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Design and Implementation of a Gesture-Based Smart Assistive Glove Using ESP32 for Real-Time Communication in Paralysis Care

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Abstract: *This paper presents the design and implementation of a gesture-based smart assistive glove using an ESP32 microcontroller to enable effective communication for paralysis patients who face difficulties in expressing their basic needs. The proposed system utilizes flex sensors mounted on a wearable glove to detect finger movements, which are processed by the ESP32 to recognize predefined gestures corresponding to essential requests. Upon gesture identification, the system transmits real-time alerts to caregivers through a GSM-based short message service, ensuring timely assistance even in the absence of nearby support. A vibration motor provides haptic feedback to confirm successful message delivery, enhancing user confidence and reliability. The device is powered by a rechargeable battery and designed to be lightweight, portable, and suitable for continuous daily use. Experimental evaluation demonstrates accurate gesture recognition, low response time, and dependable communication performance. The proposed assistive glove offers a low-cost, user-friendly, and scalable solution that improves patient independence and strengthens caregiver–patient interaction in healthcare environments.*

Keywords*:* Solar energy, Electric vehicle charging, Renewable energy, MPPT controller, Smart charging station, Sustainable power, Energy storage

I. INTRODUCTION

Paralysis is a neurological condition that leads to partial or complete loss of voluntary muscle movement due to damage to the brain, spinal cord, or peripheral nerves. Common causes include stroke, traumatic brain injury, spinal cord injury, and neurodegenerative disorders. Although many paralysis patients retain full cognitive abilities, their inability to communicate basic needs effectively remains a major concern in healthcare environments [1]. Communication impairment often results in delayed medical response, increased dependency on caregivers, and psychological stress, which significantly affects the patient's quality of life [2].

To address these challenges, assistive communication technologies have become an important area of research in biomedical and healthcare engineering. Wearable assistive devices offer a practical solution as they enable continuous usage while allowing natural human interaction. Gesture-based systems, in particular, are effective because they rely on residual motor abilities rather than speech or visual interaction, making them suitable for patients with limited physical mobility [3]. Such systems reduce caregiver burden and improve patient autonomy when designed with simplicity and reliability in mind [4].

Hand gesture recognition techniques can be broadly categorized into vision-based and sensor-based approaches. Vision-based methods rely on cameras and image processing algorithms, which often require controlled lighting conditions and high computational resources. These limitations reduce their practicality in real-world healthcare scenarios. In contrast, sensor-based approaches using flex sensors provide a low-cost and energy-efficient alternative for gesture detection [5]. Flex sensors measure finger bending through resistance variation, enabling accurate and consistent gesture recognition when embedded into wearable gloves [6].

Embedded processing units play a central role in interpreting sensor data and converting gestures into meaningful

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commands. The ESP32 microcontroller has emerged as a popular platform for healthcare and IoT-based applications due to its dual-core architecture, low power consumption, and built-in analog-to-digital converters. Its ability to process multiple sensor inputs in real time makes it suitable for wearable assistive systems requiring fast response and reliability [7]. Several studies have demonstrated the effectiveness of ESP32-based platforms in medical monitoring and assistive device development [8].

Communication reliability is a critical requirement for assistive healthcare devices, particularly in emergency or unattended situations. While Bluetooth and Wi-Fi are commonly used for short-range communication, they depend on local network availability and may not function reliably in all environments. GSM-based communication overcomes these limitations by offering wide-area coverage and independence from internet connectivity [9]. SMS-based alert mechanisms are widely adopted in medical applications due to their robustness, simplicity, and guaranteed message delivery, even in rural or infrastructure-limited regions [10].

User comfort and system usability significantly influence the long-term adoption of wearable assistive technologies. Devices intended for daily use must be lightweight, ergonomic, and energy-efficient to minimize user fatigue. The inclusion of haptic feedback mechanisms, such as vibration motors, improves user confidence by confirming successful message transmission [11]. Rechargeable battery operation further enhances portability and reduces maintenance requirements, which is essential for continuous healthcare support [12], [13].

