

Hand Gesture Recognition for Indian Sign Language Communication

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Abstract: *Effective communication between people with hearing impairments and the wider population continues to pose challenges in education, work, and daily life. Indian Sign Language (ISL) serves as a crucial communication tool for individuals with hearing and speech difficulties in India. This study proposes an automated system for recognizing ISL gestures, utilizing computer vision and machine learning techniques to translate hand movements into text or speech in real time.*

The system captures gestures through a camera and applies preprocessing steps such as background subtraction, hand detection, and feature extraction to accurately interpret hand movements. A Convolutional Neural Network (CNN) is trained on a dataset of ISL signs to classify gestures with high precision. In addition, the system can process dynamic gestures, which involve a sequence of movements, enabling comprehensive recognition of complex signs.

By converting recognized gestures into text and speech instantly, the system provides a real-time interface that enhances communication for hearing-impaired individuals in educational, social, and professional settings. Experiments demonstrate that the system performs reliably under varying lighting conditions, hand orientations, and backgrounds. Overall, this work contributes to greater accessibility and inclusivity for the hearing-impaired community in India.

Keywords: Indian Sign Language, Gesture Recognition, Machine Learning, Convolutional Neural Networks, Real-Time Translation, Accessibility

I. INTRODUCTION

Communication plays a vital role in human life, influencing learning, social interaction, and professional activities. For individuals with hearing and speech impairments, expressing themselves and connecting with others can be challenging. In India, Indian Sign Language (ISL) is the main form of communication for this group. However, because most people are not familiar with ISL, hearing-impaired individuals often face difficulties in education, healthcare, workplaces, and daily life.

Recent developments in artificial intelligence, machine learning, and computer vision have made it possible to reduce these barriers. Indian Sign Language Recognition (ISLR) systems are designed to capture hand gestures and translate them into text or speech in real time. Such systems rely on cameras or sensors to record gestures, which are then processed using techniques like hand segmentation, background removal, and feature extraction to highlight important details. Machine learning models, particularly Convolutional Neural Networks (CNNs), are trained to recognize gestures accurately. Dynamic gestures, which involve motion over time, are also analyzed, enabling the system to interpret complex sign sequences.



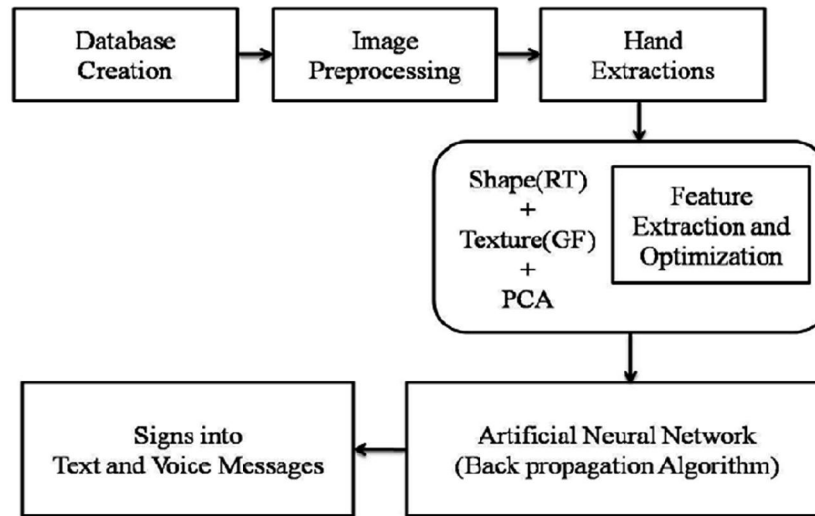


Fig1. System architecture of Hand Gesture Recognition for Indian Sign Language Communication

Creating a reliable ISLR system presents several challenges. Differences in hand size, shape, orientation, and movement speed can affect recognition accuracy. Environmental conditions such as lighting, background clutter, and occlusions can further complicate the process. Additionally, analyzing dynamic gestures requires more computation. Therefore, the system must balance accuracy, speed, and real-time performance.

