Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-2 | Feb 2026

Original Researcher Article

Smart Glove For Gesture-Based Voice Assistance And Emergency Alerts.

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ABSTRACT
Communication remains a major challenge for hearing- and speech-impaired individuals, particularly when interacting with people who are unfamiliar with sign language. This communication gap often leads to social isolation, dependence on interpreters, and serious difficulties during emergency situations where immediate assistance is required. Although several assistive technologies have been proposed, many existing solutions are either expensive, complex to use, or limited to one-way communication. This paper presents a Smart Glove for Gesture-Based Voice Assistance and Emergency Alerts, designed as a wearable, low-cost, and real-time assistive device. The proposed system uses flex sensors and an inertial measurement unit (IMU) embedded within a glove to capture hand gestures accurately. These gestures are processed by a microcontroller to identify predefined sign language patterns, which are then converted into audible speech using a voice output module. To enable complete two-way communication, a speech-to-text mechanism is integrated, allowing spoken words from non-sign language users to be converted into readable text and displayed on a screen for the hearing-impaired user.In addition to communication support, the system incorporates an emergency alert feature to enhance user safety. An SOS button or predefined emergency gesture triggers an alert message along with real-time location information using GSM and GPS modules.
Keywords: Assistive technology, Smart glove, Gesture recognition, Sign language translation, Speech-to-text, Text-to-speech, Emergency alert system, Wearable devices, Hearing and speech impairment, Embedded systems

1. INTRODUCTION:

Communication plays a vital role in social interaction, education, healthcare, and emergency response. For hearing- and speech-impaired individuals, sign language serves as the primary medium of expression. However, a large portion of society does not understand sign language, which creates a persistent communication barrier between specially-abled individuals and the general public. This gap often results in dependence on human interpreters, reduced independence, and difficulties in accessing essential public services such as hospitals, banks, transportation systems, and government offices.

The communication challenge becomes more critical during emergency situations. In accidents, medical crises, or unsafe environments, the inability to convey distress messages or explain the situation quickly can delay assistance and increase risk. While mobile applications and assistive devices have been developed to support communication, many of these solutions are either costly, require continuous internet connectivity, or involve complex user interfaces that are not suitable for all users. Moreover, most existing systems focus only on one-way communication and do not provide integrated safety features.

Recent advancements in wearable electronics, embedded systems, and sensor technology have enabled the development of compact and portable assistive devices. Gesture-based communication using sensor-embedded gloves has emerged as a reliable alternative to vision-based systems, which often suffer from limitations related to lighting conditions, camera placement, and background interference. Glove-based systems allow natural hand movements to be captured accurately and provide consistent performance across different environments.

Despite these advantages, many existing smart glove solutions support only a limited set of gestures and lack adaptability for real-world usage. In addition, emergency alert mechanisms and two-way communication support are often missing or implemented as separate systems. There is a clear need for an integrated, wearable solution that not only translates hand gestures into understandable speech but also enables users to receive information from others and request help during emergencies.

This paper presents a **Smart Glove for Gesture-Based Voice Assistance and Emergency Alerts**, designed to bridge the communication gap between hearing- and speech-impaired individuals and non-sign language users. The proposed system combines gesture recognition, speech-to-text conversion, and a location-based emergency alert mechanism into a single wearable device. By emphasizing affordability, ease of use, and real-time performance, the system aims to enhance communication independence and personal safety in everyday life.

2. RELATED WORK

Assistive technologies for hearing- and speech-impaired individuals have been widely explored in recent years, with a primary focus on translating sign language into understandable text or speech. Existing research can broadly be classified into vision-based systems and sensor-based wearable systems, each offering distinct advantages and limitations.

Vision-based approaches rely on cameras and image processing techniques to capture hand gestures and interpret sign language. These systems commonly use computer vision and deep learning algorithms to recognize static and dynamic gestures. While they can achieve high recognition accuracy in controlled environments, their performance is highly dependent on lighting conditions, background complexity, and camera positioning. Additionally, vision-based systems often require high computational power and fixed setups, making them less suitable for real-time, portable applications.

