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IoT and cloud enabled Motion Communication and ML Assisted Recovery system for Paralytics

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Abstract
Effective communication remains a significant challenge for individuals with paralysis or severe physical disabilities. Existing communication aids such as sign language and speech-generating devices often face limitations related to complexity, cost, and the requirement of prior training. This research introduces a novel "IoT and cloud enabled Motion Communication and ML Assisted Recovery system for Paralytics," a wearable, gesture-based communication system integrated with Internet of Things (IoT) technology. The device employs a glove embedded with five flex sensors to detect finger movements and translate these into binary signals corresponding to predefined messages. An ESP32 microcontroller processes these signals and transmits messages via Wi-Fi using the Blynk IoT platform to caregivers' mobile applications in real time.

Additionally, integrated biomedical sensors continuously monitor vital signs including body temperature, heart rate, and blood oxygen saturation (SpO_2), providing crucial health data for proactive caregiving. The system's design prioritizes lightweight, cost-effectiveness, and ease of use, making it suitable for continuous operation in diverse healthcare environments, including resource-constrained settings. Experimental evaluation confirms high gesture recognition accuracy, low latency, and reliable biomedical sensing, highlighting the device's potential to enhance communication autonomy and health monitoring for physically challenged individuals.

1. INTRODUCTION

Communication is a critical component of human interaction and independence. For individuals with paralysis or severe physical disabilities, the inability to communicate effectively results in social isolation, emotional distress, and reduced quality of life. Current communication methods such as sign language require extensive training, while advanced speech-generating devices tend to be expensive, cumbersome, and not universally accessible. Consequently, there is a pressing need for cost-effective, user-friendly communication aids that can operate reliably in real-world scenarios, especially in resource-limited settings.

Recent advances in wearable technologies and IoT offer promising avenues to address these challenges. Gesture-based systems, which translate physical finger and hand movements into meaningful messages, provide intuitive communication channels for those with limited mobility. Furthermore, integrating biomedical monitoring allows continuous health assessment, which is vital for this vulnerable population. Incorporating machine learning can further enhance system accuracy and adaptability, tailoring communication to individual users' unique movement patterns.

This research introduces an innovative system combining these technologies—a glove-based wearable device embedded with flex sensors for motion detection, an ESP32 microcontroller for processing and communication, biomedical sensors for vital sign monitoring, and a cloud-based platform utilizing ML algorithms to refine gesture recognition. The system aims to restore communication abilities, support health monitoring, and facilitate recovery for paralytic individuals.

Recent advances in wearable technologies and the Internet of Things (IoT) offer promising avenues to address these challenges. Gesture-based systems, which translate physical finger and hand movements into meaningful messages, provide intuitive communication channels for those with limited mobility. Furthermore, integrating biomedical monitoring allows continuous health assessment, which is vital for this vulnerable population. Incorporating machine learning can further enhance system accuracy and adaptability, tailoring communication to individual users' unique movement patterns.

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2.Related Works

Recent advancements in assistive technologies have demonstrated promising solutions for improving communication and healthcare monitoring among physically challenged individuals. These systems typically integrate sensors, microcontrollers, and IoT platforms to enable non-verbal users to convey essential messages and share vital health data with caregivers. Below are key contributions in this field.

Ali et al. (2010) designed an electronic speaking glove aimed at converting hand gestures into speech for speechless patients. This glove used sensors to detect finger movements and translate them into audible words, enhancing communication. [1] Bhatti et al. (2009) proposed an electronic hand glove to assist speech-impaired and paralyzed individuals. The glove translated sign language gestures into speech, providing a low-cost and efficient communication tool. [2] Edin et al. (2013) developed a wearable real-time hand data glove for human-computer interaction. It enabled gesture recognition with improved precision, facilitating applications in robotics and assistive technologies.[3] Fahn and Sun (2000) introduced a sensory data glove using neural-network-based calibration. Their glove improved gesture recognition accuracy and adapted to individual user patterns for better usability. [4] Ingulkar and Gaikwad (2013) created a real-time wearable hand data glove similar to Edin et al., focusing on intuitive human-computer interactions through gesture recognition, beneficial for both medical and tech fields.[5] Peng et al. (2015) also developed a hand data glove emphasizing real-time interaction and ergonomic design. It enhanced usability for disabled users by accurately capturing hand gestures. [6] Radzi et al. (2019) designed a smart glove for speech and hearing impaired people, integrating sensors and microcontrollers. It offered real-time gesture-to-speech translation with improved reliability.[7] Rajamalli and Premalatha (2018) presented a smart glove targeting communication needs of deaf and dumb individuals. The glove converted hand signs into voice, ensuring greater independence. [8] Patel et al. (2023) introduced a smart glove integrated with

