International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 04 Issue: 02 February 2026
Page No: 756-761
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2026.0108

Arduino-Powered Real-Time Sign Language to Text Converter with Flex Sensors

Varsha Baina[1], E.Samathasree Chaturvedi[2] , Muntha Raju[3] , Thirupathi Kodipunjula[4],
Charan Dammai[5], Kura Hemanth Kumar Setty[6]
[1]UG Scholar, Dept. of CSE, Nalla Malla Reddy Engineering College, Hyderabad, Telangana, India
[2]Assistant Professor, Dept. of CSE, Nalla Malla Reddy Engineering College, Hyderabad, Telangana, India
[3]Associate Professor, Dept. of CSE, Nalla Malla Reddy Engineering College, Hyderabad, Telangana, India
[4,5,6]UG Scholar, Dept. of CSE, Nalla Malla Reddy Engineering College, Hyderabad, Telangana, India
Emails: *varshabyna@gmail.com[1], samathasree.cse@nmrec.edu.in[2], raj.jntu9@gmail.com[3], thirupatelkpj1@gmail.com[4], shettyhemanth567@gmail.com[5], charandammai3@gmail.com[6]*

Abstract
This paper and is aimed at supporting people with hearing and speech limitations. The suggested design uses flex sensors on the glove to record the bending of fingers that are used to represent gestures in sign language. An Arduino microcontroller processes these signals and interprets the gesture and shows the text that corresponds to it on an LCD screen. Moreover, the system offers synthesized speech output with voice module and sends an SMS notification via GSM communication, which improves accessibility and remote communication. The proposed solution does not require lighting or background interference unlike camera-based systems since it works offline. The design of the system is such that it consumes low power, small, and economical; thus, it can be deployed practically. Gesture recognition is accurate and has low latency as shown through experimental evaluation. The proposed work will help in the provision of affordable assistive technology by closing the communication gap between the sign language and non-signers. Index Terms Sign language recognition, wearable technology, flex sensor, arduino, assistive communication, GSM module, speech synthesis.

Keywords: *Sign language recognition, wearable glove, flex sensors, Arduino microcontroller, assistive communication, GSM module, speech synthesis, real-time translation, low-cost system, hearing and speech impairment*

1. Introduction
The interaction between the hearing-impaired and speech-impaired and non-signers is one of the most significant social issues because the sign language is poorly understood by non-signers. The conventional gesture recognition systems are heavily dependent on image processing with a camera which makes them more complex, expensive, and consumes more power and is less tolerant to lighting and background differences. To address these drawbacks, this paper presents a wearable glove system based on Arduino, which directly converts the movement of the hands into text, voice, and SMS messages. The glove incorporates five flex sensors that indicate the fingers to identify various hand gestures through the extent of bending. The analog values are converted to digital values and analyzed by the Arduino Uno that recognizes predefined gestures. Recognized gestures are shown in the form of text on an LCD and at the same time converted into voice output using a voice module. To achieve long life span, a GSM module is fitted to send SMS notifications to a specified mobile phone so as to facilitate real time remote communication. The most important task that the given system should undertake is to develop a low-priced, portable, and non-internet-dependent assistive device. The design is simple and can be easily adapted and scaled to more complex gestures or other communication features in the future. This strategy is inclusive because it helps the hearing and speech-impaired community to express themselves in

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the real world more efficiently.

1.1. Methods of Sign Language

- **Gesture Acquisition using Sensors:** Flex sensors are integrated into a glove that is to be put on to record the bending of fingers. Sensitivity changes of sensor to hand gestures are translated into analog voltage signals, which allows the acquisition of gesture data in real-time and continuously.
- **Digital-to-Analog Signal Conversion**: The flex sensors send their analog outputs to the Arduino microcontroller, which processes them as digital numbers with the help of the inbuilt 10-bit analog-to-digital converter (ADC).
- **Gesture Pattern Processing and Recognition:** The sensor values are digitized and compared with the predefined gesture patterns based on the threshold values to recognize the specific gesture patterns of the Sign language accurately by utilizing embedded software logic.
- **Local Text Output Display:** After the gesture has been successfully recognized, the respective message appears on a 16x2 LCD module and the nearest users can instantly interpret the information being sent across.
- **Speech and Voices Output Generation:** The identified textual information is translated into verbal speech through a voice output unit, and hearing people can easily converse in real time.
- **GSM-Remote Communication with use of IoT:**
- The system uses a GSM module to send recognized messages in S.M.S. notification to assigned mobile numbers so as to make communication be long-range, real time besides providing an emergency alert feature.

