Smart Glove For Sign Language To Speech Conversion Using Flex Sensors And ESP32

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ABSTRACT

Communication is a fundamental aspect of human interaction, yet individuals with speech or hearing difficulties often encounter substantial challenges in expressing themselves effectively within society. To address these barriers, this paper presents the development of a **Smart Gesture-to-Speech Glove**, an assistive wearable technology capable of converting hand gestures into audible speech. The system utilizes **flex sensors [self-assembled sensor**] mounted on each finger, where variations in electrical resistance correlate with finger bending to interpret predefined gestures. An **ESP32** microcontroller acquires and processes the sensor data, subsequently transmitting the encoded gesture information wirelessly to an Android smartphone via Bluetooth. A customized mobile application developed using **MIT App Inventor** decodes the received data and employs **Text-to-Speech (TTS)** technology to generate real-time audible voice output. Experimental validation confirms that the prototype accurately recognizes common sign gestures with low latency and stable wireless performance. Owing to its low cost, portability, and ease of use, the proposed smart glove represents a practical and supportive communication aid for individuals with speech disabilities, promoting greater inclusivity and independence.

Keywords: Flex sensors; ESP32; Bluetooth; Sign language translation; Text-to-Speech; Assistive technology

1. INTRODUCTION

Language is one of the most essential and powerful tools of human communication. For individuals with communication challenges due to speech or hearing limitations, **sign language** serves as their primary means of expression [4], [6]. However, since the majority of the population is unfamiliar with sign language, these individuals often face significant **communication barriers**, isolating them from the hearing community [5], [9]. This disconnect not only limits their day-to-day interactions but also affects their **social inclusion**, **education**, **and employment opportunities**, underscoring the urgent need for a more universal form of interaction.

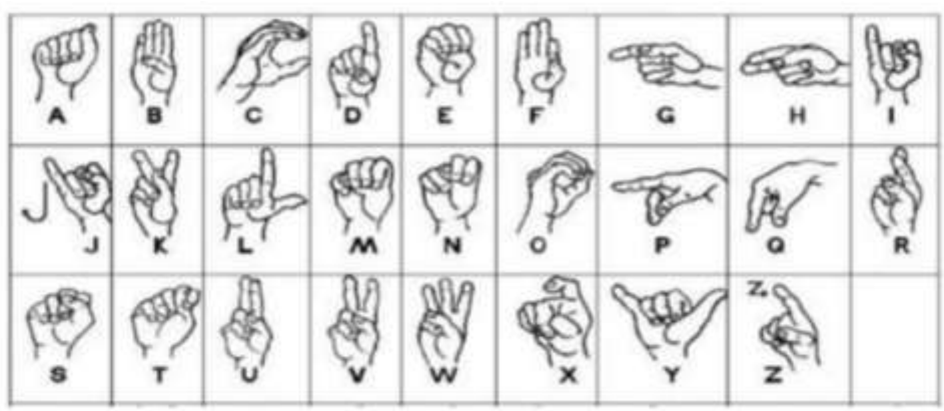
In recent years, researchers have developed various **sign-to-speech and sign-to-text systems** aimed at bridging this communication divide [1], [3], [8], [15]. Vision-based methods employing image processing and machine learning have shown potential in recognizing complex gestures with high precision [10], [14]. However, these solutions are often constrained by external factors such as lighting variations, camera positioning, and processing overhead, making them less suitable for portable or real-time applications [2], [13]. This limitation opens an intriguing opportunity — can gesture translation be achieved using a simpler, wearable, and environment-independent approach.

Addressing this question**, wearable sensor-based systems** have emerged as a compelling alternative. These devices leverage **flex sensors, accelerometers, and gyroscopes** to detect finger and hand movements, offering advantages like low power consumption, mobility, and real-time responsiveness [7], [18]. Prior works have demonstrated the effectiveness of integrating **IoT-based control and microcontroller** platforms to enhance system adaptability and communication reliability [9], [16], [21].

Building upon these foundations, this paper presents a Smart Glove that converts **hand gestures** into **audible speech**. Each finger is equipped with self-fabricated flex sensors that vary in resistance when bent, enabling accurate gesture detection [12], [20]. The ESP32 microcontroller processes the sensor data and wirelessly transmits the interpreted gestures to a smartphone via **Bluetooth Serial Port Protocol** (SPP) [16], [22]. A custom MIT App Inventor application then decodes the signals and produces real-time speech output using Text-to-Speech (TTS) technology.

