SMART GLOVES FOR GESTURE RECOGNITION AND HEALTH MONITORING

[1]Neha Santhosh, [2]Dawn Dennis, [3]Harigovind H, [4]Jasmin V Jose, [5]Neethan Elizabeth Abraham

Dept. of Electronics and Communication Engineering St. Joseph's College of Engineering and Technology Palai (Autonomous), Kerala, India

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Abstract-*In today's world, ensuring the well-being of individuals with speech and mobility impairments is a significant challenge, as traditional care methods remain vulnerable to communication gaps and delayed emergency response. To address these issues, a Smart Glove System is proposed to enforce seam-less assistive communication and real-time health monitoring through affordable wearable technology. The system utilizes an ATmega328P microcontroller as the central processing unit, integrated with flex sensors for gesture-based message transmission. By leveraging an MPU6050 IMU for fall detection and a MAX30102 pulse oximeter for heart rate monitoring, and providing clear Bluetooth-based audio-visual feedback, this device offers a comprehensive and cost-effective solution for elderly care and individuals with physical impair-ments, ensuring a safe and responsive caregiving environment.*

Index Terms-Assistive Technology, ATmega328P, Flex Sensor, Gesture Recognition, MPU6050, MAX30102, Bluetooth Commu-nication.

I. INTRODUCTION

Speech and mobility impairment significantly affect communication and emergency response for elderly and physically challenged individuals. Many users are unable to express their needs during critical situations, increasing their dependence on caregivers. Existing healthcare systems often lack integrated communication and health-monitoring features within a single wearable device.

To address these challenges, this project proposes a Smart Glove System capable of gesture recognition, heart-rate monitoring, and fall detection. The system uses flex sensors for detecting finger gestures, an MPU6050 IMU for fall detection, and a MAX30102 pulse oximeter for heart-rate monitoring. An Arduino Uno acts as the processing unit, while an HC-05 Bluetooth module enables wireless communication with caregivers.

The proposed system provides a low-cost, portable, and real-time healthcare assistance solution suitable for elderly people, paralysis patients, and speech-impaired individuals.

A. Problem Statement

To develop a microcontroller-based smart glove us-ing integrated sensors for empowering individuals with movement difficulties by providing a smart, easy-to-use glove that enables communication and ensures safety through real-time health monitoring at an estimated cost of Rs.4500 ± 10%.

B. Objectives

1) To develop a system for translating hand gestures into speech.
2) To facilitate the real-time monitoring of heart rate.
3) To enable the detection of falls and provide timely alerts.
4) To design a cost-effective and user-friendly assistive device.
5) To improve the overall quality of life of individuals with speech and mobility impairments.

In view of these objectives, the proposed system is designed to deliver a comprehensive solution that improves communication and health monitoring for individuals with speech and mobility disabilities. By integrating gesture recognition, fall detection, and heart rate monitoring into one wearable device, the proposed system ensures prompt assistance and patient safety. Its affordability and ease of use make it appropriate for hospital and home care settings. Overall, the proposed Smart Glove System is designed to enhance independence and quality of life for individuals with speech and mobility disabilities.