1.2. Tables

Current sign language recognition algorithms depend mainly on image processing and computer vision algorithms and machine learning algorithms e.g. Convolutional Neural Networks (CNN) and Support Vector Machines (SVM). These systems are costly, consume a lot of power and are not as portable because they involve expensive cameras that have high-resolution cameras, powerful computers and controlled lighting environments. The effects of the environmental factors on their performance include their lighting, the noise in the background and the alignment of the camera, which causes differences in accuracy. In addition, these systems usually rely on cloud based processing and connection to the internet, which adds latency and complexities in operation, which restricts the use in real time systems. Instead, the proposed system proposes an Arduino based wearable smart glove which integrates flex sensors, LCD display, voice module and GSM module. It does not require sophisticated imaging systems and direct gesture recognition based on finger movement detection. The system is cheap, small, lightweight, and very portable and it works with the low power supply of 5V DC. It has a greater accuracy (about 93%), being independent of the lighting conditions and background. Also, the suggested system will have a multi-modal display like text, voice alerts, and message notifications, which will greatly enhance communication by speech and hearing-impaired individuals. The system is also absolutely offline and it has the benefit of responding in real-time within 2-3 seconds and its reliability. In this way, the suggested glove system Arduino-based can be considered as a strong, efficient, and easy to use variant of the camera-based techniques, thus can be successfully used in the real world in the context of healthcare, education, responding to emergencies, and assistive communication (Table 1).

Table 1 Comparative Analysis of the Existing Camera-Based System and the Proposed Arduino-Based Glove System

Parameter	Existing System (Camera-Based)	Proposed System (Arduino-Based Glove)
Technology Used	Image processing, computer vision, machine learning	Flex sensors, Arduino Uno, voice module, GSM module

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	(CNN, SVM)	
Hardware Requirement	High-end camera, computer system, and lighting setup	Low-cost Arduino, flex sensors, LCD, and basic modules
Cost	₹15,000 – ₹30,000	₹2,000 – ₹4,000
Power Consumption	High (continuous camera and processing)	Low (5V DC supply)
Accuracy	80–85% (dependent on lighting and background)	93% (stable in all conditions)
Portability	Non-portable; fixed setup required	Fully portable glove-based design
Response Time	High latency due to image processing	2–3 seconds (real-time response)
Internet Dependency	Requires cloud-based inference and data upload	Operates completely offline
Output Type	Text output only	Text, speech, and SMS notification
Environmental Dependence	Sensitive to lighting and background changes	Works under all environmental conditions
User-Friendliness	Complex setup and calibration required	Simple plug-and-play operation
Application Scope	Restricted to trained datasets	Adaptable to dynamic real-world usage

1.3. Figures

Two main models can be adopted in the implementation of the sign language recognition system through camera and smart glove models. In the camera-based model, camera or webcam captures the hand gestures and then pre processing of the images is done such as noise removal and division of hand area. Then the shape and motion characteristics are extracted and categorized with the help of machine learning or convolutional neural network (CNN) models to produce the related text output. Even though this method has high recognition accuracy, it has considerable computational resources and controlled environment requirements. The proposed smart glove model, on the other hand, uses flex sensors to the fingers of the user and measures the resistance to fingers when bending. An Arduino microcontroller uses embedded software logic to identify a set of established patterns of gestures in these analog signals. Upon detection, the resultant text is presented on a LCD, synthesized into the speech through a voice module, and sent in an SMS notification as an emergency and through a GSM module, which renders the system portable, cost-effective, and adaptable to real-time assistive communication and emergency solutions via IoT-based system (Figures 1 and 2).