The goal of this research is to develop a system that allows hearing-impaired individuals to communicate easily with people who do not know ISL. This system can be used in schools, workplaces, public spaces, and social environments, promoting independence and inclusion. By converting gestures into text and speech, the system helps overcome communication barriers and improves accessibility for the hearing-impaired community in India.

In conclusion, this study focuses on building a real-time, intelligent, and reliable ISLR system using computer vision and machine learning. The work aims to advance assistive technology while empowering hearing-impaired individuals to communicate effectively in both social and professional settings.

System Architecture of Hand Gesture Recognition for ISL

1. Dataset Creation:

A collection of hand gesture images is compiled to create a dataset for training and testing the system.

2. Image Preprocessing:

Images are enhanced by removing noise, improving clarity, and standardizing size and format for consistent processing.

3. Hand Segmentation:

The system isolates the hand region from each image to focus on the gesture and remove unnecessary background.

4. Feature Extraction and Optimization:

Key gesture attributes, such as shape and texture, are extracted. Principal Component Analysis (PCA) is used to reduce feature size for efficient processing.

5. Artificial Neural Network (ANN) Classification:

The optimized features are fed into an ANN, which uses backpropagation to accurately classify gestures.



6. Gesture-to-Text and Speech Conversion:

Recognized gestures are translated into text and synthesized speech, allowing sign language to be communicated in an understandable form.

II. LITERATURE SURVEY

[1]. Anuja V. Nair & Bindu V. developed a system for recognizing both static and dynamic Indian Sign Language gestures using image processing and machine learning techniques. The system captures hand gestures through a camera and extracts features such as hand shape, contour, and edges for classification. Its main aim is to provide a real-time communication tool for hearing-impaired users. The implementation used Python libraries, SVM classifiers, and webcam integration. Experimental results showed high accuracy for static gestures, making it suitable for educational and assistive communication purposes.

[2]. H.K. Vashisth et al. proposed a hybrid CNN-LSTM system to recognize both static and dynamic ISL gestures in real time. CNN was used for extracting spatial features from hand images, while LSTM captured temporal information for continuous gestures. The system was designed to enhance recognition accuracy and processing efficiency compared to conventional methods. It was implemented using Python, TensorFlow, and real-time camera input. The findings demonstrated consistent performance for dynamic gestures, indicating applicability in assistive communication.

[3]. U. Rastogi et al. presented a dynamic gesture recognition system for ISL that considers variations in hand shape, orientation, and skin tone. The system combines feature extraction methods with machine learning classifiers to improve recognition accuracy. Its primary objective is to translate gestures into text in real time. Using hand segmentation, classifier algorithms, and video processing modules, the system showed improved performance across diverse users and varying lighting conditions.

[4]. Poornima B.V. & Srinath S. proposed a vision-based ISL recognition system that employs digital image processing and machine learning algorithms such as SVM and Random Forest. The system focuses on recognizing static hand gestures efficiently to support hearing-impaired communication. Image preprocessing, feature extraction, and classifier modules were used. The results highlighted high accuracy for static gestures and demonstrated the importance of preprocessing in gesture recognition.

[5]. Kumar & Roy developed an ISL recognition system based on Bayesian classifiers that integrates hand gestures and facial expressions to provide better contextual understanding. The system is designed to improve translation accuracy for both static and dynamic gestures, enabling real-time communication. Using feature extraction, Bayesian classifiers, and gesture mapping tools, the system achieved high recognition rates and reliable performance.

[6]. Rastogi & Sharma presented a CNN-based approach for recognizing dynamic ISL gestures across multiple frames. The system preprocesses video frames, extracts features using CNN, and classifies gestures into text outputs. Its main goal is to provide real-time interpretation of continuous ISL signs. Implemented with Python, OpenCV, and TensorFlow, the system showed high accuracy and consistent performance across multiple users.

