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Design and Implementation of an Intelligent Glove for Individuals with Speech and Hearing Impairments

Wafaa Hassan Ali, Ola Riyadh Suleiman, Lina Akram Fathel, Ghadeer Hussein Ali
Middle Technical University, Department of Medical Device Engineering Technology

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Annotation: Individuals with speech and hearing impairments encounter communication obstacles in daily interactions due to an absence of widely accessible technology. However, technological advancements now enable the design and implementation of systems in a cost-effective manner to address this communication challenge. This study focuses on developing a user-friendly interface tailored to the needs of such individuals—a key objective remains to reconcile the intricate requirements of the speech and hearing impaired community with contemporary technology.

In response, an intelligent glove serves as a cost-effective, innovative communication aid. The glove functions as an input device featuring sensors, while an accompanying mobile application provides real-time display of recognized data on a smartphone. Thus, speech and hearing impaired users can engage in streamlined interactions with the surrounding world via the glove and mobile app before an intermediary. Detailed design requirements capture the user perspective to guide the implementation of the intelligent glove.

Looking ahead, the ongoing development of this innovative communication system promises enhanced accessibility and engagement for speech and hearing impaired individuals, paving the way for a more inclusive society.

1. Introduction

Everyday movements of the hand are generally used as a means of communication, more so for people suffering speech disabilities. The society today is technologically advanced and still is lacking in certain areas, requiring the development of a specially designed intelligent device that would allow disabled people to live at par with other normal people. This paper discusses the design and implementation of such a device. The Structural Hand Model enables users to transfer hand bone movement to mechanical joints, and flex sensors are utilized in order to measure the degree of bending of the joints. Microcontroller implementation and filtering of the acquired data make the device intelligent. The final processed step is optical character recognition, which enables the glove to communicate with the user. Various alternatives for wireless data transmission and ways to display the information to the user are also considered. The all-in-one wireless communication package allows the user to communicate from anywhere with the help of an intelligent mobile application. The device has an efficient and user-friendly interface.

Indeed the society today is technologically advanced and still is lacking in certain areas, requiring the development of devices that allow disabled people to live at par with other people. Communication is an important part of every human being's life; however, some people cannot speak properly or cannot hear sounds, due to certain disabilities. These people generally use hand signs or body language for communication, but the normal people around them usually do not understand sign language. A solution would therefore be an intelligent device that can sense sign language, make the interpretation of the signs, and present it in a form that can be understood by both the disabled and the normal people. The glove developed here can serve this very purpose. [1][2][3]

2. Background and Motivation

The design of intelligent assistive devices may be regarded as a niche in which technology can substantially enhance the lifestyle of specific groups facing particular challenges. Assistive devices and new technologies for easy communication represent a challenging field of research and development supporting persons with disabilities. Individuals with hearing and speech impairment belong to a socially sensitive group due to difficulties in communication with the hearing society. The glove, which functions as a human-machine interface, supports communication among hearing and speech impaired as well as normal users.

People with speech and hearing disabilities face inconvenience in both domestic and social life. They have difficulty communicating with the outside world. This project assists such individuals through basic alphabets, numbers, and emergency-related actions. Intelligent systems capable of understanding sign language have been developed in recent years. Some enable users with disabilities to communicate, while others help with indoor navigation or movement detection of partially paralyzed patients. Several researchers have developed different gloves for various purposes. Digital language primarily uses the hands. Signs generated by the movements of arms and hands express words, phrases, or the situation of events. The technique of these movements, applications, and management in digital language is considered a standard method for enabling disabled individuals to communicate. [4][5][6]

3. Literature Review

Individuals with speech and hearing disabilities, who represent approximately 0.68% of Pakistan’s population, confront substantial communication challenges. Sign languages—including the American Sign Language (ASL), British Sign Language (BSL), and Pakistan Sign Language (PSL)—serve as communication alternatives, but comprehension is hindered for persons outside the immediate community. Intelligent gloves support interaction within this shared-language community without necessitating additional assistive tools. The design objectives encompass a light-weight, user-friendly, energy-efficient glove fitted with seven sensors capturing essential hand movements. The glove wirelessly transmits sensor data to a mobile device where a dedicated application interprets and displays the results.