II. LITERATURE REVIEW

In recent times, significant research has been conducted in the area of assistive technologies to enhance the quality of life for individuals suffering from various speech and mobility disorders. Various methods have been proposed for gesture recognition, wearable technology, fall detection sys-tems, and real-time health monitoring systems. Studies indi-cate that sensor technology and embedded systems can be combined effectively to enhance communication and patient care. However, existing studies have focused on individual areas, and little emphasis has been placed on developing a comprehensive and cost-effective system that integrates communication assistance and continuous health monitoring. Hence, it is important to perform a comprehensive literature review to understand various methodologies and justify the importance of developing such a system. Various researchers have proposed wearable smart glove systems and sensor-based healthcare technologies for gesture recognition, activity monitoring, rehabilitation, and assistive communication. Smart glove systems using flex sensors, MPU6050 gyroscope sensors, MAX30100 sensors, Arduino microcontrollers, and GSM modules have been developed for gesture recognition, fall detection, and health monitoring in paralysis patients [1]. Wearable sensing technologies involving accelerometers, gyroscopes, IMUs, EMG sensors, and force sensitive resistors have also been widely studied for activity monitoring and motion control applications in healthcare and rehabilitation systems [2]. IoT-based smart gloves integrating Arduino, ESP8266 modules, cloud platforms, SMS alerts, and health-monitoring sensors have been proposed for elderly care and emergency communication [3]. In addition, wearable assistive gloves using flex sensors, pulse sensors, ultrasonic sensors, and ESP32 controllers have been designed for gesture based communication, obstacle detection, and patient safety [4]. Recent studies have also focused on multimodal wearable sensors, biochemical biosensors, and advanced data-processing techniques for continuous and non-invasive health monitoring applications [5]. Across the reviewed studies, various smart glove systems and wearable sensor technologies have been proposed to help individuals suffering from communication difficulties and health monitoring requirements. However, various limitations have been identified in all these studies. Some of these limitations include the requirement for communication technologies such as GSM, which increases power consumption and is not compatible with modern applications based on smartphones [1]. Challenges related to multi-modal sensor integration, reliability, and user compliance have been identified observed [2]. Additionally, limitations related to sensor precision, difficulty in precise gesture recognition, lack of system miniaturization, and security concerns related to data transmission and connectivity in remote areas have been identified [3]. Some systems lack reliability in terms of fall detection and remote health monitoring, and various systems have been identified to increase hardware complexity and power consumption [4]. Furthermore, limitations related to reliability, security, user variability, and lack of standardization have been identified in wearable health monitoring [5]. There-fore, there is a need for a comprehensive wearable system that effectively combines communication assistance with real-time health monitoring and emergency support, which motivates the development of the proposed Smart Glove System.

III. METHODOLOGY

The proposed Smart Glove System is designed as a wearable assistive device that combines gesture recognition, health monitoring, and emergency alert functionalities into a single portable platform. The system integrates flex sensors, MPU6050 inertial measurement unit, MAX30102 pulse oximeter sensor, HC-05 Bluetooth module, piezoelectric buzzer, and Arduino Uno microcontroller for real-time communication and monitoring.

A. Detailed Block Diagram Description

The Smart Glove System is designed by dividing the hardware architecture into multiple functional subsystems to ensure efficient signal processing, reliable communication, stable power management, and continuous health monitoring. The major subsystems of the Smart Glove are described below:

- **Power Supply System:** The Smart Glove is powered using a rechargeable 3.7V lithium-ion battery integrated with a TP4056 charging module for safe charging and battery protection. Since the Arduino Uno and connected peripherals require a stable 5V supply, an MT3608 boost converter is used to step up the battery voltage to a regulated 5V DC output. This subsystem ensures unin-terrupted and portable operation of the wearable device.
- **Processing Core Subsystem:** The processing unit of the Smart Glove is built around the Arduino Uno based on the ATmega328P microcontroller operating at a clock speed of 16 MHz. The microcontroller continuously collects and processes sensor data from all connected modules. It also manages UART and I^2C communication interfaces for wireless data transmission and sensor integration.
- **Gesture Recognition Interface:** The gesture recognition subsystem consists of flex sensors mounted on the fingers of the glove. The flex sensors operate as variable resis-tance sensors whose resistance changes according to the amount of finger bending. The analog voltage variations are read by the Arduino Uno through analog input pins

and processed to identify predefined hand gestures.

- **Health Monitoring Subsystem:** The MAX30102 pulse oximeter sensor is used for continuous heart-rate monitoring. The sensor measures pulse signals using photo plethysmo graphy (PPG) technology and communicates with the Arduino Uno through the I²C communication protocol. This subsystem enables real-time monitoring of the user's physiological condition.
- **Motion Detection Subsystem:** The MPU6050 inertial measurement unit consists of a 3-axis accelerometer and a 3-axis gyroscope for detecting motion and orientation. The sensor continuously monitors sudden changes in acceleration and abnormal movement patterns to identify fall conditions. The MPU6050 communicates with the Arduino Uno using the I²C interface.
- **Wireless Communication Interface:** The HC-05 Blue-tooth module establishes wireless communication be-tween the Smart Glove and the caregiver's mobile de-vice. The module is connected through the UART serial interface and transmits gesture messages, health data, and emergency alerts in real time.
- **Alert and Notification System:** A piezoelectric buzzer is connected to the digital output pin of the Arduino Uno to generate immediate audible alerts during emergency situations such as fall detection or abnormal health con-ditions. This subsystem provides additional safety support for the user.