The proposed Smart Glove demonstrates **low latency**, **high recognition accuracy**, and **stable wireless performance**, providing a user-friendly and cost-effective assistive communication solution. Unlike camera-dependent systems, it functions reliably in all environments and requires minimal computational resources. Insights from recent advancements in gesture-based IoT systems and sensor calibration optimization have been incorporated to enhance **precision** and **comfort**.

Ultimately, this research envisions a future where technology amplifies expression — where every gesture can find its voice. By merging wearable sensing, embedded intelligence, and wireless communication, the Smart Glove takes a significant step toward inclusive, natural, and **independent communication** between the speech-impaired and the broader society [1], [5], [18].

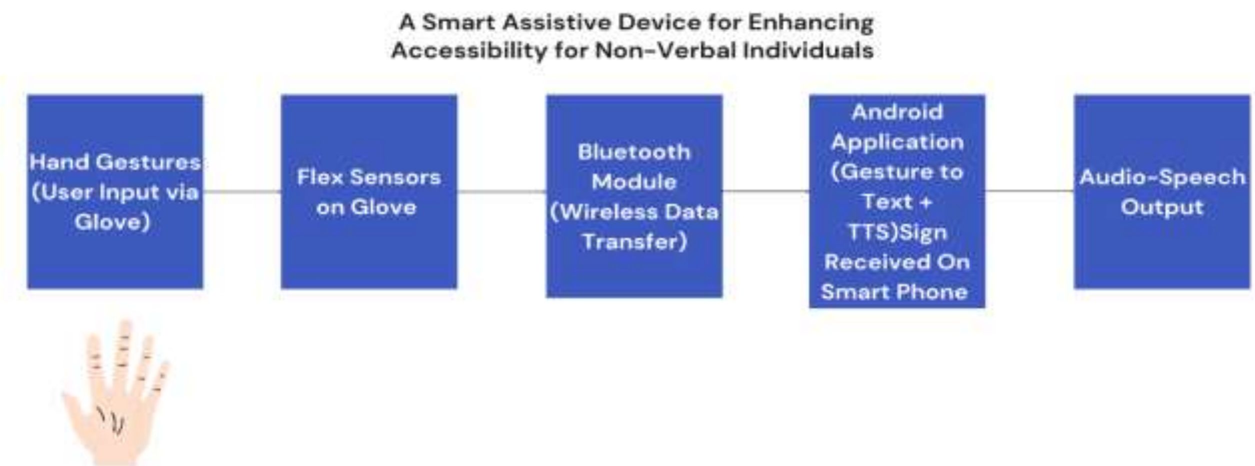


2. MATERIALS AND METHODS

2.1 System Overview

The Smart Glove system comprises three main sections:

1. **Sensor Unit** – Five flex sensors mounted on each finger detect the bending of joints.
2. **Processing Unit** – The ESP32 microcontroller reads sensor data, processes analog values, and transmits corresponding text messages.
3. **Output Unit** – An Android application receives the transmitted data and generates speech output using Text-to-speech.



2.2 System constituents

The proposed system comprises several key hardware and software components that work together to enable gesture recognition and speech conversion, as outlined below:

- **ESP32 Dev Module:** Serves as the main controller, offering dual-core processing and built-in Bluetooth communication.

  Operating Voltage: 3.0V – 3.6V (typical 3.3V)
  I/O Voltage: Not 5V tolerant
  Current Consumption: 80–260 mA (peak), ~10 µA in deep sleep
  CPU: Dual-core Xtensa LX6 @ 240 MHz
  Memory: 520 KB SRAM, 4 MB Flash
  Connectivity: Wi-Fi 802.11 b/g/n (2.4 GHz), Bluetooth v4.2 BR/EDR + BLE
  ADC: 12-bit, up to 18 channels

DAC: 2 channels, 8-bit
GPIOs: ~34 pins, multiple functions (PWM, I²C, SPI, UART, etc.)
Operating Temperature: –40°C to +125°C

- **Resistors (10 kΩ):** Used in a voltage-divider arrangement paired with each flex sensor.
- **Power Supply:** USB power bank or Li-ion battery.
- **Android Smartphone:** Acts as the output and Text-to-speech device through the MIT App.
- **Flex Sensors:** Resistive sensors that change resistance depending on bending angle; homemade or commercial types can be used.