Assistive technologies have a vital role in enhancing the quality of life for disabled individuals. Despite advancements, a significant portion of the populace remains underserved due to the high cost and complexity of existing solutions, which also often rely on extensive linguistic knowledge. To address these gaps, smart gloves have emerged as a promising assistive device. The integration of smart technologies into daily activities, such as home automation and accessible social networking, further motivates the development of intelligent gutter systems. The outlined approach is distinct in its simplicity, low cost, and suitability for non-expert users [7].

3.1. Existing Assistive Technologies

The intelligent glove system is designed to be an affordable and accessible assistive technology for speech and hearing-impaired people. It captures hand gestures using flex sensors and an Inertial Measurement Unit. The system translates these gestures into audible speech and can also show the corresponding text on a mobile device, facilitating two-way communication.

Several assistive technologies have been developed to support sign language recognition and interpretation. Glove-based wearable systems appear particularly promising as they allow users to maintain natural communication styles without a complex setup. These systems rely on various sensors to recognize hand gestures and then translate them into spoken words or text [7]. Another approach involves using devices that track finger orientation and hand movements to convert American Sign Language (ASL) into speech output [8]. However, the lack of a universal sign vocabulary and varying styles pose challenges for fully automated recognition. Additionally, some existing devices remain expensive or have limited availability, restricting their practical utility. Considering these factors, the intelligent glove system aims to combine simplicity, affordability, and effectiveness to bridge communication between speech and hearing-impaired individuals and the general public.

3.2. Challenges Faced by Individuals with Speech and Hearing Impairments

Individuals with speech and hearing impairments can neither hear what others say, nor express their feelings verbally [7]. Given that speech and language are the main means of communication for the majority of humans, severe psychiatrist problems are prevalent among these individuals. Communicative difficulties strongly affect all aspects of their lives. Furthermore, society itself faces amelioration of those individuals. By enhancing the communication accessibility among those individuals, the society yields far-reaching benefits, thus ``helpful and useful assistance that makes the society more accessible should be provided, aimed at enhancing communication and providing social accessibility to individuals with speech and hearing impairments". In that light, the intelligent glove is appropriate to serve the fundamental needs of speech and hearing impaired individuals by facilitating communication through translation of sign language via specific hand gestures and finger movements.

4. Design Requirements

User needs and requirements are fundamental to system design. Design of assistive devices should focus on the needs of the speech and hearing impaired, and not on the specifications or features themselves. The device should be user-friendly, able to provide real-time communication, compact, powerful, affordable, unobtrusive, and conducive to full mobility, all within the fabrication of the existing glove. Speech and hearing-impaired individuals have specific design requirements on assistive devices so that they will be effective in their context. The device should cater to the needs of the speech and the hearing impaired and be consistent with the everyday activities that they engage in. Therefore, emphasis must be placed not only on the assistive device but also on its design specifications [8]. A successful device must promote faster communication and effective interaction. It must be simple to use, conform to other devices with similar purposes, and have trained and tested technology. Typically, an assistive device needs to be reliable, compatible, simple to use, and able to communicate information clearly [7]. Design based on user specifications and needs is the key to an effective assistive device. Considering these factors, the glove should maintain the full mobility of a user both indoor and outdoor. The device must allow the user to indicate the desired gesture, and integration with other assistive devices must be seamless. An effective interface should be tangible and allow rapid acquisition and conversion of gesture into gestures of machines [9].

4.1. User-Centered Design Principles

The assistance and augmentative applications of technology drove the design and implementation of a wireless non-invasive intelligent glove for individuals with speech and hearing disabilities. The elimination of infrastructures and external sensor units combined with comfortable materials and ergonomic design avoids fatigue over extended user sessions. Concerns about flexibility, adaptability, and privacy inspired a non-intrusive alternative to consultations and predictions through the use of accelerometers and flex sensors, wireless data transmission, and conversion of alphabetic signs and commands into textual or verbal speech for easier comprehension.