[7]. Jiang & Sun proposed a multi-modal ISL recognition system that combines hand gestures with skeletal body features to enhance recognition of complex dynamic gestures. The system integrates multiple sources of information to improve accuracy for gestures involving motion sequences. Using depth sensors, skeletal tracking algorithms, and machine learning classifiers, the system demonstrated significant improvement over single-modal systems.

[8]. Meng & Li introduced an attention-based Graph Convolutional Network (GCN) for ISL gesture recognition. The system focuses on key movement features in dynamic gestures and captures temporal dependencies to improve real-time translation. Using deep learning frameworks, GCN layers, and video processing modules, the system achieved high accuracy for complex gestures.

[9]. Singhal & Gupta developed a real-time ISL recognition system using RGB cameras and CNN classifiers. The system converts hand gestures into text or speech to support communication for hearing-impaired users. Using image preprocessing, CNN feature extraction, and classifier models, the system achieved high generalization across different users and hand orientations.

[10]. Mariappan & Kumar proposed a system for static ISL gesture recognition using Histogram of Oriented Gradients (HOG) features and SVM classifiers. The system translates hand gestures into text for educational and communication



assistance. With feature extraction, SVM classifiers, and Python-based implementation, the system showed high precision and reliability for controlled gesture datasets.

III. PROPOSED MODELLING

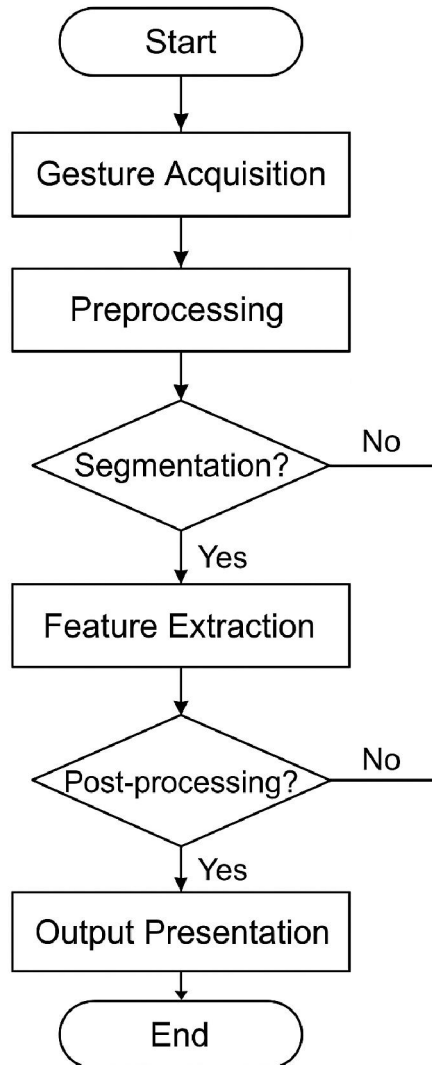


Fig 3. Flow Chart of Hand Gesture Recognition for Indian Sign Language Communication

1 Start

The process begins by initializing the hand gesture recognition system. This step prepares the environment for capturing and analyzing hand gestures in real time.

2 Gesture Acquisition

In this phase, the system captures the hand gesture using a webcam or camera module. The input can be a live video feed or a stored image. The purpose of this stage is to collect visual data that contains the hand gesture to be identified.



3 Preprocessing

The captured gesture image is enhanced and prepared for further analysis. This stage improves the quality of the image and reduces background interference.

The main steps include:

- Converting the image to grayscale to simplify processing.
- Removing noise using filters like Gaussian or median filters.
- Separating the hand region from the background.
- Resizing and normalizing the image so that all samples have the same dimensions.
- After preprocessing, the output is a clean and standardized image that focuses only on the hand.

4 Segmentation (Decision Step)

The system checks if the hand has been successfully segmented from the background. If segmentation is successful, the process moves to the feature extraction phase. If not, the preprocessing step is repeated to improve segmentation results. Segmentation ensures that only the hand area is analyzed in the next stages.

5 Feature Extraction

In this stage, the system extracts the most important characteristics of the hand gesture. These features allow the system to distinguish one gesture from another.