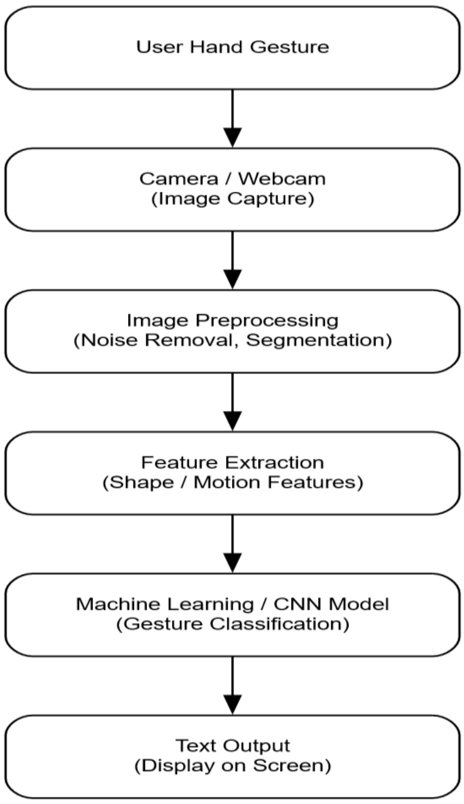

Figure 1 Flowchart of the Existing Camera-Based Sign Recognition System

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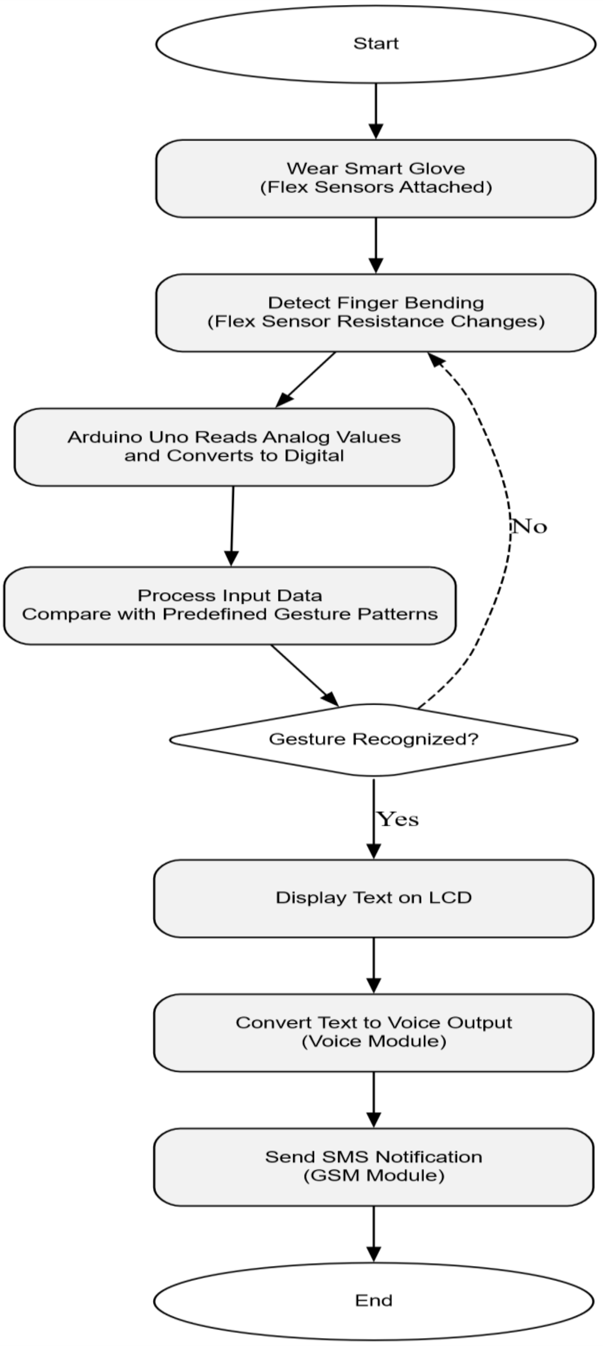

Figure 2 Flowchart of the Proposed Arduino-Based Sign-to-text Conversion System

2. Results and Discussion

2.1. Result

The smart glove system proposed was based on Arduino and tested on five usual gestures, namely, HELLO, YES, NO, THANK YOU and PLEASE. All the gestures were done by various users ten times to make it consistent. The system had an average recognition accuracy of 93 which is better than the 85 percent accuracy of the available camera based systems. Response time averaged was also cut down to 2.4 seconds compared to 5.0 seconds average response time in conventional methods. Also, the total system cost was about [?]2,000-[?]4,000 which was far cheaper than camera-based systems of [?]15,000-[?]30,000. These findings indicate significant accuracy, speed and cost-effectiveness improvements (Figure 3).