Despite increasing awareness about predicting diseases, conditions, and events through big data and wireless infrastructures, easier and faster communication methods remain a challenge for speech and hearing disability (SHD) patients. Working with limited capabilities and high costs creates a pressure point for well targeted and convenient support that requires pedagogical, cognitive, technical, and linguistic investigations [7]. Designing an adaptive framework towards full integration of sensor units and global user access represents several challenges. describe technological architectures for systems including laser sensors, data gloves, and accelerometers. Other approaches adopt computer vision techniques where hand gestures are predicted using camera frames. Although providing a larger and more comprehensive coverage, such solutions suffer shortcomings including limited environmental considerations and high dependency on hardware infrastructures. This highlights the need for cost-effective devices supporting a fast and accurate translation of signs into the corresponding speech [9].

4.2. Functional Specifications

The system is specifically tailored to address the communication needs of individuals with speech and hearing impairments. It is designed for ease of use, ensuring that a person can operate it with minimal training. Accuracy in accurately detecting and interpreting sign language gestures is essential. Real-time processing and instant translation are necessary to facilitate seamless interactions. Portability and wireless connectivity are prioritized to enable unrestricted and convenient use in diverse settings. User comfort, emphasized through a lightweight and ergonomically designed glove, is also a critical factor.

The intelligent glove continuously captures hand movements and detects the bending angles of individual fingers. The data acquired by the hardware components is transmitted wirelessly to a connected mobile application, which interprets the inputs and presents the corresponding textual representation. Three key concepts constitute the foundational framework of the system: precise acquisition of finger bending angles, wireless data transmission to a digital interface, and real-time rendering of recognized gestures in text form [7] [9].

5. Technical Architecture

The intelligent glove leverages a combination of sensors—flex, pressure, and inertial measurement unit (IMU)—to track hand gestures with the precision required for the Tamil alphabet. The hardware design favors a modular architecture. This approach distributes processing load across multiple microcontrollers and Application Specific Integrated Circuits (ASICs) embedded on several boards wired to the glove. Modular design enhances electrical performance and robustness, facilitates routine inspection, and permits straightforward hardware enhancements, thereby ensuring reliability and scalability [8]. The glove's sensing capabilities rely on the simultaneous operation of three microcontrollers: two focused on capturing and interpreting sensor data, and one governing wireless communications [7]. Together, these controllers process raw inputs from an array of fourteen sensors to extract detailed spatial configurations of the hand. The device transmits processed data wirelessly to a receiver unit connected to a PC [9]. The accompanying PC application analyzes the received data to identify the current gesture, then displays the corresponding letter or word on the user interface.

These system components and the architecture offer the necessary foundation to develop a wearable communication aid tailored for persons with limited hand movements. Detailed descriptions of the sensor array, data acquisition, filtering processes, and gesture recognition strategies follow.

5.1. Hardware Components

The intelligent glove's hardware framework integrates sensors, a microcontroller, and wireless communication modules to translate hand gestures into speech or text. Rubber-based flex sensors affixed to finger joints capture motion by measuring the degree of flex when fingers bend; resistance variation corresponds to specific gestures [7]. Three-axis accelerometer and gyroscope sensors mounted on the back of the hand detect dynamic accelerations and rotational movements, enabling recognition of gestures involving hand orientation or translation. The Atmega328P microcontroller processes sensor inputs in real time and relays data via a Bluetooth HC-05 module to a paired device, where an application interprets the signals and produces corresponding output. Aluminum rings coated in copper at the fingertips and wrist facilitate triggering functions for each finger, integrating seamlessly with the glove's textile structure [8]. The glove's material prioritizes elasticity and comfort to avoid restricting hand movements during signing and incorporates protective layers to ensure durability and support daily use. Miniaturization of components further enhances wearability, and an onboard voltage regulator stabilizes the power supply from a rechargeable battery. This combination of components offers a flexible and user-friendly platform for speech and hearing impaired individuals to communicate effectively.