2.3 Sensor Design

Commercial flex sensors are costly and exhibit inconsistent threshold values; therefore, a self-fabricated sensor was developed to ensure affordability and uniform performance.

Materials:

Paper strip, flexible cardboard/plastic, aluminum foil, wires, pencil, silicone, adhesive.

Fabrication of Flex Sensor

1. **Material Preparation**: Paper and two flexible cardboard/plastic strips were cut to finger length

2. **Conductive Layer Formation**: Both sides of the paper were coated with graphite using a pencil to create a resistive layer.

3. **Electrode Preparation**: Aluminium foil was fixed on each cardboard piece to serve as electrodes.

4. **Electrical Connection**: Wires were attached to the foil using solder or adhesive.

5. **Encapsulation**: Silicone or glue was applied to seal and protect the sensor.

6. **Sensor Replication**: The process was repeated to produce five sensors for the five fingers.

2.4 Implementation

Each flex sensor is connected using a voltage-divider setup to convert resistance changes into measurable voltage signals. The divided voltage is fed into the analog input pins of the ESP32 (GPIOs 32–36) [11]. Typical wiring configuration:

Finger	ESP 32 GPIO	RESISTOR
Thumb	GPIO 25	10kΩ
Index	GPIO 26	10kΩ
Middle	GPIO 27	10kΩ
Ring	GPIO 32	10kΩ
Pinky	GPIO 33	10kΩ

When a finger bends, the corresponding analog voltage changes, allowing the ESP32 to detect specific gestures [12], [20].

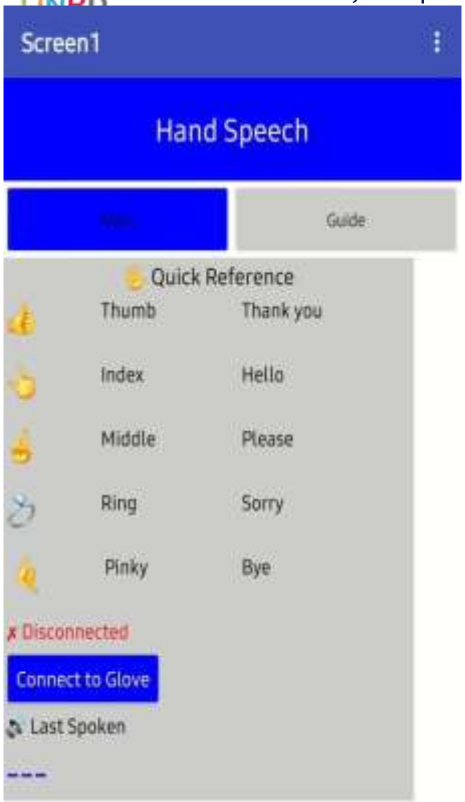
2.5 Software Implementation

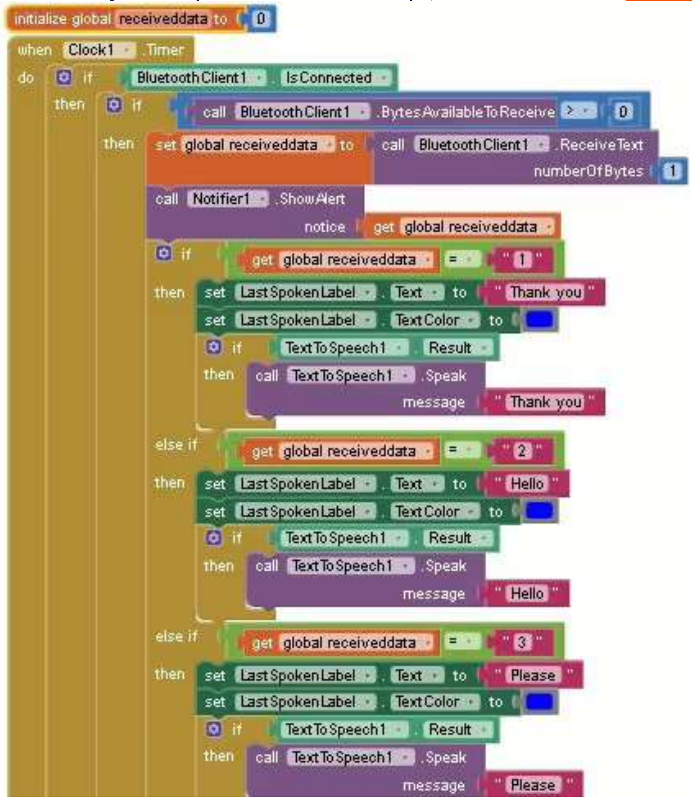
The ESP32 was programmed using **Arduino IDE** with the **BluetoothSerial.h** library [16]. The microcontroller continuously reads analog signals from the flex sensors, compares them with predefined threshold values, and transmits the corresponding text to a smartphone using Bluetooth Serial communication [11].