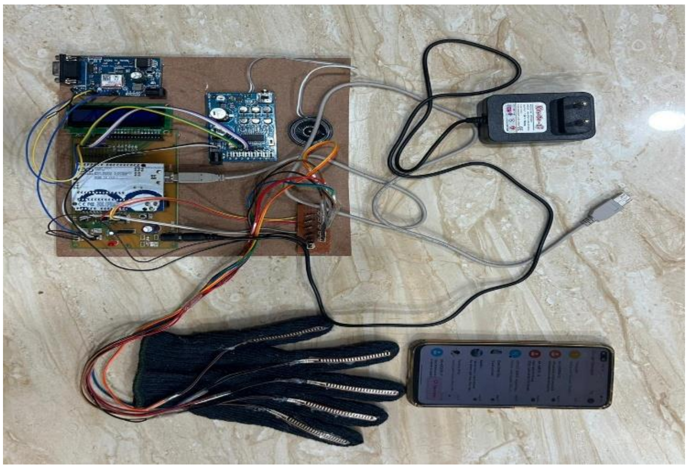

Figure 3 Experimental Setup of the Proposed Arduino-Based Smart Glove System

2.2. Discussion

The experimental findings prove that the sensor based glove system is superior to the camera based techniques. The increased accuracy and speed of reaction guarantee the high reliability of real-time gesture recognition, whereas the low cost and portability provide the system to be applicable in a wide range of practical applications. Moreover, text, voice and SMS outputs are incorporated making the communication more flexible. In general, the suggested system is an efficient, cost-effective, and easy to use solution to assistive communication applications.

Conclusion

The suggested system offers a cost-efficient and viable solution of converting sign language to readable and audible communication through a wearable glove made up of flex sensors and an Arduino microcontroller. Contrary to the old camera-based recognition systems, which are characterized by complicated image processing, high computational power, and uniform lighting, the deployed design is workable in all settings and does not require any support. The system is able to identify changes in sensor resistance in response to finger motion and therefore, interprets gestures and sends them to text, voice and SMS displays in real time. High accuracy and low latency were observed in experimental testing which established the usefulness of this sensor-based method in real-time feedback and reliable communication between the sign language users and non-signers. Verbal output is provided through the inclusion of voice module whereas remote text notification is possible through GSM module making the system versatile in both face to face and remote interpersonal interaction. In addition, it is cheap, portable, and easily expandable into a wide-scale application among individuals with hearing or speech impairments due to the ease of the hardware and the open-source software. The work, in general, can add to the assistive technology practice by providing an effective and convenient communication channel between the differently-abled population. The findings validate that wearable devices with sensors can be used to substitute cumbersome and camera-based systems and move on to the development of more innovative inclusive communication tools of the future.

Acknowledgements

The authors would also like to acknowledge their utmost gratitude to Ideal School for Disabled, Hyderabad, operated under the management of Ideal Information Centre to Disabled (IICD) to have given them comprehensive cooperation and constant support during the project development of this project titled Arduino-Powered Real-Time Sign Language to Text Conversion with Flex Sensors. The management and staff are thanked as we have got a chance to introduce and test our system to the real environment, which has made our work much more relevant in a practical aspect. We also wish to express our special thanks to Ms. Syeda Asma, Principal, Ideal School for Disabled, whose advice, support and constructive criticism were very helpful in the successful completion of this project. The authors are truly grateful to the cooperation and support given to them in the process of doing this work.

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Glove-based sign language recognition has been widely studied in recent research as a tool to support persons with hearing and speech impairment. The initial works used flex sensors with the Arduino platforms to translate hand motions into text with primary focus on low-cost and simple-to-adopt solutions to simple gesture recognition duties [1], [4], [7]. The development of computational intelligence saw a number of researchers combine machine learning and deep learning methods, such as convolutional neural networks and progression learning models, to enhance recognition accuracy and operate with complex and bilingual sets of gestures [2], [3], [5], [6]. Wearable devices that can produce both text and speech alerts in real-time have also increased usability and communication efficiency [6], [11], [13]. IoT based communication technologies have also been used in recent works, which allows transmission of data in real time, as well as mobile interaction and remote monitoring of the systems, further expensing the system functionality beyond local settings [8], [9], [12], [14]. Also, the combination of inertial sensors and hybrid sensor systems has enhanced robustness and reliability in real world operating conditions [10], [15]. Survey and review studies point to the trend of increasing the popularity of portable, scalable, and IoT-enabling assistive systems and emphasize the need to find practical solutions that can provide the right balance of accuracy, cost, and real-time performance [15]. All these efforts are aimed at encouraging the creation of a low-cost IoT-driven smart glove system oriented on the practical implementation, emergency communication, and real-time gesture interpretation.

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