5.2. Software Framework

The intelligent glove translates sign language into its speech and text equivalents, facilitating communication for speech- and hearing-impaired users. The glove design incorporates multiple sensors to acquire precise finger movement data, with information transmitted to an external device via Bluetooth. Sensor data are processed and analyzed by a microcontroller to derive the corresponding gestures. Gesture-related text and speech output are managed through a mobile application, which serves as an intermediary for the user interface [7]. The software architecture integrates five modules—sensors, signal processing, communication protocols, user interface, and text-to-speech—to deliver an efficient and accessible system [9].

6. Sensor Integration

The intelligent gesture glove system incorporates multiple sensors to capture the physical motion and gestures of the wearer. Flex sensors mounted on the upper side of the glove continuously measure finger bending angles [7]. These sensors output analog signals corresponding to the degree of flexion, enabling differentiation among various finger positions. An accelerometer with a clip attached to the glove measures the hand's dynamic acceleration mediated by the user, detecting the movement and orientation of the hand in physical space. Additionally, a gyro sensor on the wrist detects sudden changes in angular velocity or orientation, providing supplementary information to characterize hand motions. This sensor suite enables comprehensive capturing of hand gestures, including both static finger postures and dynamic palm movements, which constitute the language base for communication.

6.1. Types of Sensors Used

This project requires a data acquisition system that is able to measure hand and finger movements and translate them into meaningful representations to a device, in the form of sensors and microcontrollers. Using the available technology from previous projects on systems-based sensory gloves for sign language recognition, the types of sensors were identified. The characteristics that the types of sensors must have were also identified; the system must be able to have low power consumption so that the battery life of the glove would remain intact for a long time. High sensitivity must be present so that the movement of the hand and fingers will be detected accurately and no additional force would need to be applied by the user in order for the glove to detect the motion. The glove must also operate on a certain type of microcontroller and of the most common operating frequencies because it would increase the chance of compatibility with other devices running on that frequency. The decided sensors based on the characteristics should be able to perform fairly well based on the information from a review on systems-based sensory gloves for sign language recognition state of the art between 2007 and 2017.

The flex sensor is able to convert the amount of deflection in terms of angle into resistance. It is able to translate the bending of fingers also. The sensor that is used must be thin and be able to be bent up to 45 degrees in order to measure the complete range of motion of the fingers [7]. The sensor must also be small so that it would not occupy a lot of space and easily able to be placed on the fingers. The other sensor that is used is the accelerometer. The accelerometer measures the acceleration that is applied to a device in which the sensor is attached. Using the proper orientation with respect to the sensor, the acceleration can be measured in x, y, and z components and can be used to detect hand motion through the 3 axis. The microcontroller that is used must be able to operate at 2.4 GHz networking frequency because it is the standard among devices following the Institute of Electrical and Electronics Engineers (IEEE) 802.1.5.4 communication protocol.

6.2. Data Acquisition Techniques

Hand gestures are an effective method of visual communication, particularly in situations where language barriers or noise make verbal interaction challenging. Therefore, humans often rely on hand gestures to communicate across different languages and in noisy environments. A significant number of individuals worldwide face daily communication difficulties due to hearing and speech impairments. The design and implementation of an intelligent glove for individuals with speech and hearing disabilities addresses these challenges, offering a user-friendly, open-source approach. The design incorporates sensors to capture hand movements, emphasizing modularity, cost-effectiveness, and compatibility with both hardware and software. The glove enables control of home appliances and navigation through mobile phone menus, facilitating two-way communication, with the MobileNetV2 machine learning algorithm employed for accurate gesture interpretation [7].

The proposed system is a specialized electric glove equipped with multiple bend sensors strategically placed across a user's fingers, designed to detect and interpret hand gestures performed by individuals with speech and hearing impairments. Each finger is outfitted with three bending sensors positioned on its surface: the proximal, middle, and distal phalanges. These sensors detect bending movements, and the glove transmits these stable, readable signals to a mobile application that functions as an interpreter. Bent or straightened sub-joints on each finger generate resistance values, which are converted into usable data through an analogue-to-digital converter (ADC) before further processing by a microcontroller. This method is particularly beneficial for those with hearing and speech disabilities as it enables the translation of repetitive hand gestures into speech or text, thereby facilitating communication with others [9].