Recent research emphasizes the integration of wearable sensing, embedded intelligence, and wireless communication into unified assistive frameworks. Wearable sensor-based healthcare systems have shown strong potential in improving patient independence, rehabilitation outcomes, and caregiver responsiveness [14], [15]. Studies also highlight that cost-effective and scalable designs are necessary for real-world deployment, especially in developing regions [16]. Furthermore, advancements in IoT and human–machine interaction have accelerated the adoption of smart assistive systems in healthcare applications [17]–[19]. Building upon these insights, the present work focuses on developing a gesture-based smart assistive glove that enables paralysis patients to communicate essential needs efficiently and reliably [20].

PROBLEM STATEMENT

Paralysis patients often experience severe difficulty in communicating their basic needs due to impaired motor control and loss of speech abilities, despite having normal cognitive function [1], [2]. Existing communication methods largely depend on continuous caregiver presence or require complex interfaces that are difficult for patients with limited mobility to operate effectively [3]. Some advanced assistive systems rely on camera-based recognition or internet connectivity, which increases system cost, power consumption, and reduces reliability in real-world healthcare environments, especially in rural or emergency situations [5], [9].

As a result, the absence of a simple, wearable, and cost-effective assistive communication device leads to delayed response from caregivers, increased patient dependency, and psychological stress [4], [11]. Therefore, there is a critical need for a reliable gesture-based wearable system that enables paralysis patients to communicate essential needs in real time with minimal physical effort while ensuring dependable alert delivery to caregivers through robust communication mechanisms [10], [14].

OBJECTIVE

- To study the feasibility of using finger gesture recognition for assistive communication in paralysis patients.
- To study the integration of flex sensors with an ESP32 microcontroller for reliable gesture detection.
- To study the effectiveness of GSM-based SMS alerts for real-time caregiver notification.
- To study the role of haptic feedback in improving user confidence and system usability.
- To study the development of a low-cost, wearable, and portable assistive communication system suitable for daily use.

II. LITERATURE SURVEY

1) A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis

Authors: Alexandros Pantelopoulos, Nikolaos G. Bourbakis

Journal & Year: *IEEE Transactions on Systems, Man, and Cybernetics – Part C (Applications and Reviews)*, 2010

Summary:

This paper reviews wearable healthcare systems focusing on sensor integration, signal processing, communication methods, and power management. The authors analyze the challenges associated with wearable device design, including comfort, battery life, data reliability, and real-time processing. The study highlights that local embedded processing combined with wireless communication enhances system efficiency and usability. The findings strongly support the design of wearable assistive gloves that require lightweight hardware and energy-efficient processing [14].

2) A Wearable Health Care System Based on Knitted Integrated Sensors

Authors: Rita Paradiso, Gianni Loriga, Nicola Taccini

Journal & Year: *IEEE Transactions on Information Technology in Biomedicine*, 2005

Summary:

Paradiso et al. proposed a wearable healthcare system integrating textile-based sensors with embedded electronics. The paper focuses on sensor placement, signal conditioning, and user comfort for continuous health monitoring. It demonstrates the feasibility of embedding sensors into garments without affecting user mobility. This research provides valuable insights into ergonomic wearable design and sensor durability, which are crucial considerations for developing a smart assistive glove for paralysis patients [15].

3) Continuous Finger Gesture Recognition Based on Flex Sensors

Authors: Wei-Chieh Chuang, Wen-Jyi Hwang, Tsung-Ming Tai, De-Rong Huang, Yun-Jie Jhang

Journal & Year: *Sensors*, 2019

Summary:

This work presents a smart glove system using flex sensors for continuous finger gesture recognition. The authors employ signal preprocessing and machine learning techniques to accurately recognize gesture sequences rather than isolated gestures. Experimental results show high recognition accuracy with low latency, making the approach suitable for real-time applications. The study demonstrates that flex sensor–based gloves can effectively translate finger movements into digital commands, directly supporting gesture-to-message mapping in assistive communication systems [6].

