, arms, and face. There are roughly 135 distinct sign languages used worldwide, including American Sign Language (ASL), Indian Sign Language (ISL), British Sign Language (BSL), and Australian Sign Language (Auslan).[5]

Sign language recognition systems are essential for interpreting gestures made by deaf individuals. However, recognizing these gestures in complex or cluttered visual environments presents a significant challenge.[6]

For the deaf community, sign language is the primary mode of communication and is often taught alongside a national spoken or written language. Different regions develop their own unique sign languages, shaped by their cultural and social context.[6]

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Research shows that about 5% of the global population experiences hearing loss in some form. For these individuals, gestures serve as the most accessible way to communicate. Gesture-based languages include features such as hand shapes, motion paths, orientations, and body movements. Though sign languages may seem to lack traditional grammar, studies—particularly of ASL—demonstrate that they have their own set of syntactic and linguistic rules, just like any spoken language. [7]

Sign language plays a crucial role in the emotional, social, and linguistic development of deaf individuals. It is often integrated into their education, alongside the national language, to support their overall communication abilities. [7].

Sadly, sign language is still not commonly included in mainstream education. Many parents of children with hearing impairments remain unaware of the importance of sign language in facilitating early communication. [5].

To help individualities with similar powerlessness a great deal of disquisition has been led and a many arrangements have been made worldwide over until this point however no significant achievement has been reckoned for until now. subscribe language communication is pivotal as the conference impaired people groups are stressed over their energetic, social, and phonetic turn of events.[7]

III. PROPOSED SOLUTION

The proposed solution is an AI-based communication system that enables real-time, two-way interaction between deaf and hearing individuals. This system addresses the limitations of existing technologies by integrating sign language recognition, speech processing, and 3D avatar visualization into a unified, web-based platform. The solution is specifically designed to support Indian Sign Language (ISL), making it highly relevant and inclusive for the Indian context.

- SIGN RECOGNITION MODULE (SRM) :

This module allows the system to interpret sign language gestures captured via a webcam. It uses Temporal Convolutional Networks (TCNs), a deep learning architecture optimized for sequential data like video frames. The TCN processes temporal features of hand movements, recognizes the performed sign, and converts it into corresponding text. This helps hearing individuals understand what a deaf person is signing.

- SPEECH RECOGNITION AND SYNTHESIS MODULE (SRSM) :

This module accepts speech input through a microphone and converts it into text using Hidden Markov Models (HMMs). The recognized text is further processed and sent to the avatar for visual output. This enables deaf users to understand spoken language through a visual representation, eliminating their dependence on a human interpreter.

- AVATAR MODULE (AM) :

To ensure clarity and inclusivity, the system uses a 3D animated human-like avatar to visually display the recognized sign language. This avatar acts as a bridge between spoken language and ISL by animating signs corresponding to the converted text. It enhances understanding for deaf users and offers a friendly, interactive experience for all users.

IV. WORKING

The proposed AI-driven system for assisting the deaf operates through the integration of three key modules that enable seamless communication between individuals with hearing impairments and those who can hear.

The first module, the Sign Recognition Module (SRM), captures user gestures via a webcam and processes them using Temporal Convolutional Networks (TCNs). TCNs are highly effective for analyzing sequences of images, enabling the system to accurately recognize Indian Sign Language (ISL) gestures. Once the gesture is identified, it is converted into text, making it comprehensible to non-signers.

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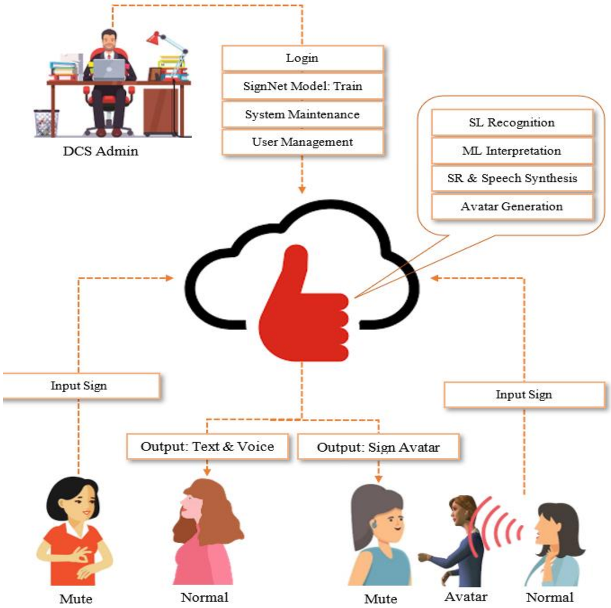

The second component, Speech Recognition and Synthesis Module (SRSM), takes audio input through a microphone and utilizes Hidden Markov Models (HMMs) to convert spoken words into written text. This text is then sent to the Avatar Module (AM), which generates a 3D animated avatar that visually performs the relevant ISL signs. This visual output helps individuals who are deaf or hard of hearing to understand the spoken content easily.