Google Assistant to aid disabled people in controlling devices. It showcased a fusion of IoT and assistive tech for daily utility.[9]

Gayathri et al. (2021) proposed a communicative guiding system for physically challenged individuals. Using embedded systems, it enhanced navigation and interaction abilities of users with mobility issues. [10] Future of Privacy Forum (2018) explores the advantages and potential privacy challenges of IoT for persons with disabilities, providing insights into ethical concerns and inclusive design practices. [11] ScienceDirect (2020) presents an IoT device aimed at enhancing daily assistance for disabled individuals, with sensors and automation improving their interaction with the environment. [12] Springer (2021) details an intelligent control system for physically disabled people using IoT to facilitate remote access and control of essential appliances.[13]

WSEAS (2021) proposes a smart home automation system using IoT to aid disabled individuals, focusing on personalized control and energy-efficient accessibility.[14] ScienceDirect (2023) introduces a secure communication system that ensures data privacy while supporting assistive functionalities for disabled users via smart devices.[15] ScienceDirect (2023) discusses an IoT-based home automation solution designed to cater to various disabilities, enhancing independence and convenience in daily activities.[16]

IEEE (2017) proposes a wearable aid for visually impaired users combining haptic and audio feedback, improving spatial awareness and navigation. [17] Springer (2023) introduces a voice-activated IoT system to assist disabled individuals in controlling devices and communicating with ease, enhancing smart living.[18] IJERT (2023) discusses IoT-based smart assistance gloves that convert gestures into text or speech, supporting communication for people with speech impairments.[19] IJERT (2023) introduces a wearable glove for speech and hearing-impaired individuals, using sensors to translate sign language into voice signals.[20] IJERT (2023) presents a smart speaking glove designed for deaf and mute users, enabling real-time gesture recognition and voice output.[21]

JETIR (2024) details the design of a sensor-based smart glove that aids physically challenged individuals in communication and device interaction. [22] JETIR (2019) presents a wearable smart glove for disabled users, converting hand gestures into readable outputs, improving accessibility.[23] IJERT (2023) duplicates [19], describing gesture-recognition smart gloves that offer IoT-based assistance for disabled communication. [24] IJERT (2023) is the same as [20], introducing smart gloves that aid hearing and speech-impaired users through gesture-to-speech functionality.[25]

IJERT (2023) duplicates [21], focusing on speech conversion from gestures via smart gloves for deaf and mute individuals. [26] JETIR (2024) is the same as [22], explaining the sensor-enabled smart glove design aimed at assisting the physically disabled in interaction.

[27] JETIR (2019) matches [23], featuring a wearable device that interprets gestures for improved communication among disabled individuals.[28]

3.Proposed system

The proposed system is an IoT-based wearable communication and health monitoring device, specifically designed to assist individuals who are paralytic or have severe physical disabilities. These individuals often face communication barriers due to limited motor functions and lack of speech ability. Traditional methods such as sign language, cue cards, or expensive speech-generating devices are not always practical, affordable, or accessible. To bridge this gap, the system combines gesture recognition and vital health monitoring into a single, compact, user-friendly solution.

3.1. System Overview

At the core of the device is a smart wearable glove embedded with five flex sensors—one for each finger. These sensors detect the bending or straightening of fingers. Each finger position is translated into a binary digit:

- '**1**' for a bent finger
- '**0**' for a straight or relaxed finger

With five fingers, the system can generate up to 32 unique binary combinations ($2^5 = 32$), each mapped to a predefined message (e.g., "I need water", "Call for help", "I'm in pain"). This allows the user to communicate a variety of essential needs and emotions.

3.2 Signal Processing and Microcontroller

The glove is powered by an ESP32 microcontroller, known for its integrated Wi-Fi and Bluetooth capabilities, enabling wireless data transmission. Since the flex sensors produce analog signals, they are first converted into digital format using an ADS115 Analog-to-Digital Converter (ADC). Once converted, the ESP32 processes these digital signals to identify the specific gesture made by the user.