The integration of these functional subsystems enables the Smart Glove System to provide reliable gesture-based commu-nication, continuous health monitoring, emergency detection, and wireless caregiver assistance within a compact and wear-able embedded platform.

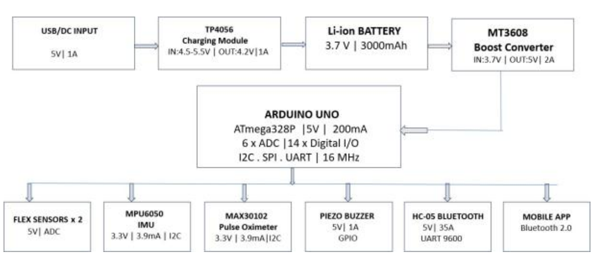

Fig. 1. Detailed Block Diagram of the smart glove system

B. Use Case Analysis

The Smart Glove System consists of three major actors: User, Caregiver, and Healthcare Professional. The user interacts with the system by performing hand gestures using the wearable glove. Flex sensors detect finger movements and the Arduino Uno processes the signals to identify predefined gestures such as "Need Water", "Need Food", and "Need Help".

The caregiver receives gesture messages, heart-rate data, and emergency alerts through Bluetooth communication. The caregiver can continuously monitor the user's condition and respond quickly during emergencies.

Healthcare professionals can use the Smart Glove System for monitoring patients during rehabilitation and recovery. The system also assists in observing health conditions and detect-ing emergency situations such as falls using the MPU6050 sensor.

The use case analysis demonstrates that the Smart Glove System provides effective communication assistance, continu-ous health monitoring, and emergency support for individuals with speech and mobility impairments.

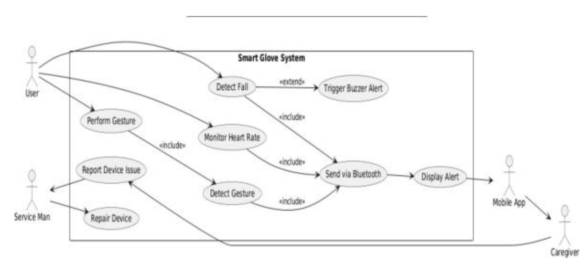

Fig. 2. Use Case Diagram of the Smart Glove System

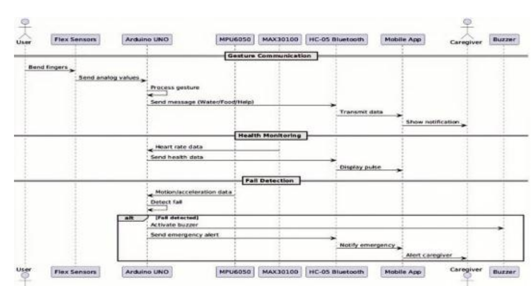

Fig. 3. Sequence Diagram

C. Actor Roles and Responsibilities

- **User:** The primary actor who wears the Smart Glove and performs hand gestures for communication. The user also benefits from continuous heart-rate moni-toring and fall detection functionalities provided by the system.

- **Caregiver:** The caregiver receives gesture mes-sages, health-monitoring data, and emergency alerts through Bluetooth communication. The caregiver can continuously monitor the user's condition and provide immediate assistance during emergencies.
- **Healthcare Professional:** Doctors, nurses, and re-habilitation specialists use the Smart Glove System for patient monitoring, rehabilitation support, and health assessment during treatment and recovery processes.
- **Service Technician:** The service technician is re-sponsible for maintaining the proper functioning of the Smart Glove System, including sensors, com-munication modules, battery system, and hardware connections.