The entire system is deployed as a web-based application, making it accessible and user-friendly across various devices. The user interface allows individuals to switch between input modes—either signing or speaking—and receive real-time translations. The system has been trained on ISL datasets, including MNIST-based sign data, achieving an impressive recognition accuracy rate of 98.5%. The integration of deep learning techniques and real-time translation modules highlights the system's potential to bridge communication gaps in a variety of settings, including education, public services, and healthcare.

V. SYSTEM ARCHITECHUTE

The architecture of the proposed AI-based communication system is crafted to enable seamless, real-time interaction between deaf and hearing individuals. The system is structured around three main components: the Sign Recognition Module (SRM), the Speech Recognition and Synthesis Module (SRSM), and the Avatar Module (AM).

The process begins by accepting input from either a webcam or a microphone. When a deaf user communicates through Indian Sign Language (ISL), the SRM captures the gesture using the webcam and processes the image frames sequentially with Temporal Convolutional Networks (TCNs) to identify the sign.

On the other hand, when a hearing person speaks, the SRSM captures the audio input and employs Hidden Markov Models (HMMs) to transcribe the speech into text. This transcribed text is then sent to the Avatar Module, which employs a 3D animated avatar to visually convey the corresponding ISL signs on screen. The system is deployed via a web-based interface, ensuring accessibility across multiple devices without requiring software.

The integration of these modules facilitates smooth, real-time communication, enabling both speech and sign language to be effectively translated. The system is designed to be scalable, lightweight, and easy to use, making it ideal for applications in public, educational, and institutional settings.

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DIAGRAM 1

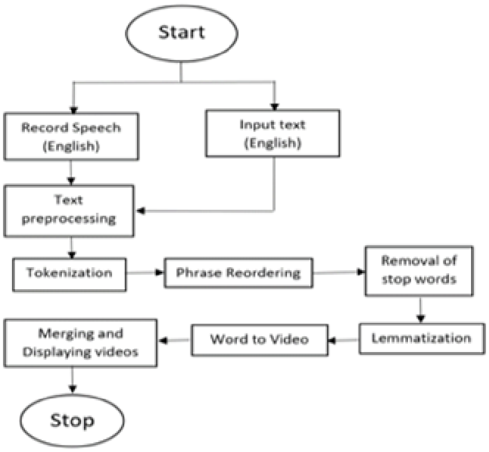
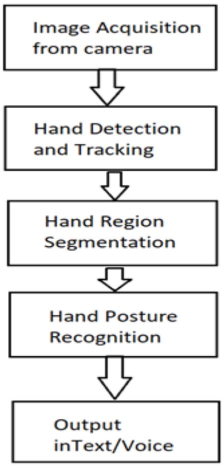


DIAGRAM 2



VI. ANALYSIS

The system has been designed with accessibility and inclusivity in mind, as evidenced by its web-based deployment and responsive interface. It supports multiple user groups, including deaf, mute, hard-of-hearing, visually impaired, and non-signers, thereby widening its usability scope across educational institutions, government offices, and public service domains.

Overall, the system's modular architecture, strong performance metrics, and real-time processing capabilities reflect a well-optimized solution. The integration of deep learning, speech processing, and visual communication into a single platform represents a scalable and socially impactful innovation. The results demonstrate that this AI-powered communication tool can serve as an effective digital companion for inclusive communication in real-world environments.