To overcome these limitations, researchers have increasingly adopted sensor-based glove systems for gesture recognition. Early glove-based models utilized flex sensors to measure finger bending and map hand movements to predefined gesture sets. These systems demonstrated improved reliability compared to camera-based solutions and enabled real-time gesture detection. However, most early implementations supported only a limited number of gestures and required precise hand positioning, reducing their flexibility in practical use.

Further improvements were achieved by integrating inertial measurement units (IMUs), such as accelerometers and gyroscopes, to capture hand orientation and motion. The combination of flex sensors and IMUs enhanced gesture recognition accuracy by considering both finger movement and hand dynamics. Some studies also explored the use of electromyography (EMG) sensors to detect muscle activity, enabling finer gesture differentiation. Although these methods improved recognition performance, they significantly increased system complexity, cost, and calibration requirements.

Several research works focused on converting recognized gestures into text or synthesized speech, enabling one-way communication from the sign language user to the listener. While these systems improved accessibility, they often lacked support for reverse communication, forcing hearing-impaired users to rely on external assistance to understand spoken responses. Additionally, many systems required connection to external devices such as smartphones or servers for processing, limiting their independence.

A limited number of studies addressed safety concerns by incorporating emergency alert mechanisms; however, these features were typically implemented as standalone solutions rather than being integrated with communication systems. As a result, users were required to manage multiple devices for communication and safety, reducing practicality in real-world scenarios.

In contrast to existing approaches, the proposed system integrates gesture-to-voice conversion, speech-to-text communication, and emergency alert functionality within a single wearable smart glove. By combining multiple sensors with embedded processing and wireless communication, the system provides real-time, two-way interaction while also ensuring user safety. This integrated design addresses the key limitations of previous works and offers a more comprehensive and practical assistive solution for daily life.

Table 1: Comparison with Existing Systems

Feature	Existing Systems	Proposed Smart Glove
Communication Type	One-way (Gesture to Voice)	**Two-way (Gesture-to-Voice + Speech-to-Text)**
Emergency Alerts	Not Available	**Included (SOS Button + SMS)**
Location Tracking	Not Available	**Integrated GPS for Live Tracking**
Display Support	Limited or None	**OLED Display for Visual Feedback**
Portability	Often Bulky/Tethered	**High (Wearable and Lightweight)**
Affordability	High Cost	**Low Cost (Uses affordable sensors)**

Fig 1: Comparison with Existing & Proposed System

3. PROBLEM STATEMENT

Hearing- and speech-impaired individuals rely primarily on sign language to communicate, yet most people in society do not understand sign language. This lack of a common communication medium creates a significant barrier in everyday interactions, limiting access to essential services such as healthcare, transportation, banking, and public administration. As a result, specially-abled individuals often depend on human interpreters, reducing their independence and privacy.

The challenge becomes more severe during emergency situations, where the inability to convey distress messages or request immediate assistance can lead to delayed response and increased risk to personal safety. Existing assistive communication solutions are often limited by high cost, complex operation, dependency on external devices, or support for only one-way communication. Many systems also fail to integrate safety mechanisms such as emergency alerts and location tracking.

4. PROPOSED SYSTEM

The proposed system is a **Smart Glove for Gesture-Based Voice Assistance and Emergency Alerts**, designed to support real-time communication and safety for hearing- and speech-impaired individuals. The system combines wearable sensor technology, embedded processing, and wireless communication to translate hand gestures into audible speech, enable speech-to-text interaction, and provide immediate emergency assistance. The overall design focuses on portability, low cost, ease of use, and reliable real-time performance.