On the smartphone, an application developed using **MIT App Inventor 2** performs two functions:

1. Establishes a Bluetooth connection with the ESP32.
2. Uses the **Text-To-Speech** component to vocalize received messages.

The app also provides a user interface displaying connection status and received text in real time.





2.6 Working

The **Smart Glove system** functions as an intelligent bridge between human gestures and spoken language. It detects finger movements using an array of **flex sensors** carefully mounted on the glove—one for each finger—to capture even subtle variations in motion [12]. When a user bends their fingers to form a gesture, the **resistance of each sensor changes proportionally** to the degree of bending, generating a distinct analog signature [20]. These signals are routed through a **signal conditioning circuit** to stabilize and amplify the voltage levels, ensuring accuracy and noise immunity before reaching the **Analog-to-Digital Converter (ADC)** of the **ESP32 microcontroller** [17].

Within the microcontroller, these digitized values are analysed and **mapped to predefined words or phrases** stored in memory, effectively translating physical movement into meaningful data [19]. The recognized gesture information is then **transmitted wirelessly** via **Bluetooth** to a **custom smartphone application** built using **MIT App Inventor**, which performs **Text-to-Speech (TTS)** conversion to produce natural, audible output [16], [22].

By transforming silent gestures into spoken words in real time, this smart-glove system empowers individuals who **experience speech or hearing limitations** to communicate effortlessly with the world around them—bridging the gap between expression and understanding through the language of technology.

3. RESULTS AND DISCUSSION

The prototype was successfully implemented and tested with one to five flex sensors. Table 1 shows sample analog readings obtained for one finger (index) during operation.

Condition	Sensor Reading (ADC)	Status
Straight	400±50	Normal
Bent	0	Gesture Detected

When the measured sensor value falls below a predefined **threshold value** (e.g., 1300), the ESP32 controller unit transmits the corresponding message to the smartphone application, which then converts it into its **equivalent verbal output** [3]. The system demonstrated stable wireless performance and consistent operation within a **Bluetooth range of up to 10 meters**, aligning with prior studies that reported similar reliability in short-range IoT-based communication systems [7], [18].

The delay between **gesture detection and audible output** was observed to **be less than one second**, ensuring **near real-time performance**, consistent with the findings reported in [8], where low-latency wireless transmission was achieved in similar sensor-based assistive systems. The developed system consumed approximately **100 mA of current** during active Bluetooth transmission, indicating **energy efficiency** and suitability for **portable, battery-powered applications.**

4. CONCLUSION & FUTURE SCOPE

The developed **Smart Glove** successfully converts basic hand gestures into audible speech using manually fabricated flex sensors and the ESP32 platform. The integration of Bluetooth connectivity with a **smartphone-based text-to-speech** application ensures real-time and wireless communication between the glove and the mobile device, providing immediate speech output for simple gestures [1], [17]. The system is compact, portable, and utilizes inexpensive, easily available electronic components, making it a **low-cost assistive** solution [7], [12]. Its user-friendly Android interface is designed to require minimal interaction, enhancing accessibility for individuals with speech impairments [22], and supporting their participation in both social and professional environments [19]. Furthermore, the proposed design is scalable, offering significant potential for enhanced communication features. Future developments will focus on **recognizing multiple gesture** combinations using machine learning-based pattern recognition and **integrating additional motion sensors** such as accelerometers or gyroscopes to achieve more comprehensive sign language translation at multi-word or sentence level [5], [15], [16].

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