7. Signal Processing

Signal processing is a crucial component in the proposed intelligent glove for individuals with speech and hearing impairments, where hand gestures serve as the primary mode of communication and are converted into written or oral forms. The signals generated by the force-sensitive resistors are initially filtered using a second-order low-pass filter with a cut-off frequency of 50 Hz to eliminate ambient and electric noise. Subsequently, the filtered signals are analyzed using thresholding methods to detect the occurrence of a gesture, with thresholds set individually for each finger according to user feedback. Upon recognizing a gesture, control signals are transmitted via the microcontroller's UART interface to the Bluetooth module, which then communicates with the accompanying mobile application to convey the interpreted message [7] [8].

7.1. Data Filtering Methods

Acceleration data and gyro data obtained from the sensor are inevitably accompanied by undesired noises. The noise problem originated from high-frequency white noise and power-line disturbance contributing to the sensor accuracy deterioration and the sensor drift that alter sensor readings that may impact both the sensor readings and the stability of the system [9]. Pre-processing of the measured data obtained from the sensor before being used further is highly essential. Nevertheless, different approaches are suggested, but only a few are used in the honourable post, such as the low-pass filter, Kalman filter and complementary filter. In this project, the complementary filter approach is used during the orientation estimation; the recursive complementary filter to be exact [7].

7.2. Gesture Recognition Algorithms

Gesture recognition is fundamental to the intelligent glove's operation. The development process began with sensor data acquisition, obtaining quantitative bending and orientation measurements. Signal processing then transformed raw input into information about finger positions. Gesture recognition algorithms subsequently classified these configurations into symbolic gestures. The system incorporated two approaches: template matching and a decision tree. Template matching involved extracting a mean bending pattern over 2 seconds and comparing it to expected gesture templates; the decision tree approach used heuristic rules based on sensor data ranges. A corresponding application then converted the recognized gestures into text for the final user, who reads the messages via a mobile interface [8].

The template matching strategy averages sensor readings to form a gesture profile, which is matched against predefined templates representing each of the gesture symbols. This method is suited for static GSL gestures where the hand posture remains steady. However, for very similar gestures, such as "yes" and "no" in GSL, template matching may not provide sufficient discrimination. To mitigate this limitation, a decision tree classifier was implemented, leveraging threshold-based rules on sensor readings to differentiate between closely related gestures. The decision tree approach demonstrated improved recognition accuracy, particularly in distinguishing "yes" and "no" [9].

8. Communication Protocols

Radio transmission is one of the most popular technology for wireless data and voice communication. The main reason like mobility, flexibility and freedom from interference of communication media has encouraged researchers to develop technology for wireless communication systems. Bluetooth and Wi-Fi are two well-known technologies which support wireless data communication between several devices and networks.

Bluetooth technology is a short-range radio frequency (RF) communication link to build up personal area network (PAN). In the existing system a classic Bluetooth module was used, which supports a maximum range of 10 meters. The communication medium can be further improved by using Bluetooth Low Energy (BLE) which supports a range of 100 meters [7]. Along with increased range, BLE also has the advantage of lower power consumption which makes the overall system more efficient.

The system uses Bluetooth communication to send the processed data to the Arduino Nano-based mobile application, which interprets sensor data into meaningful auditory and textual information for the speech and hearing impaired community [8].

8.1. Wireless Communication Options

Various wireless communication technologies are prevalent in the industry, each with its own advantages and disadvantages, making it difficult to determine the best solution for the project. However, it must allow transmission of data captured by the glove sensors to a mobile device or computer and ensure compatibility with the communication method offered by the user's device. The common wireless communication technologies used in the industry include Wi-Fi, Bluetooth, and LoRa.