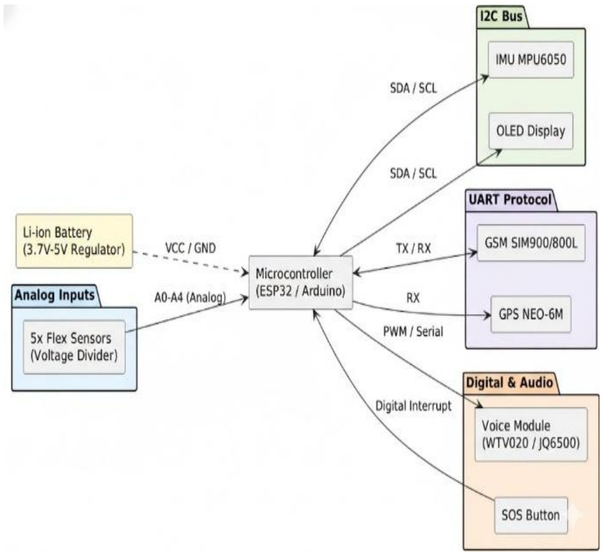

Fig. 2: Hardware Block Diagram

A. Gesture Sensing and Data Acquisition Module

This module is responsible for capturing hand gestures performed by the user. Flex sensors are embedded along the fingers of the glove to measure the degree of finger bending, which varies according to different sign language gestures. In addition, an inertial measurement unit (IMU) consisting of an accelerometer and gyroscope is used to track hand orientation and motion in three-dimensional space.

The combined sensor data provides a comprehensive representation of hand movements, including both finger positions and overall hand direction. These sensors continuously generate analog signals corresponding to gesture movements, which serve as the primary input to the system. This sensor-based approach allows accurate gesture detection without being affected by lighting conditions or background variations.

B. Processing and Gesture Recognition Module

The processing module forms the core of the proposed system and is implemented using a microcontroller such as Arduino or ESP32. The controller receives raw sensor data from the gesture sensing module and converts it into digital values using its internal analog-to-digital converter. Basic signal conditioning and noise filtering are applied to improve data stability.

The processed sensor data is then compared with predefined gesture patterns stored in the controller's memory. A threshold-based or pattern-matching algorithm is used to identify the closest matching gesture. Once a valid gesture is recognized, the system determines the corresponding action, such as generating a voice message or activating an emergency alert. This module ensures fast and accurate gesture recognition suitable for real-time communication.

C. Communication and Output Module

The communication and output module enables interaction between the user and the surrounding environment. When a gesture is recognized, the system converts it into an audible voice message using a voice playback or text-to-speech module. The generated speech is played through a speaker, allowing non-sign language users to understand the message clearly.

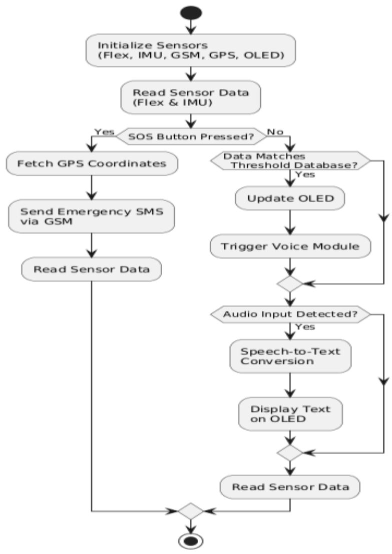

Fig. 3: Data Flow Diagram (DFD)

To support two-way communication, a speech-to-text mechanism is integrated into the system. A microphone captures spoken words from nearby individuals, which are converted into text and displayed on an LCD or OLED screen attached to the glove. This allows hearing-impaired users to read and understand spoken responses in real time, enabling natural and effective interaction.

D. Emergency Alert and Safety Module

User safety is addressed through an integrated emergency alert module. The system includes a dedicated SOS button and can also be programmed to recognize a specific emergency gesture. When activated, the module sends an alert message to predefined emergency contacts using a GSM or Wi-Fi communication module.