After recognizing the gesture, the microcontroller maps it to a corresponding message and sends it in real-time to a mobile application using the Blynk IoT platform.

The mobile application displays this message instantly to the caregiver, facilitating timely action.

3.3. Health Monitoring Integration

In addition to gesture communication, the glove integrates real-time health monitoring sensors, including:

- Body Temperature Sensor
- Heart Rate Sensor
- SpO_2 Sensor (Blood Oxygen Monitor)

These sensors continuously collect the user's vital data, which is also transmitted through the Blynk platform. This ensures that caregivers are not only informed about the user's needs but are also alerted if any medical emergency arises based on abnormal health readings.

3.4. User Calibration and Adaptability

Before first-time use, the system performs a threshold calibration to assess the patient's finger movement capability. If a user cannot meet the minimum bend threshold, the system recommends physiotherapy. Once the user's movement improves, the device can be recalibrated and activated. This step ensures that the device works accurately and reliably, tailored to the user's physical ability.

3.5. Output and Alerts

The system uses dual output modes:

- Visual display on the caregiver's mobile application
- Text-to-speech (planned for future versions) for voice-based alerts

In addition, automated alerts are triggered if any health parameter crosses critical limits—for example, low SpO_2 or abnormal heart rate. These alerts are displayed on the mobile app, enabling fast medical response.

3.6. Design Considerations

The glove is designed to be:

- Lightweight and comfortable for extended wear
- Battery-powered and rechargeable
- Cost-effective, using easily available components

4.SYSTEM ARCHITECTURE

The system architecture of the Motion-Based Message Conveyer is designed as a layered and modular structure that enables seamless gesture-based communication and real-time health monitoring for physically challenged individuals. It integrates hardware components, firmware logic, cloud-based communication, and mobile interfacing into a compact, efficient, and wearable assistive device. The architecture can be broadly divided into five major layers:

4.1 Input Layer – Sensor Interface

This layer captures real-world physical inputs from the user through various sensors:

4.1.1 Flex Sensors (x5):

Placed on each finger of the wearable glove, these sensors detect bending motions. Each bend produces a variable resistance, which is converted into analog voltage. A bent finger is interpreted as binary '1', and a straight finger as '0'. This binary pattern is later used to identify gestures.

- Health Monitoring Sensors:
- Temperature Sensor – Measures body temperature.
- Heart Rate Sensor – Detects pulse via fingertip or wrist.
- SpO_2 Sensor – Measures blood oxygen saturation levels.

These sensors continuously collect data, which is essential for interpreting both communication gestures and the user's current health status.

4.2. Processing Layer – Data Handling and Interpretation

At the core of the system is the **ESP32 microcontroller**, which serves as the main processing unit. It performs the following tasks:

4.2.1 Analog-to-Digital Conversion:

The ESP32 receives analog signals from the flex sensors, which are digitized using the ADS115 ADC module to ensure accurate resolution.

4.2.2 Gesture Recognition:

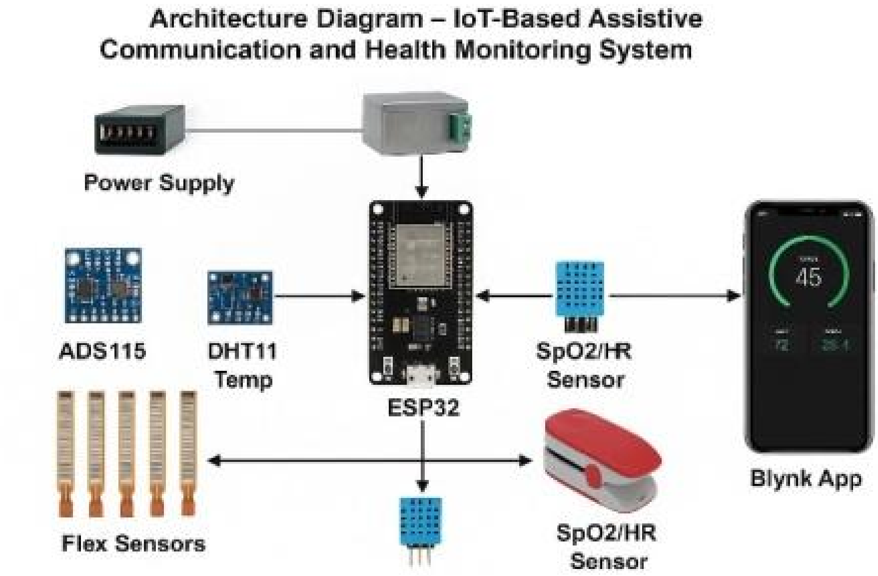
Based on the binary values derived from the five fingers (e.g., 10101), the system maps the pattern to a predefined message (like “Need Water” or “Emergency Help”).