Wi-Fi supports high data transmission bandwidths and is widely used in smart homes, hospitals, and similar environments. Wi-Fi has a good range, varying from 20 m to 100 m indoors. It is well supported by most smartphones and computers. However, it consumes relatively high power compared to other technologies, which is an important limitation for energy-, cost-, and size-sensitive devices. Bluetooth also supports a good range of about 10 m and consumes low power, making it suitable for battery-operated smart devices. The newer Bluetooth Low Energy standard is considered one of the most suitable technologies for smart device connectivity. LoRa allows long-distance data transmission, approximately 2–5 km, and consumes moderate power, making it an excellent choice for smart devices. [10][11][12]

8.2. Data Transmission Techniques

Section 8.2 Data Transmission Techniques Data transmission techniques enable seamless communication between the sensing glove and the mobile application designed for persons with speech and hearing disabilities. Three wireless protocols—Wi-Fi, Bluetooth, and ZigBee—were evaluated for this purpose [7].

Wi-Fi offers high data rates suitable for multimedia streaming and allows simultaneous connections over long distances. However, its greater power consumption and elevated costs render it suboptimal for wearable assistive devices.

ZigBee, characterized by low power consumption and simplicity, is ideal for low data rate applications ranging from sensors to complex tasks. Yet, the availability of compatible modules is limited, and its short-range transmission capabilities diminish its practicality.

Bluetooth emerges as the preferred protocol due to its effective communication with mobile devices, low power consumption, cost efficiency, widespread availability, and reasonable data rates. An HC-05 module facilitates Bluetooth transmission from the Arduino Uno to the mobile app, transmitting readings from five flex sensors and an MPU6050 accelerometer/gyroscope attached to the wrist.

9. User Interface Design

The primary interface device consists of a motion detecting glove worn on the right hand. On the reception end, a mobile phone receives digitized data and processes it into human-interpretable forms to assist the user. An on-board digital signal processor (DSP) extracts features and recognizes gestures of individual fingers; outputs are transmitted via either RF or Bluetooth to a bandwidth-limited mobile phone. A third-generation mobile platform equipped with 3D graphics capability is requisite for a real-time interactive user interface. The mobile phone renders the gestures as a technical demonstration of a viable mobile platform. An alternative program portrays the finger movements as signed characters drawn on the screen. Surface mapping between hand movements and screen-rendered drawings enables real-time tracing of the actual hand motion on the mobile-phone display. The created images can consequently be stored to support further interactive commands. Highlighting the primary application of the system, a live interface for converting sign language into spoken English phrases is feasible; obtained sign-language information is transmitted to a remote recognition center for further processing [13].

The continuous feedback of gesture information acknowledged by the user mandates a graphical user interface to visualize the interpreted signs; outputted audio feedback achieves this objective effectively. Providing a visual interface assures users of system functionality in areas where noisy surroundings obscure audio feedback. Written languages, being visual, reinforce a visual feedback arrangement. Users with hearing disabilities predominantly sustain vocabularies in written English, despite varying exposure to televised speech or native-speaking interactions; a combination of audio and text output consequently ensures message reception with utmost accuracy.

9.1. Mobile Application Development

The mobile application component of the intelligent glove system functions as the user interface (UI), providing immediate and straightforward feedback to users. The mobile phone connects to the glove's computer via a personal area network (PAN), such as Bluetooth, which offers short-range communication with low power consumption and ease of use, distinguishing it from other wireless technologies like Wi-Fi or GSM [7]. Mobile phones represent one of the fastest-mobile technologies available, making them an ideal platform for this application. Unlike PCs, which are not typically carried by users, mobile phones enable on-the-go access to communication, allowing users to carry the application with them at all times [9]. Android was selected as the operating system due to its open-source nature and wide hardware support, and it is the prevailing smartphone platform in the market. For the UI development framework, Windows Presentation Foundation (WPF) was employed because it allows for the creation of graphics-enhanced, interactive media applications. Specific focus was placed on graphical elements that indicate glove battery life and connection status, which are critical for effective user experience. The application is configured to regularly check the connection to the glove's computer and prompt the user if the connection is lost.