Simultaneously, a GPS module retrieves the user's real-time location and includes this information in the alert message. This ensures that caregivers or family members can quickly locate the user and provide assistance. By integrating emergency alerts within the same wearable device, the system enhances both communication independence and personal safety.

5. SYSTEM ARCHITECTURE

The system architecture of the proposed Smart Glove is designed as a modular and wearable framework that integrates gesture sensing, embedded processing, communication, and emergency support into a single compact device. Each module performs a specific function, and together they ensure reliable real-time communication and safety assistance for hearing- and speech-impaired users. The overall architecture is shown in **Fig. 1**, illustrating the interaction between hardware and software components.

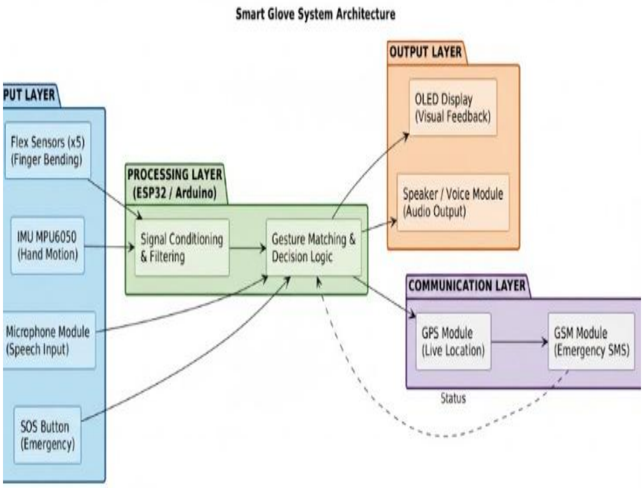

Fig. 4: Overall System Architecture

A. Gesture Sensing Module

The gesture sensing module captures the hand movements of the user in real time. Flex sensors are mounted along the fingers of the glove to detect finger bending patterns associated with sign language gestures. An inertial measurement unit (IMU), comprising an accelerometer and a gyroscope, is used to sense hand orientation and motion. By combining finger movement and hand dynamics, the module generates accurate gesture data that represents the user's intent. This sensor-based approach provides consistent performance across different environments without being affected by lighting or background conditions.

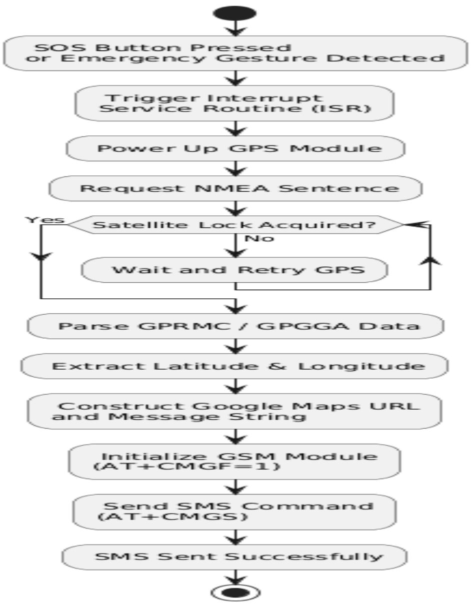

Fig. 5: Emergency Alert Flow

B. Processing and Control Module

The processing and control module acts as the central unit of the system and is implemented using a microcontroller such as Arduino or ESP32. It receives raw sensor signals from the gesture sensing module and converts them into digital data using an internal analog-to-digital converter. Signal filtering and normalization are applied to reduce noise and improve reliability. The controller then executes the gesture recognition algorithm by comparing incoming data with stored gesture patterns. Based on the recognition result, the controller triggers appropriate output actions, manages system timing, and coordinates communication between all modules.