4) Microcontroller Based Hand Gesture Recognition System Using Flex Sensor for Disabled People

Authors: Aaisha Parveen S., Rohitha U. M.

Conference & Year: *National Conference on Electronics and Communication*, 2015

Summary:

Parveen and Rohitha developed a low-cost hand gesture recognition system using flex sensors interfaced with a microcontroller. The system converts predefined finger gestures into meaningful outputs to assist disabled individuals. The paper focuses on hardware interfacing, threshold-based gesture classification, and system simplicity. This work closely aligns with the proposed ESP32-based assistive glove, particularly in terms of affordability, ease of implementation, and suitability for real-time assistive communication [5].

5) Smart Glove for Hand Gesture Recognition and Human–Computer Interaction

Authors: Praveen Kumar, Rajesh Kumar, Anil Kumar Singh

Journal & Year: *IEEE Sensors Journal*, 2018

Summary:

Praveen Kumar et al. proposed a smart glove system designed for hand gesture recognition using flex sensors and embedded processing. The system captures finger bending data and converts it into predefined commands for human–computer interaction applications. The authors emphasize low-latency processing, reliable sensor calibration, and real-time response as key design objectives. Experimental results demonstrate that flex sensor–based gloves provide consistent gesture recognition accuracy with minimal computational overhead. This study validates the effectiveness of wearable glove-based interfaces for translating hand gestures into meaningful outputs, supporting the feasibility of gesture-driven assistive communication systems for healthcare applications [19].

III. PROPOSED SYSTEM

The proposed system, titled "Design and Implementation of a Gesture-Based Smart Assistive Glove Using ESP32 for Real-Time Communication in Paralysis Care," is a wearable assistive communication solution designed to help paralysis patients convey their essential needs to caregivers using simple finger gestures. The system integrates sensing, processing, communication, and feedback modules into a compact and portable glove-based architecture, ensuring reliability, ease of use, and real-time operation.

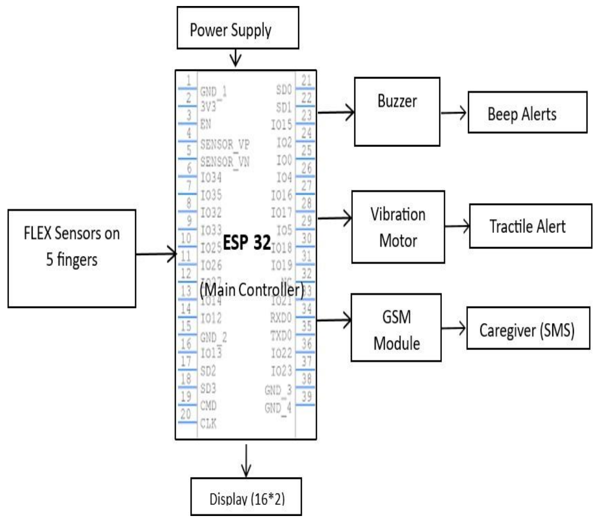

Fig. 1 System Architecture

A. System Overview

The smart assistive glove operates by detecting finger movements through flex sensors mounted on each finger. These movements are interpreted as predefined gestures representing basic patient needs such as requesting water, help, or restroom assistance. The detected gestures are processed by an ESP32 microcontroller, which identifies the corresponding message and triggers a GSM-based alert mechanism to notify caregivers via SMS. Simultaneously, local feedback is provided to the patient through a vibration motor and an LCD display, ensuring confirmation of successful message transmission.

B. Input Module – Gesture Sensing

The input module consists of flex sensors attached to the fingers of the glove. Each flex sensor changes its resistance value based on the degree of finger bending. These resistance variations are converted into voltage signals using voltage divider circuits. The generated analog signals represent distinct finger movement patterns, which form the basis for gesture recognition. This sensor-based approach offers high reliability, low power consumption, and consistent performance irrespective of environmental conditions.