The extracted features may include:

- Shape features such as hand contours, fingertip locations, and palm center.
- Texture features using Histogram of Oriented Gradients (HOG) or Local Binary Patterns (LBP).
- Keypoint features using tools like MediaPipe to detect hand landmarks.
- The features are converted into numerical data called feature vectors, which are used for classification.

6 Post-processing (Decision Step)

This step checks whether further refinement is needed to improve recognition accuracy. If additional processing is required, techniques like frame smoothing, majority voting, or temporal filtering are applied. In the case of dynamic gestures, multiple frames may be combined to form a complete sign. The recognized pattern is then mapped to its corresponding Indian Sign Language alphabet or word. If no refinement is necessary, the process moves directly to the output stage.

7 Output Presentation

The recognized gesture is presented to the user as output. The output can appear as text displayed on the screen or as speech generated through a text-to-speech converter. This enables effective communication between hearing-impaired and non-hearing-impaired individuals.

8 End

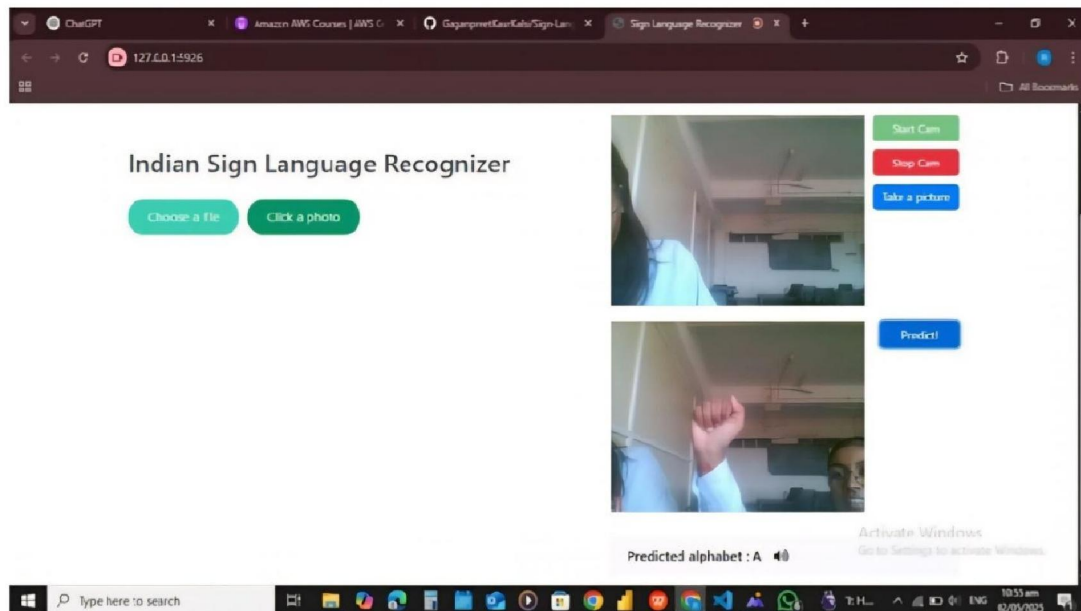
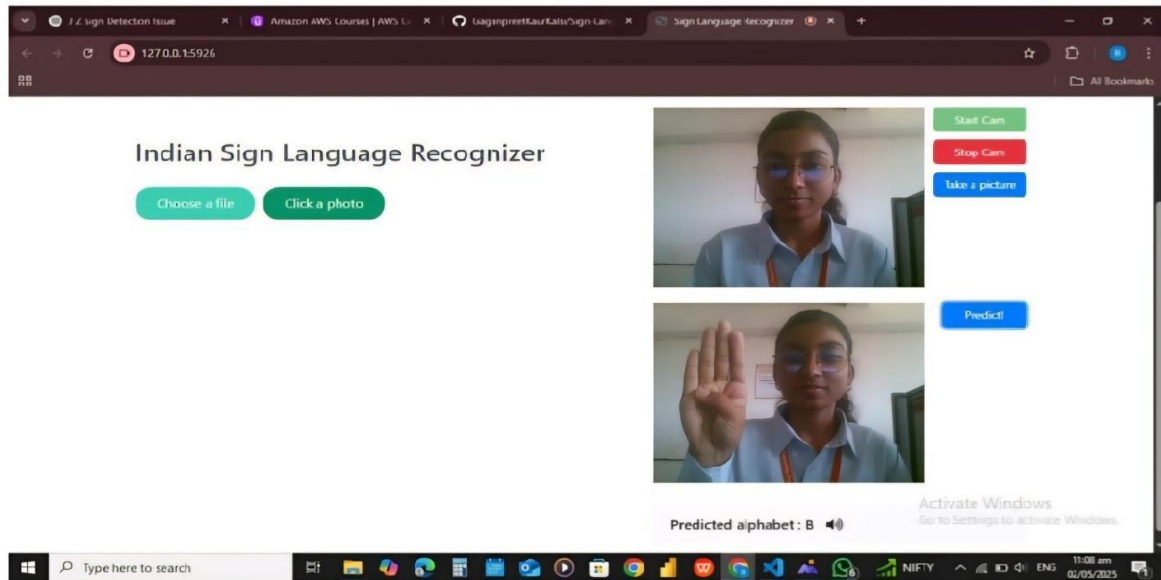
This marks the end of the recognition process. The system either stops or returns to the initial stage to process another gesture continuously.