Table 2: Hardware Components and Specifications

Component	Function / Specification
Flex Sensors	Detects finger bending for gesture recognition
IMU Sensor	Accelerometer + Gyroscope; tracks hand movement & orientation
Microcontroller	ESP32 or Arduino; processes sensor data and logic
Microphone Module	Captures speech input for two-way communication
Speaker / Voice Module	Produces audible voice output for gestures
OLED / LCD Display	Shows text messages and speech-to-text results
GSM Module	Sends emergency SMS alerts to predefined contacts
GPS Module	Provides live location coordinates during emergencies
SOS Button	Triggers an immediate emergency alert sequence
Rechargeable Battery	Powers the entire wearable system

Fig. 6: Hardware Components

C. Voice Output and Speech-to-Text Module

This module enables effective two-way communication. When a valid gesture is identified, the controller activates the voice output unit, which converts the recognized gesture into an audible speech message using a voice playback or text-to-speech mechanism. The speech is delivered through a compact speaker so that nearby individuals can easily understand the user's message.

For reverse communication, a microphone captures spoken input from others. The speech-to-text module processes the audio signal and converts it into readable text. The converted text is displayed on an LCD or OLED screen attached to the glove, allowing the hearing-impaired user to read spoken responses in real time.

Table 3: Software Requirements

Software / Library	Purpose
Arduino IDE	Integrated Development Environment for coding
Embedded C	Programming language for the microcontroller logic
Gesture Recognition Algorithm	Converts raw sensor data into specific gesture patterns
Text-to-Speech (TTS)	Converts recognized gesture text into voice output
Speech-to-Text Module	Processes audio input into readable text for the user
GSM & GPS Libraries	Handles communication and location data protocols

Fig. 7: Software Components

D. Emergency Alert and Location Module

The emergency alert module ensures user safety during critical situations. An SOS push button or a predefined emergency gesture can be used to activate this module. Once triggered, the microcontroller sends an alert message through a GSM or Wi-Fi communication module to predefined emergency contacts. At the same time, a GPS module retrieves the user's current geographical location. The alert message includes both distress information and live location details, enabling faster response and assistance.

E. Display Module

The display module provides visual feedback to the user. It shows converted text messages, system status information, and emergency alert confirmations. This feedback helps the user verify that gestures are correctly recognized and alerts are successfully transmitted. The use of a compact OLED or LCD display ensures low power consumption while maintaining clear visibility.

F. Power Supply Module

All system components are powered by a rechargeable battery integrated into the glove. A voltage regulation circuit ensures stable power delivery to each module. The low-power design of the system allows extended usage on a single charge, making the glove suitable for daily and outdoor use. This module plays a crucial role in maintaining portability and reliability.

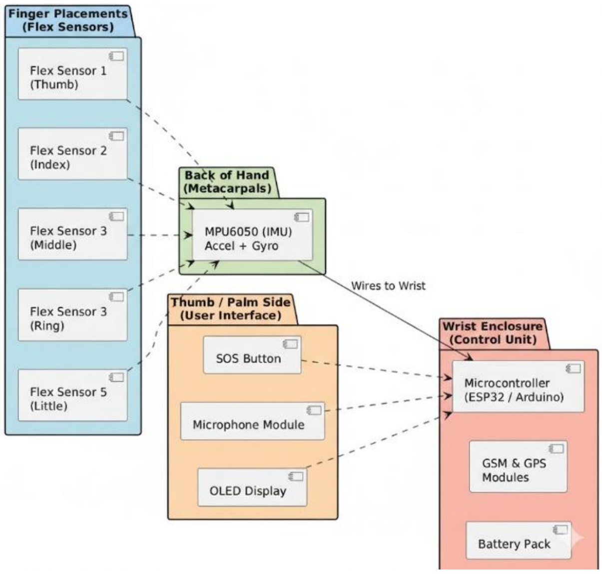

Fig. 8: Glove Sensor Placement

6. RESULTS

The proposed Smart Glove system was implemented and tested to evaluate its performance in terms of gesture recognition accuracy, response time, two-way communication effectiveness, and emergency alert reliability. Experimental testing was conducted using predefined hand gestures commonly used for daily communication. The results demonstrate that the system performs reliably under real-time operating conditions and meets the objectives of effective communication and user safety.