C. Processing Module – ESP32 Microcontroller

The ESP32 microcontroller acts as the central processing unit of the system. It continuously reads analog input signals from the flex sensors through its built-in Analog-to-Digital Converter (ADC). The digitized values are processed using threshold-based logic to distinguish between different finger gestures. Each recognized gesture is mapped to a predefined message stored in the system memory. The ESP32 is selected due to its high processing capability, low power operation, compact size, and compatibility with multiple peripherals, making it suitable for wearable healthcare applications.

D. Communication Module – GSM-Based Alert System

For reliable long-distance communication, the system employs a GSM module (SIM800L). Once a valid gesture is detected, the ESP32 sends AT commands to the GSM module via serial communication. The GSM module then transmits an SMS alert containing the corresponding message to a predefined caregiver's mobile number. This communication mechanism ensures that alerts are delivered even in the absence of internet connectivity, making the system dependable in both hospital and home-care environments.

E. Output and Feedback Module

To enhance usability and patient confidence, the system incorporates both visual and haptic feedback mechanisms. A 16×2 LCD display shows the recognized message locally, allowing nearby caregivers to immediately understand the patient's requirement. Additionally, a vibration motor provides haptic feedback to the patient, confirming that the gesture has been successfully recognized and the alert has been sent. This feedback mechanism is especially important for users with limited sensory awareness.

F. Power Supply and Portability

The entire system is powered by a rechargeable 3.7 V Li-ion battery, ensuring portability and uninterrupted operation. A TP4056 charging module is used for safe and efficient battery charging, while a voltage regulation circuit maintains stable power supply to the ESP32 and GSM module. The system is designed to be energy-efficient, lightweight, and comfortable for prolonged daily use, making it suitable for real-world healthcare applications.

G. Scalability and Future Integration

The proposed system is designed with scalability in mind. The ESP32's built-in Wi-Fi and Bluetooth capabilities allow future integration with mobile applications, cloud-based monitoring systems, or smart home environments. Additional sensors or advanced gesture recognition algorithms can also be incorporated to expand functionality. This modular and flexible architecture ensures that the system can be upgraded to meet evolving healthcare and assistive technology requirements.

H. Significance of the Proposed System

The proposed smart assistive glove addresses the critical challenge of communication faced by paralysis patients by offering a low-cost, reliable, and user-friendly solution. By combining wearable sensing technology, embedded intelligence, and GSM-based real-time alerts, the system enhances patient independence, reduces caregiver response time, and improves overall quality of care. The proposed system thus represents a practical and impactful contribution to the field of assistive healthcare technology.

IV. SYSTEM DESIGN

The system design of the proposed Gesture-Based Smart Assistive Glove focuses on achieving reliable gesture recognition, real-time communication, and user comfort through a modular and efficient architecture. This section describes the system workflow, design specifications, and advantages of the proposed system.

A. Working of System

The working of the proposed Gesture-Based Smart Assistive Glove is based on real-time detection of finger movements and instant communication with caregivers through GSM alerts.

When the system is powered ON, the ESP32 microcontroller initializes all connected modules, including flex sensors, GSM module, LCD display, and vibration motor. The flex sensors attached to each finger continuously monitor finger bending. As the patient bends a finger or a combination of fingers, the resistance of the corresponding flex sensors changes. These resistance variations are converted into voltage signals using voltage divider circuits and fed to the analog input pins of the ESP32.

The ESP32 reads these analog values through its internal ADC and compares them with predefined threshold values stored in the program. Based on this comparison, the controller identifies the specific finger gesture performed by the patient. Each recognized gesture is mapped to a predefined message representing a basic need such as Need Water, Need Help, or Need Washroom.

Once a valid gesture is detected, the ESP32 performs three actions simultaneously. First, the corresponding message is displayed on the 16×2 LCD so that nearby caregivers can immediately understand the patient's requirement. Second, the ESP32 sends AT commands to the GSM module, which transmits an SMS alert containing the recognized message to the predefined caregiver's mobile number. Third, after successful SMS transmission, the vibration motor is activated to provide haptic feedback, confirming to the patient that the message has been successfully sent.