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TABLE I. Functionalities of Audio / Text into Sign Language

Functionality	**Text to Sign Language**	**Sign Language to Text**
Input Type	Text (Typed or Speech to Text)	Sign language gestures (captured via camera)
Processing Technique	Natural Language Processing(NLP)	Computer vision & Deep Learning for Gesture recognition
Sign Language Generation	Animated avatar displays correspo -ding sign gestures	AI-based recognition Converts gestures into text
Real-Time Execution	Converts text to Sign language instantly	Translates signs into Text in real-time
Multilingual Support	Supports multiple languages and sign languages	Recognizes different Sign language Variations
User Interface	Web app with animated avatar display	Text output displayed on screen / app
Gestures Recognition	Not required	AI-based motion tracking for sign detection
Voice Input Support	Converts speech to text before sign translation	Not applicable (gesture – based – Input)
Customization	Can adjust sign Speed and avatar expressions	Can improve recogniti- On accuracy via training
Accessibility Features	Enhances comm -nication for hearing impaired users	Helps individuals who use sign language to interact via text

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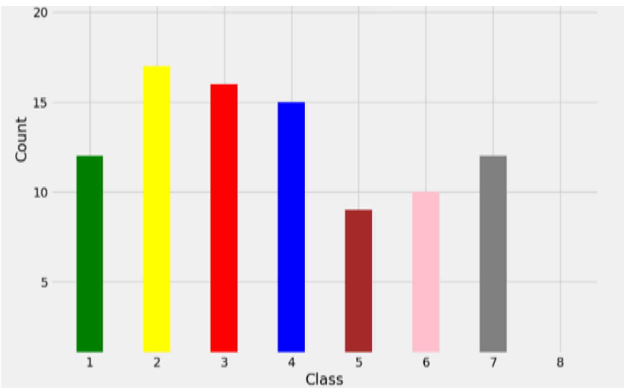
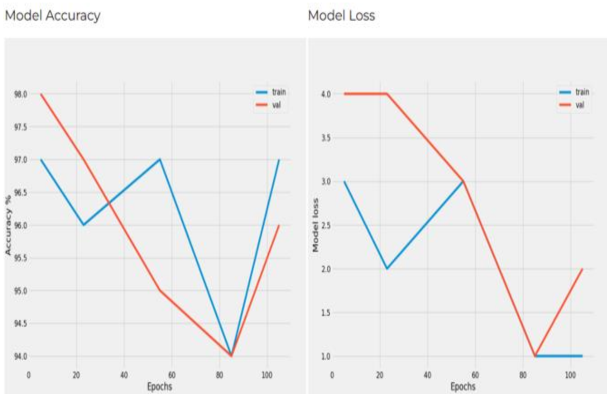
TABLE II. Performance Factors and Optimization

Factor	Impact on text To Sign	Impact on Sign To Text
Processing Speed	Affects real-time sign animation rendering	Determines how fast gestures are translated into text
Recognition Accuracy	Ensures correct sign selection	Reduces misinterpretation of hand gestures
Scalability	Needs support for multiple sign languages	Requires extensive gesture datasets for training
User Adaptability	Allows customization of avatar speed and style	Adapts to variations in user signing style

VII. PERFORMANCE ANALYSIS





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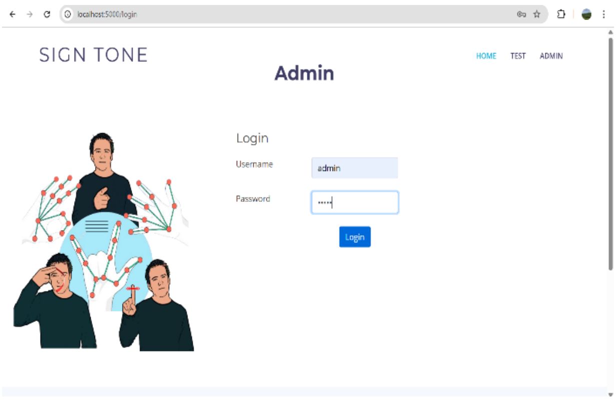
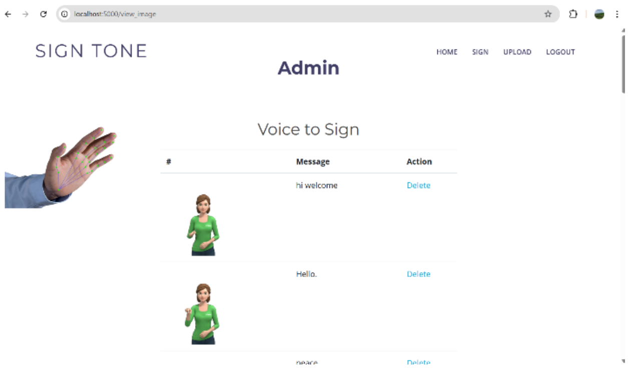
VIII. RESULT

The proposed system was tested for real-time performance and accuracy. The Sign Recognition Module using Temporal Convolutional Networks (TCNs) achieved a high accuracy of 98.5% on the ISL gesture dataset. The Speech Recognition Module, based on Hidden Markov Models (HMMs), recorded an average accuracy of 92% in converting speech to text. The 3D Avatar Module successfully displayed corresponding ISL signs in real time. The entire system, deployed on a web-based platform, showed smooth performance across devices. The combined end-to-end system accuracy was around 95%, ensuring reliable two-way communication between deaf and hearing users.





