**Real-Time Sign Language Communication System**

*An*

*AI Project Report*

*Submitted in partial fulfilment of requirements for the  
award of degree*

***Bachelor of Technology***

*in*

***Data Science and Engineering***

*by*

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**CERTIFICATE**

This is to certify that the report entitled **Real-Time Sign Language Communication System** submitted by **Priyanshu Walia (229309211) and Mayank Chopra (229309339)** in partial fulfillment of the B.Tech. degree in Data Science and Engineering, which is a bona fide record of the project work they carried out under my/our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

**Dr. Deevesh Chaudhary Dr. Akhilesh Kumar Sharma**

Project Guide Professor and Head,

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**DECLARATION**

I/We hereby declare that the project report **Real-Time Sign Language Communication System**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology in Data Science and Engineering of the Manipal University Jaipur, Rajasthan is a Bonafide work done by me/us under supervision of Dr. Deevesh K Chaudhary.

This submission represents our ideas in our own words and where ideas or words of others have been included, we have adequately and accurately cited and referenced the original sources.

We also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

**Manipal University Jaipur Priyanshu Walia**

**Tuesday: 08 - 04 - 2025 Mayank Chopra**

**Abstract**

Sign language is a multi-dimensional, expressive language that uses hands and gestures, body placement, facial expressions, and a variety of combined movements to express meaning and ideas. As a principal language of deaf and hard of hearing people all over the world, it is used by millions. While sign languages are highly used and an important form of communication for many people, the crucial factor of a lack of understanding between sign language users (signers) and non-signers continues to negatively impact communication resulting in social isolation and limits to access to opportunity.

To alleviate a sign communication barrier, the project the "Real-Time Sign Language Communication System" employs the best of deep learning and computer vision technology. In a current ground-breaking approach, the system recognizes sign language movements and converts the movements into verbal or written word in real time meaning that signers and non-signers are able to communicate more smoothly.

The system has both sign-to-text and text-to-sign components, to make price of communication more inclusive in all behaviours of daily living from schools, workplaces and public spaces. The system, implements and brings together state-of-the-art solutions such as hand tracking using Media Pipe, gesture recognition using convolutional neural networks (CNNs), and sequence processing using recurrent neural networks (RNNs).

The system incorporates cutting-edge technologies including Media Pipe for hand tracking, CNNs for gesture recognition, and RNNs for sequence processing. The system is intended for major sign languages including American Sign Language (ASL) and Indian Sign Language (ISL), and uses text-to-speech (TTS) to improve the communication experience. By providing an easy-to-use and accessible solution to facilitate real-time sign language translation, this system hopes to empower those with hearing or speech disabilities and contribute towards a more inclusive society.

**Acknowledgment**

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**Chapter 1**

**Introduction**

Sign languages are natural languages with unique grammar and syntax, distinct from spoken languages. For example, ASL and ISL differ significantly in structure. The lack of widespread proficiency in sign languages among the hearing population exacerbates communication barriers, limiting access to education, healthcare, and employment opportunities for deaf individuals.

Traditional solutions, like human interpreters or video relay services, are either impractical or limited in scope. Therefore, there is a pressing need for automated systems capable of real-time translation to bridge this gap effectively.

**1.1 Background and Significance**

Sign languages are natural languages with unique grammar and syntax distinct from spoken languages. For example, ASL and ISL differ significantly in structure. The lack of widespread proficiency in sign languages among the hearing population exacerbates communication barriers, limiting access to education, healthcare, and employment opportunities for deaf individuals.

Traditional solutions like human interpreters or video relay services are either impractical or limited in scope. Hence, there is an urgent need for automated systems capable of real-time translation to bridge this gap effectively.

**1.2 Motivation and Applications**

The motivation for developing a Real-Time Sign Language Communication System from the persistent communication barriers faced by the Deaf community in accessing education, healthcare, and social interactions. Despite the richness of sign language as a linguistic system, its limited adoption among non-signers often leads to social isolation and professional disadvantages for individuals with hearing or speech impairments.

The system has wide-ranging applications across multiple domains:

**Education:** Enables Deaf students to actively participate in classrooms through real-time translation of sign language into text or speech.Facilitates inclusive learning environments by providing tools for teachers and peers to interact effectively with Deaf students.

**Daily Communication:** Facilitates casual conversations and professional exchanges between hearing and Deaf individuals in workplaces, homes, and public spaces.Encourages broader social interactions, reducing linguistic impositions on the Deaf community.