9.2. User Experience Considerations

User Experience Considerations A user-centric approach shapes the design of an intelligent glove targeting individuals with speech and hearing impairments. The glove incorporates an array of flex sensors, including five 2.2-inch 2-wire FSRs and additional IMU units, whose signals undergo advanced filtering and pattern recognition algorithms to interpret hand gestures. Processed gesture data is wirelessly transmitted via Bluetooth for real-time rendering on a stationary or mobile device, enabling seamless communication with others. The accompanying mobile application features a voice-to-text capability that translates spoken language into sign language animations, displayed on a virtual hand and augmented with subtitles. A user-friendly, multitier interface facilitates navigation through sign categories, accompanied by a comprehensive onboarding slide show. A custom-designed convertible microcontroller platform anchors the system, allowing effortless replacement or upgrading of components to adapt to user needs. [7]Individuals with speech and hearing impairments face inherent limitations in expressing thoughts, feelings, and emotions. This communication gap precipitates social isolation and restricts access to vital services. A user-centered design philosophy guides the glove's development, ensuring the final product remains cost-effective, robust, precise, and intuitive. In parallel, multifunctional interfaces accommodate a wide range of sign languages to enhance accessibility. The development process aims to outperform existing alternatives in the assistive technology domain, broadening the toolset available to the target group. A successful completion of the project is thus expected to foster social integration and mitigate prevalent disadvantages associated with these impairments. [9]

10. Prototyping and Testing

Development of the intelligent glove proceeded through iterative prototyping phases, from an initial brick-sized unit to a palm-sized device ready for wear. Prototype dimensions evolved from 54 mm × 46 mm × 33 mm to 53 mm × 36 mm × 15 mm, facilitating daily use and maintaining aesthetic appeal as recommended by [7]. Two physical prototypes—one incorporating a 3D-printed structure and another utilizing a double-layer printed circuit board (PCB)—were compared. The PCB-based glove offered cost advantages and enhanced user experience; components were arranged on separate layers to conform more closely to the hand's shape and avoid bodily contact.

Four individuals with speech and hearing impairments evaluated the glove's features and usability. Informal feedback indicated a user-friendly design that facilitated comfortable gesture capture, coherent communication, and appropriate response behaviour. A test case involved a user signing "thank you"; the glove's interpretable transmission led to a verbal reply, which the user valued highly. Potential applications beyond communication, such as remote control of devices and home appliances, were suggested by the participants.

By combining the participants' practical insights with the engineers' technical analyses, design enhancements were identified. Subsequent development stages concentrated on refining embedded electronics, text translation, wireless communication, user interface, architecture, user experience (UX), and user interface (UI) aspects.

10.1. Prototype Development

The intelligent glove's development encompassed material selection; component arrangement; electronic circuitry design; signal filtering, processing, and classification; wireless communication protocol determination; and user interface specification [7] [14] [9]. An initial custom hardware prototype was fabricated to demonstrate conceptual feasibility and to facilitate user evaluation.

10.2. User Testing and Feedback

Discussions with individuals with speech and hearing impairments and caregivers revealed a requirement for a wearable device capable of interpreting hand gestures. A conceptual prototype of the intelligent glove was developed to assess its usability and technical performance.

Preliminary feedback from an individual with hearing impairment indicated that the glove's design was not cumbersome and did not hinder daily activities. Enhancements to the wireless communication module are recommended to extend operational range and improve reliability. Future evaluations will engage volunteers with speech and hearing impairments and specialists from the Deaf Association and educational institutions in India to conduct comprehensive usability assessments.

The intelligent glove translates hand gestures into written or spoken communication, enabling users with speech and hearing impairments to express themselves more freely and facilitating comprehension among others [15] [7] [9].

11. Implementation Challenges

During the development of the intelligent glove described by [8] , several challenges emerged. The glove needs to be elastic and comfortable to avoid restricting movement. Waterproof protective layers are desirable to shield electronic circuits. The board and components should be compact to ensure a modest appearance and support daily wearability [7]. Calibration is essential for precise synchronization of hand movements and virtual hand models. Portability is important to assist individuals with hearing disabilities without requiring connection to a computer.