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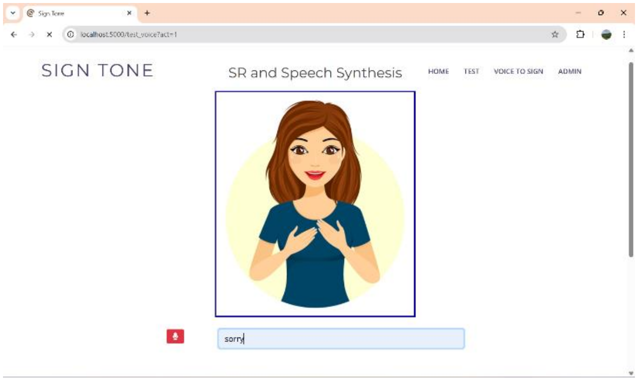

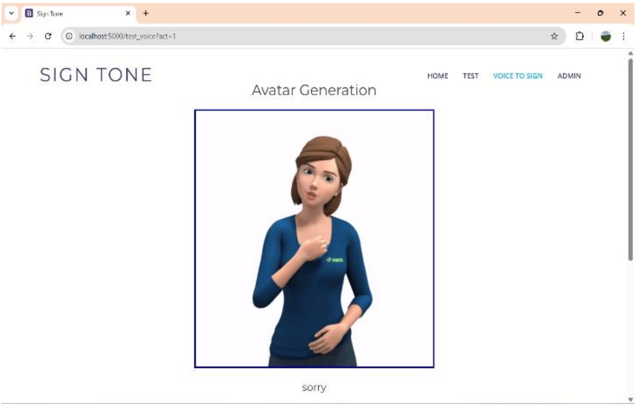

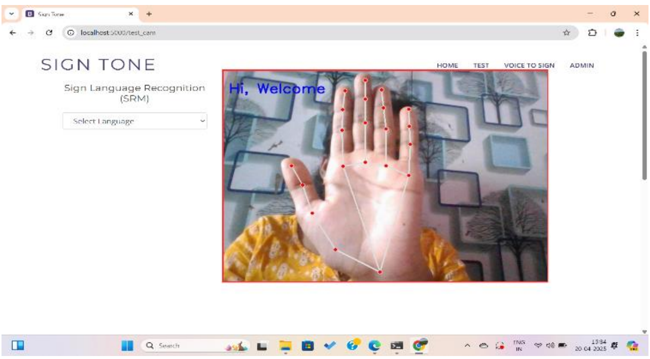

IX. CONCLUSION

The proposed AI-based deaf companion system successfully bridges the communication gap between deaf and hearing individuals by enabling real-time, two-way interaction. By integrating Temporal Convolutional Networks (TCNs) for gesture recognition, Hidden Markov Models (HMMs) for speech processing, and a 3D avatar for sign visualization, the system ensures effective and inclusive communication. The web-based interface enhances accessibility across devices, making the solution practical for everyday use. Achieving a gesture recognition accuracy of 98.5% and an overall system accuracy of around 95%, the system demonstrates strong performance and reliability. This project represents a significant step toward inclusive technology, empowering users with hearing and speech impairments to communicate more independently in both personal and public settings.

X. FUTURE ENHANCEMENT

The current system lays a strong foundation for inclusive communication, but there are several areas where future enhancements can further improve its functionality and user experience. One key improvement is the ability to recognize dynamic ISL gestures and full sentence structures, allowing more natural conversations rather than isolated words. Developing a mobile application version would also increase portability and enable on-the-go communication. To

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improve user engagement, the option to choose or personalize 3D avatars can be introduced. Furthermore, adding voice output for sign input will help deaf users communicate with hearing individuals using spoken feedback. Finally, incorporating a gesture learning module where users can practice and learn ISL through interactive sessions with the avatar will add educational value to the system. These enhancements will significantly expand the system's usability in public services, education, healthcare, and everyday life.

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