4.2.3 Health Data Interpretation:

The ESP32 also collects raw data from the health sensors and applies filters like moving average smoothing to reduce noise and improve reliability.

4.2.4 Data Packaging:

Once processed, gesture commands and health readings are formatted into a structured format (e.g., JSON or key-value pairs) for transmission.



4.3. Communication Layer – IoT Integration

This layer ensures seamless data exchange between the device and the external monitoring interface.

4.3.1 Wi-Fi Communication:

The ESP32's built-in Wi-Fi module connects to the internet and communicates with the cloud.

4.3.2 Blynk IoT Platform:

The system uses the Blynk platform to send real-time messages and sensor data to the caregiver's smartphone. Blynk provides virtual widgets such as LED indicators, text displays, graphs, and alert notifications that reflect current system status.

4.4 Output Layer – User Interface

The output is delivered to the end user—typically a caregiver—through the Blynk mobile application, which provides:

4.4.1 Real-time message display (e.g., "Call Family", "Help Me").

4.4.2 Live health monitoring dashboard for temperature, heart rate, and SpO_2 levels.

4.4.3 Instant alerts when critical thresholds (e.g., low oxygen levels) are crossed. This layer ensures that the communication is timely, understandable, and actionable by the caregiver.

4.5 Power and Enclosure Layer – Wearability & Portability

4.5.1 Power supply

The system runs on a rechargeable battery, ensuring portability and uninterrupted usage.

4.5.2 Enclosure:

All components are embedded into a lightweight, wearable glove that is designed for comfort and ease of use. The design ensures that users can wear the device for extended periods without fatigue or discomfort.

5. Experimentation and Results

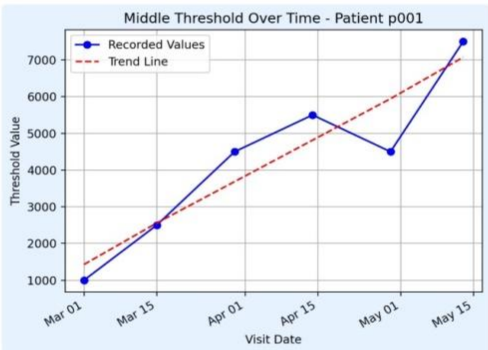
To evaluate the effectiveness and reliability of the proposed wearable notification system, a series of experiments were conducted. These experiments focused on testing gesture recognition accuracy, real-time data transmission, and health parameter monitoring. The system was assembled using the ESP32 microcontroller, flex sensors, and vital sign sensors, and it was programmed and integration to the Blynk IoT platform. The primary objective was to verify whether different hand gestures could be accurately recognized and converted into predefined commands, and whether real-time notifications and health updates could be reliably transmitted to a caretaker's mobile device. The outcomes were recorded, analyzed, and assessed based on communication efficiency, system responsiveness, and health data accuracy.

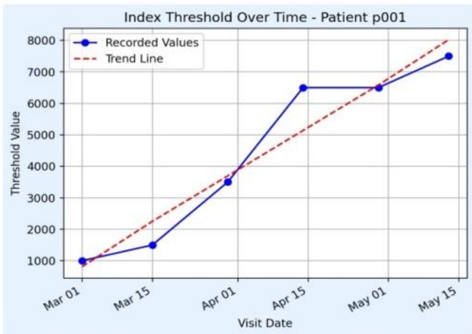
5.1 **Experimental Setup**

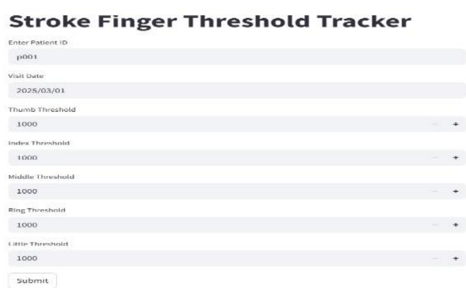
The experimental setup involved assembling both the hardware and software components of the IoT-based assistive communication device. The primary goal was to test the functionality of gesture recognition and real-time health monitoring for physically challenged individuals.