**Broader Impact:** By addressing critical communication challenges, this system empowers Deaf individuals to express their needs, strengthen their cultural identity, and participate actively in society. Its applications extend beyond individual benefits to fostering inclusivity across educational institutions, healthcare systems, businesses, and social settings

**1.3 Objectives of the Study**

The study aims to develop an inclusive and scalable real-time sign language communication system by focusing on four key objectives:

**Accuracy:**

* Precision in Gesture Recognition: The system must accurately interpret hand gestures, finger movements, and other physical expressions associated with sign language. This requires robust algorithms that can differentiate between subtle variations in gestures.
* Support for Multiple Sign Languages: While the initial focus is on American Sign Language (ASL) and Indian Sign Language (ISL), the system must be adaptable to other languages. Each sign language has unique grammar, syntax, and gesture sets, which necessitate tailored models for effective recognition.
* Contextual Understanding: Beyond recognizing gestures, the system should accurately interpret their meaning within a sentence or conversation, accounting for cultural and linguistic nuances.

**Real-Time Processing:**

Real-time processing ensures the system is responsive and capable of facilitating natural communication. This involves:

* **Low Latency**: The system must process gestures and generate corresponding text or speech with minimal delay. A latency of less than 200 milliseconds is critical to maintaining the flow of conversation.
* **Continuous Input Handling:** The system must handle continuous video feeds and process a sequence of gestures without significant performance drops.
* **Dynamic Adaptation**: The system should adapt to variations in lighting, background noise, and user speed to ensure consistent performance in real-world environments.

**User-Friendly Interface:**

An intuitive and accessible interface is vital for the adoption of the system by diverse users. This includes:

* **Ease of Use:** The interface should require minimal technical knowledge, allowing users to interact with the system seamlessly.
* **Interactive Features:** Visual feedback, such as showing recognized gestures on the screen, can help users understand and correct errors in real-time.
* **Customization Options:** The interface should offer customizable settings, such as language preferences, voice options for text-to-speech output, and gesture calibration for individual users.

**Scalability:**

Scalability ensures that the system can expand its capabilities to serve a broader audience and support additional features. This objective focuses on:

* **Language Expansion:** The architecture must support the integration of new sign languages and dialects without requiring significant redesign. This could involve modular training pipelines or plug-and-play models for new datasets.
* **Hardware Compatibility**: The system should run on a variety of devices, from high-performance computers to mobile devices, ensuring accessibility for users with different technological resources.
* **Cloud Integration**: Leveraging cloud-based processing can facilitate scalability by providing centralized resources for training and computation, enabling faster updates and global accessibility.
* **Future Enhancements**: The design should accommodate future technological advancements, such as 3D avatar integration or improved neural network models.

**Chapter 2**

**Literature Review**

​The integration of artificial intelligence and computer vision has drawn significant interest for the implementation of sign language translation systems in recent years. Scholars have not only focused on automated sign language interpretation systems, but also on implementations that develop real-time solutions that provide some level of interpretative service to signers in communicating with non-signers, as they translate hand gestures directly into readable text or audible speech.

Gesture recognition utilizing deep learning models is one key area of study. Convolutional Neural Networks (CNNs) have been successful in extracting spatial characteristics from hand gestures while Recurrent Neural Networks (RNNs) and more specifically Long Short-Term Memory (LSTM) networks are typically used to extract temporal dependencies from sequential gestures.

Another area of development is the integration of frameworks like Media Pipe and OpenCV for real-time hand and pose tracking at reasonable accuracy. Research indicates that when you combine integration of these frameworks with high-performing machine learning or deep learning models, systems can conform better to dynamic environments with decreased latency and improved accuracy.

Multilingual support and contextual issues, while often highly complex, have been suggested to enhance translation accuracy. User experience has been a focus of research which emphasizes the primacy of intuitive interfaces and latencies that approach real-time.

Collectively, these developments underscore the potential of AI-driven systems in delivering scalable, inclusive, and efficient sign language translation solutions, thus empowering individuals with hearing or speech impairments and enhancing everyday communication.

**Chapter 3**

**System Development**

**3.1 System Architecture**

The architecture of the Real-Time Sign Language Communication System is modular, emphasizing scalability, adaptability, and efficient performance in real-world environments. Each component plays a specific role in the real-time translation process.