IV. SURVEY ANALYSIS AND RESPONSES

The survey analysis showed strong acceptance of the proposed Smart Glove System among users, caregivers, and healthcare professionals.

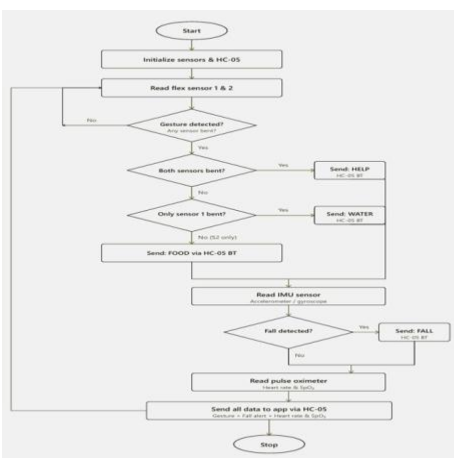

Fig. 4. System Flowchart representing Core Firmware Logic

- Around **60–70%** of respondents prioritized gesture-based communication for improving daily indepen-dence.
- More than **90%** of caregivers monitored patients daily, while over **85%** showed willingness to use wearable assistive systems.
- Safety features such as **fall detection, emergency alerts, and heart-rate monitoring** received the highest preference among users.
- Most respondents expected an emergency response time below **5 seconds** and a minimum battery backup of **6 hours.**
- Preferred system cost was below **Rs. 5000**, high-lighting the need for an affordable and portable design.
- Major concerns identified were **comfort, reliability, ease of use, and low power consumption**.

The survey responses confirmed the feasibility and prac-tical importance of the Smart Glove System for assisting individuals with speech and mobility impairments.

V. TARGET USERS

- Primary Users: Individuals with Paralysis, Stroke Sur-vivors, Elderly people
- Secondary Users: Caregivers and Family Members, Healthcare Professionals, Hospital and Clinical Staff
- Teritiary Users: Healthcare Institutions, Researchers and Developers, Disability Advocacy Organizations

VI. SYSTEM REQUIREMENTS

The hardware specifications and component requirements of the proposed Smart Glove System are summarized in the following configuration tables.

TABLE I ARDUINO UNO SPECIFICATIONS

Parameter	**Value Specification**
Microcontroller	ATmega328P
Operating Voltage	5V DC
Clock Frequency	16 MHz
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Digital I/O Pins	14 Pins
Analog Input Pins	6 Pins
Communication Protocols	UART, I^2C, SPI

TABLE II FLEX SENSOR SPECIFICATIONS

Parameter	Value Specification
Sensor Type	Resistive Flex Sensor
Operating Voltage	3.3V – 5V
Resistance (Straight)	10kΩ Approx.
Resistance (Bent)	20kΩ – 30kΩ
Output Type	Analog Voltage
Application	Finger Bend Detection

TABLE III MPU6050 SENSOR SPECIFICATIONS

Parameter	Value Specification
Sensor Type	6-Axis Motion Sensor
Functions	Accelerometer + Gyroscope
Communication Protocol	I^2C
Operating Voltage	3V – 5V
Acceleration Range	±2g to ±16g
Gyroscope Range	±250°/s to ±2000°/s
Application	Fall Detection

TABLE IV MAX30102 SENSOR SPECIFICATIONS

Parameter	Value Specification
Sensor Type	Pulse Oximeter Sensor
Functions	Heart-Rate Monitoring
Communication Protocol	I^2C
Operating Voltage	1.8V – 5V
Measurement Method	Photoplethysmography (PPG)
Application	Health Monitoring

VII. RESULTS AND DISCUSSION

A. Circuit Layout Schematic and Execution Constraints

The circuit layout of the proposed Smart Glove System is designed to ensure stable signal transmission, efficient power distribution, and reliable communication between all hardware components. The system integrates flex sensors, MPU6050 motion sensor, MAX30102 pulse oximeter sensor, HC-05

TABLE V HC-05 BLUETOOTH MODULE SPECIFICATIONS

Parameter	Value Specification
Module Type	Bluetooth Communication Module
Bluetooth Version	Bluetooth v2.0+EDR
Communication Interface	UART Serial
Operating Voltage	3.6V – 6V
Communication Range	Up to 10 meters
Application	Wireless Data Transmission

Bluetooth module, piezoelectric buzzer, and Arduino Uno microcontroller into a compact wearable architecture.