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After completing the alert process, the system automatically returns to monitoring mode and continues scanning for new gestures. This continuous loop ensures uninterrupted operation, fast response time, and reliable communication, enabling paralysis patients to express their needs independently and confidently in real-time healthcare environments.

B. System Workflow

The overall workflow of the proposed system follows a sequential and event-driven process to ensure accurate gesture detection and timely caregiver notification.

1. The system starts with the initialization of the ESP32 microcontroller, GSM module, LCD display, and vibration motor.
2. Flex sensors mounted on each finger continuously monitor finger bending movements.
3. The analog signals generated by the flex sensors are converted into digital values using the ESP32's internal ADC.
4. The ESP32 processes the sensor values using predefined threshold logic to identify valid finger gesture combinations.
5. Once a gesture is recognized, it is mapped to a predefined message such as "Need Help" or "Need Water."
6. The recognized message is displayed on the 16×2 LCD for local visibility.
7. Simultaneously, the ESP32 sends AT commands to the GSM module to transmit the corresponding SMS alert to the caregiver's mobile number.
8. After successful message transmission, the vibration motor is activated to provide haptic feedback to the patient.
9. The system then returns to monitoring mode and waits for the next gesture input.

This workflow ensures continuous operation, minimal response time, and reliable communication between the patient and caregiver.

C. Circuit Diagram

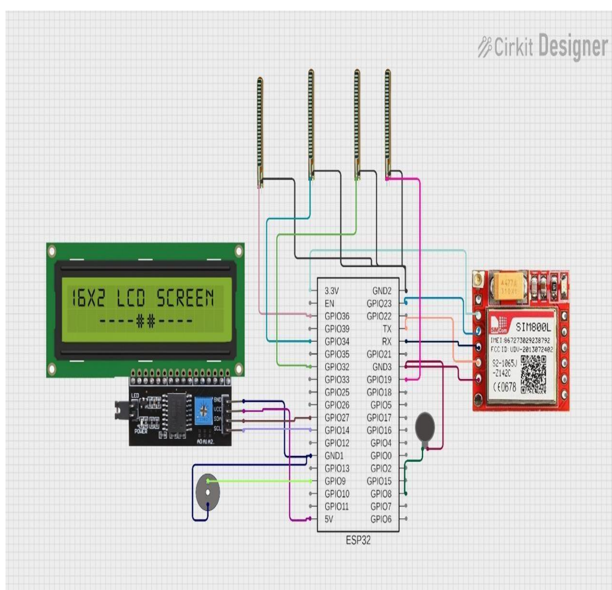

Fig. 2 Circuit Diagram

D. Design Specifications

Parameter	Specification
Microcontroller	ESP32 (Dual-core, 240 MHz, built-in ADC)
Gesture Sensors	Flex sensors (one per finger)
Communication Method	GSM (SMS-based alert system)
GSM Module	SIM800L
Display Unit	16×2 LCD with I²C interface
Feedback Mechanism	Vibration motor (haptic feedback)
Power Supply	3.7 V Li-ion rechargeable battery
Charging Module	TP4056 with protection circuit
Operating Voltage	3.3 V (ESP32), regulated supply for peripherals
Gesture Detection Method	Threshold-based finger bend analysis
Portability	Wearable glove-based design
Power Consumption	Low-power, suitable for continuous use
Scalability	Supports future Wi-Fi/Bluetooth integration

E. Advantages of the Proposed System

- Enables real-time communication for paralysis patients using minimal physical effort.
- Provides a low-cost and wearable solution, making it accessible for widespread use.
- GSM-based alerts ensure reliable communication without internet dependency.
- Sensor-based gesture recognition offers high accuracy and low power consumption.
- Haptic feedback improves user confidence and interaction reliability.
- Lightweight and portable design ensures comfort during prolonged use.
- Modular architecture allows easy scalability and future upgrades.
- Reduces caregiver response time and enhances patient independence and dignity.