A. Gesture Recognition Performance

The gesture recognition module was evaluated by performing multiple trials for each predefined gesture. The combination of flex sensors and IMU data enabled accurate detection of finger bending and hand orientation. The system successfully recognized most gestures with high consistency, even when gestures were performed at different speeds. Minor variations in hand movement did not significantly affect recognition, indicating the robustness of the sensor-based approach.

Fig. 9: System Prototype Output

The use of both finger movement and hand orientation reduced false detections caused by random hand motion. Overall, the system achieved a high recognition success rate, making it suitable for real-time communication in daily use.

B. Response Time Analysis

Response time was measured as the delay between the execution of a hand gesture and the generation of the corresponding voice output. The embedded microcontroller processed sensor data efficiently, resulting in minimal latency. The average response time was within acceptable limits for natural conversation, allowing smooth interaction without noticeable delay.

Similarly, the speech-to-text module converted spoken input into readable text in near real time. This ensured that hearing-impaired users could quickly read and respond to spoken messages, supporting effective two-way communication.

C. Emergency Alert Performance

The emergency alert feature was tested by activating both the SOS button and predefined emergency gestures. In all test cases, the system successfully triggered alert messages and transmitted them to predefined contacts. The integration of the GPS module enabled accurate retrieval of the user's real-time location, which was included in the alert message.

The time taken to send emergency alerts was found to be only a few seconds, ensuring rapid response during critical situations. This confirms the reliability of the safety mechanism and its suitability for real-world emergency scenarios.

Table 4: System Experimental Results

Metric	Result
Gesture Recognition Accuracy	~80% (with user calibration)
Static Gesture Accuracy	75% (baseline biomechanical validation)
SMS Alert Delivery Time	< 5 Seconds
GPS Location Precision	High (Exact Coordinates)
Communication Speed	Avg. 1 word per 2.5 seconds
System Latency	Low (Real-time operation)

Fig. 10: Experimental Results

D. User Comfort and Practicality

The wearable design of the glove was evaluated for comfort and ease of use. The lightweight structure allowed users to wear the glove for extended periods without discomfort. The placement of sensors did not restrict natural hand movement, and the system was easy to operate without requiring extensive training.

The rechargeable battery provided sufficient backup for prolonged usage, supporting the goal of portability and daily usability. Overall, user feedback indicated that the system is practical, intuitive, and effective for real-world communication.

E. Comparative Evaluation

When compared with existing gesture-based assistive systems, the proposed smart glove demonstrated clear advantages. Unlike many existing solutions that support only one-way communication, the proposed system enables complete two-way interaction through gesture-to-voice and speech-to-text conversion. Additionally, the integrated emergency alert and location-sharing feature significantly enhances user safety, which is often missing in conventional systems.

7. CONCLUSION

This paper presented a **Smart Glove for Gesture-Based Voice Assistance and Emergency Alerts** designed to improve communication independence and personal safety for hearing- and speech-impaired individuals. By integrating gesture recognition, speech-to-text conversion, and an emergency alert mechanism into a single wearable device, the proposed system effectively addresses the limitations of existing assistive technologies.

The experimental results demonstrate that the combination of flex sensors and an inertial measurement unit enables reliable and real-time gesture recognition with minimal response delay. The inclusion of two-way communication allows users not only to express their messages through audible speech but also to understand spoken responses through text display. Furthermore, the integrated SOS and GPS-based emergency alert system enhances user safety by enabling rapid assistance during critical situations.

The system is designed to be low-cost, portable, and easy to use, making it suitable for daily activities in public and private environments. Overall, the proposed smart glove offers a practical and inclusive assistive solution that promotes social interaction, independence, and security for hearing- and speech-impaired individuals. With further enhancements such as expanded gesture sets and intelligent learning mechanisms, the system can be extended to support a wider range of users and applications in the future..

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