The flex sensors are connected to the analog input pins of the Arduino Uno through voltage-divider circuits using 10kΩ resistors for stable analog signal generation. The MPU6050 and MAX30102 sensors communicate with the microcon-troller through the I^2C interface using SDA and SCL com-munication lines. The HC-05 Bluetooth module is connected through UART serial communication for wireless transmission of gesture messages, health data, and emergency alerts.

The system is powered using a rechargeable 3.7V lithium-ion battery integrated with a TP4056 charging module for safe battery charging and protection. An MT3608 boost converter is used to regulate the battery output and provide a stable 5V supply for the Arduino Uno and connected peripherals.

The execution constraints of the Smart Glove System mainly include sensor calibration accuracy, battery backup duration, Bluetooth communication range, and real-time processing ca-pability. The flex sensors require proper threshold calibration for accurate gesture recognition. The Bluetooth communi-cation range is limited to approximately 10 meters under normal operating conditions. Continuous sensor monitoring and wireless communication also increase power consumption, affecting battery life during prolonged usage.

The system is designed to maintain low latency during gesture detection, heart-rate monitoring, and fall detection to ensure immediate response and reliable operation in emer-gency situations.

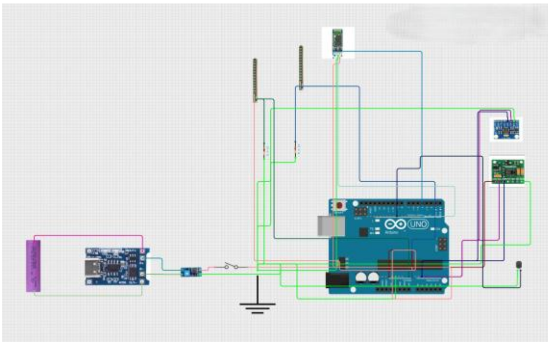

Fig. 5. Complete System Circuit Schematic Diagram

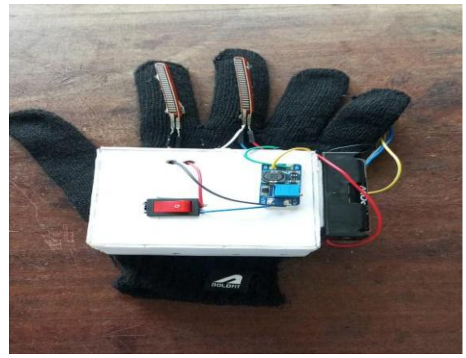

Fig. 6. PCB Implementation

B. PCB Design and Track Architecture Description

The PCB design of the Smart Glove System was developed to provide compact hardware integration, stable signal routing, and reliable wearable operation. The printed circuit board integrates the Arduino Uno interface, flex sensor connections, MPU6050 motion sensor, MAX30102 pulse oximeter sen-sor, HC-05 Bluetooth module, buzzer interface, and power-management circuitry into a single organized layout.

The PCB track architecture was designed using separate analog and digital routing paths to minimize noise and improve sensor accuracy. The analog traces from the flex sensors were routed separately to ensure stable gesture- recognition signals, while the I^2C and UART communication tracks were kept short to improve data transmission reliability between the sensors, Bluetooth module, and Arduino Uno.

Wider power tracks and ground planes were incorporated to support stable voltage distribution from the lithium-ion bat-tery, TP4056 charging module, and MT3608 boost converter. Proper component spacing and organized routing were main-tained to improve heat dissipation, reduce signal interference, and simplify hardware maintenance.

The PCB architecture demonstrated stable performance dur-ing real-time testing and supported reliable gesture recog-nition, heart-rate monitoring, fall detection, and Bluetooth communication while maintaining low power consumption and wearable portability.