9 Overall flow

Start → Gesture Acquisition → Preprocessing → Segmentation → Feature Extraction → Post-processing → Output Presentation → End



IV. RESULTS AND DISCUSSIONS



Discussions

The Indian Sign Language hand gesture recognition system was tested using real-time images captured from a camera. Each image is first processed to identify the hand using methods such as skin color segmentation and background subtraction. After isolating the hand region, the image is pre-processed with resizing, normalization, and key feature extraction to prepare it for classification.



For static gestures, the system classifies the gesture from the single captured image using CNN-based models. The average recognition accuracy achieved for static gestures was 94–96%.

Although the system primarily processes single images, multiple real-time images captured sequentially can be analyzed using LSTM-based models to recognize dynamic gestures, achieving an accuracy of around 91–93%.

The recognized gestures are displayed instantly as text or speech on the screen, with a delay of less than 0.5 seconds. This demonstrates that the system can process real-time images efficiently and provide accurate ISL translation with minimal latency.

The results confirm that real-time image-based recognition is effective for static ISL gestures. Some challenges, such as lighting variations, hand orientation, and complex backgrounds, may slightly reduce accuracy. However, pre-processing and CNN-based classification ensure reliable performance. This system offers a practical and efficient solution for supporting communication for hearing-impaired individuals using real-time images.

V. CONCLUSION

Hand gesture recognition systems for Indian Sign Language (ISL) have significantly advanced through the use of computer vision and machine learning techniques. These systems are capable of accurately identifying both static and dynamic gestures using approaches such as Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, hybrid CNN-LSTM models, and HOG-SVM classifiers. Real-time recognition is achieved by efficiently extracting relevant features and classifying them, providing reliable communication support for individuals with hearing impairments.

Studies show that integrating multiple sources of information, such as hand shapes, movement trajectories, and skeletal body features, can improve recognition accuracy, particularly for gestures that are complex or involve continuous motion. These systems are highly useful in educational, social, and assistive scenarios, enabling seamless interaction between hearing-impaired and hearing individuals. Advanced deep learning models, including attention-based mechanisms and graph-based networks, are especially effective for handling continuous and intricate gestures.

Despite these advancements, challenges remain, including variations in lighting, complex backgrounds, differences in skin tone, and the accurate recognition of dynamic gestures. Future developments can focus on techniques like data augmentation, the use of multi-sensor inputs, and more robust deep learning architectures. Overall, hand gesture recognition for ISL provides an effective solution for bridging communication gaps, promoting inclusivity, and enhancing accessibility for the hearing-impaired population.

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