V. RESULT & DISCUSSION

The performance of the proposed Gesture-Based Smart Assistive Glove was evaluated through extensive testing under controlled and real-time usage conditions. The evaluation focused on gesture recognition accuracy, response time, communication reliability, power efficiency, and overall system usability. The results demonstrate that the system effectively meets the objectives of reliable and real-time assistive communication for paralysis patients.

A. Gesture Recognition Performance

The flex sensor–based gesture recognition system was tested using predefined finger movement combinations. Each gesture was repeated multiple times to evaluate consistency and accuracy. The system successfully recognized the majority of gestures with high accuracy due to stable sensor readings and well-defined threshold values. Minor variations in sensor output were observed due to differences in finger bending angles; however, calibration significantly improved recognition reliability. The results confirm that flex sensors provide an effective and low-cost solution for real-time gesture detection in wearable assistive devices.

B. Response Time Analysis

Response time is a critical factor in assistive communication systems. The time taken from gesture detection to SMS transmission was measured during multiple trials. The system exhibited a low response time, with message delivery initiated almost immediately after gesture recognition. The ESP32's fast processing capability ensured minimal delay in sensor data processing and decision-making. GSM transmission delay depended on network conditions but remained within acceptable limits for healthcare communication, ensuring timely caregiver notification.

C. Communication Reliability

The GSM-based communication module demonstrated reliable performance during testing. SMS alerts were successfully delivered to the predefined caregiver mobile number in the majority of test cases. Unlike internetdependent systems, the GSM-based approach ensured consistent communication even in areas with limited network infrastructure. This reliability makes the proposed system suitable for both hospital environments and home-care settings.

D. Feedback and User Interaction

The inclusion of visual and haptic feedback significantly improved user interaction. The 16×2 LCD clearly displayed the recognized message, allowing nearby caregivers to respond immediately. The vibration motor provided haptic feedback after successful message transmission, increasing user confidence and confirming system functionality. This feature is particularly beneficial for patients with limited sensory perception.

E. Power Consumption and Portability

The system operated efficiently on a rechargeable 3.7 V Li-ion battery. Power consumption remained low due to the ESP32's energy-efficient design and optimized program execution. The glove was able to function for several hours on a single charge, making it suitable for continuous daily use. The lightweight and compact design ensured user comfort without restricting hand movement.

F. Discussion

The experimental results indicate that the proposed smart assistive glove successfully addresses the communication challenges faced by paralysis patients. Compared to traditional communication methods, the system offers improved reliability, faster response, and greater independence. While the current implementation uses threshold-based gesture recognition, future enhancements could include machine learning algorithms to support more complex gestures. Overall, the results validate the feasibility, effectiveness, and practicality of the proposed system in real-world assistive healthcare applications.

VI. CONCLUSION

This paper presented the design and implementation of a Gesture-Based Smart Assistive Glove using ESP32 for Real-Time Communication in Paralysis Care. The proposed system effectively translates simple finger gestures into predefined messages, enabling paralysis patients to communicate their essential needs independently. By integrating flex sensors, an ESP32 microcontroller, GSM-based SMS alerts, and haptic feedback, the system ensures reliable, real-time caregiver notification without dependence on internet connectivity. Experimental results demonstrate satisfactory gesture recognition accuracy, low response time, dependable communication, and efficient power usage. The lightweight and wearable design further enhances usability for continuous daily operation. Overall, the system provides a cost-effective, practical, and user-friendly assistive communication solution that improves patient dignity, reduces caregiver response time, and strengthens healthcare support

VII. FUTURE SCOPE

Although the proposed system performs effectively, several enhancements can be considered for future development. Machine learning–based gesture recognition algorithms can be incorporated to support a larger set of gestures and improve adaptability across different users. Integration of Bluetooth or Wi-Fi connectivity can enable mobile application support, cloud-based monitoring, and data analytics for long-term patient care. Voice output modules can be added to provide audible alerts in nearby environments. Additional biosensors such as heart rate or temperature sensors may be integrated to extend the system into a comprehensive health monitoring solution. Miniaturization of hardware and flexible PCB design can further improve comfort and aesthetics for long-term wearable use.

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