C. Hardware Implementation and Prototype Performance Analysis

The Smart Glove System was implemented by integrating flex sensors, MPU6050 motion sensor, MAX30102 pulse oximeter sensor, HC-05 Bluetooth module, buzzer, and Ar-duino Uno into a compact wearable prototype.

The prototype successfully performed gesture recognition, heart-rate monitoring, fall detection, and wireless communi-cation in real time. The system demonstrated stable Blue-tooth connectivity, reliable sensor performance, low power consumption, and efficient emergency alert generation during testing.

The hardware implementation confirmed that the Smart Glove System is suitable for wearable assistive healthcare and communication applications.

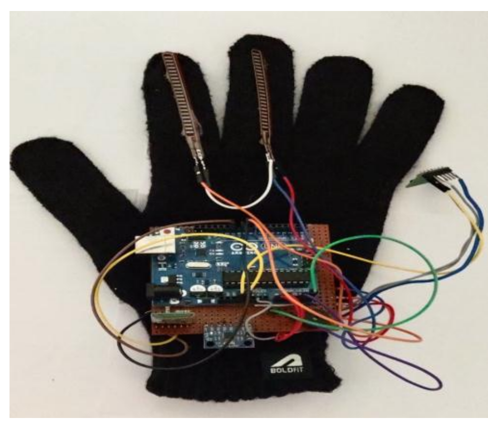

Fig. 7. Hardware Prototype

D. Website Interface Description

The website interface of the Smart Glove System was developed to provide centralized monitoring, real-time communication support, and emergency alert management for caregivers and healthcare professionals. The interface acts as a monitoring platform that receives gesture messages, health-monitoring data, and emergency notifications transmitted wire-lessly from the Smart Glove System.

The website dashboard displays predefined communication messages generated through gesture recognition using flex sensors. Messages such as “Need Water”, “Need Food”, and “Need Help” are updated in real time to assist caregivers in responding quickly to user requirements. The interface also continuously displays heart-rate values measured using the MAX30102 pulse oximeter sensor for remote healthcare monitoring.

The emergency monitoring section of the website provides instant alert notifications during fall detection and abnormal health conditions identified using the MPU6050 motion sensor.

Warning messages and alert indicators are displayed immediately to improve emergency response efficiency and user safety.

The website interface was designed with a simple and user- friendly layout to ensure easy accessibility and efficient monitoring. The integration of wireless communication, health monitoring, and emergency notification features into a single web-based platform improves the overall functionality and us-ability of the Smart Glove System for hospitals, rehabilitation centers, and home-care environments.

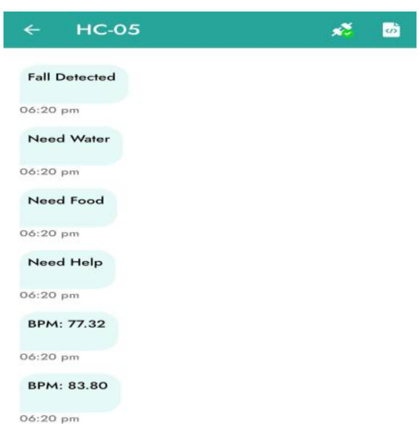

Fig. 8. Website interface of the Smart Glove System

VIII. CONCLUSION

The proposed Smart Glove System was successfully de-signed and implemented as a wearable assistive healthcare device for individuals with speech and mobility impairments. The system integrates flex sensors, MPU6050 motion sensor, MAX30102 pulse oximeter sensor, HC-05 Bluetooth module, and Arduino Uno to provide gesture-based communication, heart-rate monitoring, fall detection, and emergency alert generation.

The prototype demonstrated reliable gesture recognition, stable wireless communication, continuous health monitoring, and effective emergency detection during real-time testing. The system also showed low power consumption, portability, and user-friendly operation, making it suitable for wearable healthcare applications.

By combining communication assistance and health mon-itoring into a single embedded platform, the Smart Glove System improves user safety, independence, and caregiver sup-port. The proposed system provides an affordable and practical solution for hospitals, rehabilitation centers, and home-care environments.

Future improvements such as artificial intelligence-based gesture recognition, IoT integration, GPS tracking, and mobile application support can further enhance system performance, accuracy, and usability.

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