5.2 Preprocessing: Threshold Calibration and Patient Assessment

Prior to activating the main functionality of gesture-based communication, the system performs a **threshold calibration to** assess the patient's finger mobility. This step determines whether the patient's finger flexion meets the minimum required bend range to reliably operate the glove-based communication device. Preprocessing is a critical step to prepare the datasets for effective model :







5.2.1. Initial Check:

The patient is asked to perform simple bending and releasing movements of each finger. Flex sensor values are recorded for both fully extended (unbent) and fully bent positions. A threshold is calculated to determine the distinction between bent (1) and unbent (0) states.

5.2.2. Assessment Criteria:

If the calculated threshold value is below the required level, it indicates insufficient finger movement. Since the patient cannot talk and cannot gesture properly, physiotherapy is recommended to improve finger flexibility.

5.2.3. Post-Therapy Evaluation:

After a set period of physiotherapy, the calibration is repeated. If there is improvement in finger movement (threshold now meets the required level), the patient can communicate naturally without the glove. If there is no significant improvement, the glove system is implemented to assist with gesture-based communication.

5.3 EVALUATION METRICS

To assess the performance, reliability, and effectiveness of the wearable glove system, several evaluation metrics were defined and measured during experimentation. These metrics help determine the system's capability in accurate gesture detection, communication efficiency, and health monitoring responsiveness.

5.3.1. Gesture Recognition Accuracy

Measures how correctly the system identifies the finger combinations and translates them into predefined commands.

5.3.2. Response Time

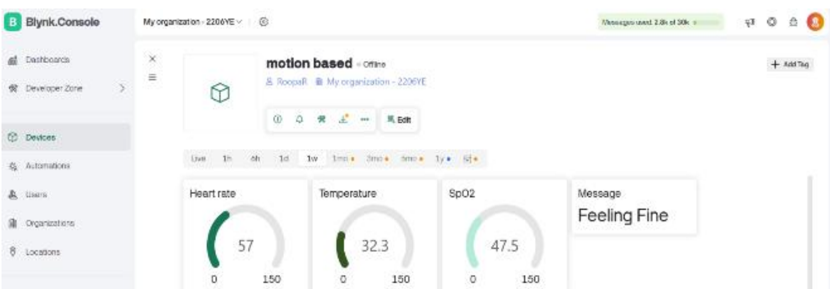
The time taken by the system to detect a gesture and send the corresponding notification to the caretaker. Lower response time indicates better real-time communication. Measured in milliseconds (ms).

5.3.3. False Positive Rate (FPR)

Indicates how often the system misinterprets a hand movement as a valid command.
Important for avoiding unintended messages being sent to caregivers.

5.3.4. Health Data Transmission Accuracy

Measures the reliability of real-time transmission of temperature, heart rate,and SpO2 values from the glove.



5.3.5. Battery Efficiency

Tracks the power consumption of the glove under continuous use. Helps estimate the operating time before requiring a recharge.

5.3.6. User Comfort and Adaptability

Collected through user feedback (or caretaker feedback, if the user is non-verbal). Measures how easy it is for the patient to use the glove and whether it causes any discomfort during prolonged usage.

6.Conclusion

The proposed IoT and Cloud-Enabled Motion Communication and ML-Assisted Recovery System for Paralytics represents a significant advancement in assistive technology, combining gesture-based communication with real-time health monitoring in a single, wearable device. Designed to empower physically challenged individuals, especially those suffering from paralysis, the system enables seamless and efficient interaction with caregivers using intuitive hand gestures.

By leveraging the ESP32 microcontroller, flex sensors, vital sign monitors, and the Blynk IoT platform, the prototype demonstrates a high degree of accuracy in recognizing predefined commands and transmitting critical health data in real-time. The integration of threshold-based preprocessing ensures adaptability to various patient mobility levels, while the modular and cost-effective architecture makes it scalable and accessible.

Despite certain limitations such as dependency on finger mobility and internet connectivity, the system offers a viable alternative to traditional communication aids, significantly enhancing the autonomy and quality of life for its users.

In conclusion, this work provides a practical and innovative solution tailored to the needs of the physically challenged community. It bridges the communication gap while prioritizing patient health and safety, thereby contributing meaningfully to the fields of healthcare, rehabilitation, and human-computer interaction.

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