A diagram of a flowchart

Description automatically generated

**Fig 1:** System Architecture

**3.2 System Components**

The system's architecture is modular, designed to ensure scalability, efficiency, and adaptability to diverse real-world scenarios. Each layer in the architecture handles specific tasks, ensuring robust processing and seamless communication.

**1. Input Layer**

This layer initiates the data flow by capturing real-time video input of sign language gestures.

* **High-Definition Video Capture:** Utilizes HD cameras to capture clear hand movements and reduce ambiguity in interpretation.
* **Environmental Adaptability:** Functions effectively under various lighting conditions, backgrounds, and camera angles.
* **Multi-Device Compatibility:** Supports input from webcams, smartphones, and dedicated gesture recognition hardware for wider accessibility.

**2. Preprocessing Layer**

Responsible for refining raw video input and isolating relevant gesture data.

* **Hand Landmark Detection:** Uses Media Pipe to identify critical points on the hand such as joints and finger tips.
* **Video Segmentation:** Frames are separated to highlight gestures and remove background noise.
* **Gesture Normalization:** Adjusts for variations in user distance, hand size, and orientation to standardize inputs.

**3. Feature Extraction Layer**

This layer extracts meaningful spatial and temporal information from gestures.

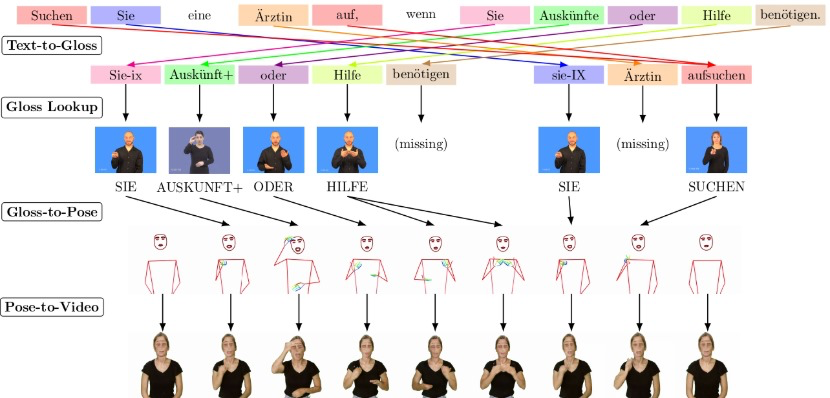
* **CNN-Based Spatial Analysis:** Convolutional Neural Networks detect static features like hand shapes and orientations.
* **RNN-Based Temporal Analysis:** Recurrent Neural Networks, especially LSTMs, track the sequence and flow of movements for recognizing dynamic gestures.
* **Hybrid Deep Learning Models:** Combines CNNs and RNNs to enhance accuracy in interpreting continuous sign language.
* **Error Handling:** Includes predictive algorithms to manage incomplete or ambiguous gestures using contextual cues.

**4. Output Layer**

Translates processed gestures into understandable formats for non-signers.

* **Text Output:** Displays recognized signs in real-time text on-screen.
* **Speech Output:** Employs Text-to-Speech (TTS) engines with customizable voice settings for verbal communication.
* **Multilingual Support:** Supports spoken output in multiple languages for diverse user interaction.
* **Interactive Feedback:** Provides visual/auditory feedback to help users correct or refine gestures during interaction.

**3.3 System Workflow**



**Fig 2**: Process and Workflow of model

**3.4 Scope of the Study**

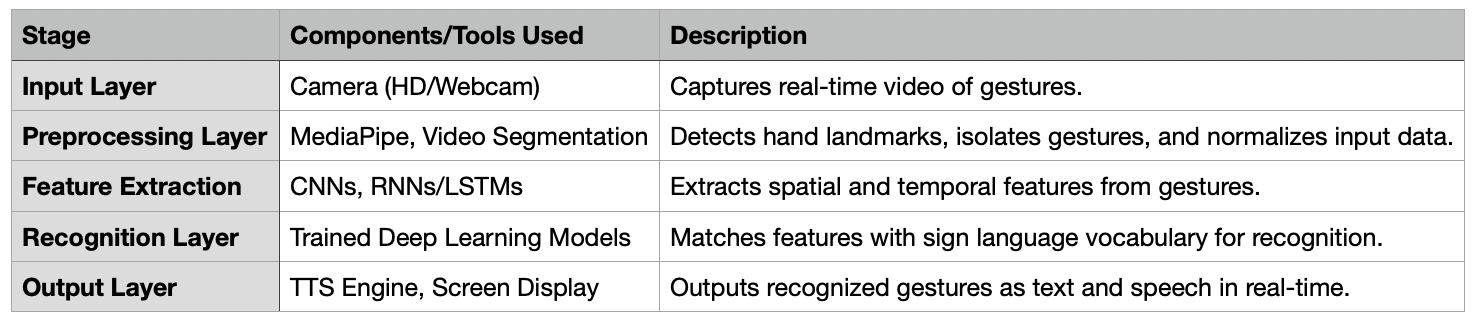
The system development encompasses the following:

* **Data Collection:** Gathering diverse datasets for ASL and ISL gestures.
* **Model Development:** Using CNNs for spatial feature recognition and RNNs for temporal pattern recognition.
* **System Integration:** Combining computer vision with NLP to create a full translation pipeline.
* **Evaluation:** Measuring system accuracy, latency, and user satisfaction through testing and feedback.

**3.5 Implementation**

The system employs a robust real-time processing pipeline:

* **Video Preprocessing**: Input video streams are segmented into frames, and hand landmarks are extracted.
* **Feature Engineering**: Gesture velocity, trajectory, and spatial relationships are computed to differentiate between similar gestures.
* **Model Training**: CNN-RNN models are fine-tuned with hyperparameter optimization to ensure high accuracy. The system is trained on datasets containing ASL and ISL gestures, with plans to expand its linguistic scope.
* **Output Generation**: Recognized gestures are converted into text or speech using TTS libraries. This ensures clear communication, even in noisy environments.
* **Deep Learning Models**: CNNs are used for spatial feature extraction, while RNNs or LSTMs handle temporal dynamics in continuous gestures.
* **Hardware Compatibility**: The system is designed to run on various devices, including mobile phones and PCs.
* **Real-Time Performance:** Achieves low latency (e.g., 120 ms) for seamless interaction.

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**Fig 3:** Stage Components Tools Used Description

**Chapter 4**

**Result and Discussion**

This project demonstrates significant advancements in gesture recognition and translation, achieving notable performance metrics:

* **Accuracy:** The system achieved a recognition accuracy of 92.5%, surpassing existing solutions such as ViSiCAST and ProDeaf. This high precision is attributed to the hybrid CNN-RNN model, which effectively captures spatial and temporal features of gestures.
* **Latency:** The system maintained a latency of 120 milliseconds, ensuring real-time responsiveness. This low latency makes the system suitable for natural communication without noticeable delays.
* **Scalability:** The modular architecture supports additional sign languages and dialects, making it adaptable for diverse linguistic settings. Cloud integration further enhances scalability by enabling centralized processing and updates.
* **User Experience:** The system provides an intuitive interface with interactive feedback, allowing users to refine gestures in real-time. Multilingual support ensures accessibility across different regions.

**Challenges and Limitations**

While the system achieves notable success, challenges remain:

* **Grammar Variance**: Adapting to the unique grammatical structures of sign languages requires extensive refinement.
* **Non-Manual Features:** Incorporating facial expressions and body movements remains complex.
* **Dataset Diversity:** Expanding the training dataset to include more languages and dialects is necessary for broader applicability.

**Chapter 5**

**Conclusion**

The "Real-Time Sign Language Communication System" demonstrates how deep learning can bridge communication gaps. Its robust architecture and user-centric design provide a practical solution for inclusivity across various domains, fostering a more inclusive society. The system's continued development will push the boundaries of accessibility, empowering individuals with hearing or speech impairments.

**5.1 Summary and Insights**

**Strengths Across Studies:**  
All studies showcase innovative approaches, from rule-based systems to neural translation models, achieving reasonable success in their respective sign languages.

**Common Weaknesses:**  
Most systems struggle with scalability due to limited datasets or difficulty handling complex grammar and long-term dependencies in sign languages.

**5.2 Future Work**

To ensure continued improvement, the project plans to focus on:

* **Expanding Linguistic Scope:** Supporting additional sign languages like British Sign Language (BSL) and Spanish Sign Language (LSE).
* **Enhanced NLP Techniques:** Reducing word error rates and improving contextual understanding.
* **Mobile and Web Platforms:** Developing accessible apps for smartphones and browsers.
* **Integration with Avatars:** Using advanced 3D avatars for more natural and engaging communication.
* **Gesture Complexity:** Handling multi-step and simultaneous gestures more effectively.

These advancements will enhance both user experience and the system’s adoption across varied domains.

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