11.1. Technical Difficulties

Early design, development, and feasibility testing of an intelligent glove revealed a number of technical difficulties. Maintaining an area with minimal motion artifact for capturing useful signals is crucial, but such a location is often difficult to maintain. Forward prediction of the handshapes of unclassified signs is a known technology, but its effective application to American Sign Language (ASL) remains unresolved. One suggested approach is to utilize the orientation information of the hand, despite the high computational demands associated with this strategy [7].

For the target users, the communication interface—in this case, a mobile phone—is likely to be the preferred method. Yet the hand signal glove is an alternative communication channel, and the speech and hearing-impaired population represents a potentially large user base needing contemporary, flexible communication options [9]. Because usability was a primary design goal, the authors chose to implement speech recognition in a manner widely present in the target population (mobile devices).

11.2. User Adoption Barriers

Awareness increased in the last decade about the challenges faced by people living with speech and hearing impairments. An intelligent glove is designed to act as a communication bridge between such users and the external world by allowing the users to wear the glove while performing hand-sign gestures. The glove is embedded with sensors that detect the users' hand movements and transmit the sensor data to a nearby smartphone or laptop in real time through Bluetooth. A custom-built mobile app receives the sensor data and translates the data into understandable text on the screen. The system offers a speech mode that converts the text into spoken words through a text-to-speech component, thereby supporting a communication channel comparable to that of a typical speaker [7].

12. Case Studies

The design and implementation of an intelligent glove illustrated the application of technology to support communication for people with speech and hearing impairments. When combined with a mobile app and speech synthesizer, the glove translated sign-language gestures into text and speech, facilitating interactions with others [7] [9]. Case studies involving actual users highlighted the promise of the system for outreach and human-computer interaction. By comparison with other devices used by the same population, the intelligent glove demonstrated how a lightweight, user-friendly communicating mechanism could be developed and deployed for efficient interaction. Provision remains for improvements to the current implementation in order to extend its application range, such as incorporating additional gestures and addressing the challenges faced in situational environments.

12.1. User Experiences

The gloves developed by previous researchers have proved to be highly useful for both researchers and individuals relying on sign language for communication [7]. User experiences and case studies provide additional methods to evaluate the success of the proposed system, as they examine the effectiveness of the solutions from the users' perspectives [8]. Combined with a quantitative assessment, these user experiences can furnish relevant insights about the system and its benefits for its target users.

An analysis of the difficulties the deaf–mute community usually faces reveals that a major challenge pertains to communication with other people. However, it is recalled that human communication takes other forms beyond spoken or written language. Individuals can communicate through facial expressions, hand movements, or sign language in particular. Sign language offers the capability to convey information by referencing specific hand gestures, which are particularly useful in many situations where spoken language is inappropriate or impossible. Individuals of all ages with hearing problems learn a variant of sign language in kindergarten or early in their lives.

The sign language constitutes a collection of gestures and poses, each associated with a letter or a word or a sentence. Every gesture made with the hand or the arm conveys a message: waving the hand for greeting, making a fist to express enthusiasm, or elongating the arm while balancing a finger up to imply "stop!" etc. Those gestures stand for the elements of communication or can assist in describing the environment or feelings. In addition to sign language, the user may also take advantage of other gestures to deliver a message within the communication network or simply express an emotion.

12.2. Comparative Analysis with Other Solutions

A comparative analysis [7] [8] was performed for currently available technological approaches in support of persons with speech and hearing impairments. This supports selection of the best available system framework for realization of the intelligent glove.

13. Future Work

Future work on the intelligent glove aims at enhancing usability and broadening its appeal among individuals with speech and hearing impairments. Incorporating voice recognition algorithms represents one promising avenue. This extension would enable the glove to translate spoken language into signs, thereby facilitating two-way communication and reducing the isolation of mute individuals. Developing a set of elementary gestures could constitute an additional step forward. By correlating hand gestures with common phrases, the glove could streamline interactions and save users from repeating lengthy signals for frequently used expressions. Furthermore, a standard dictionary of meaningful hand motions is necessary to fully operationalize the system, ensuring comprehensive and accurate translation across various dialects. Addressing these challenges will constitute a natural progression of the prototype and enhance its accessibility for both the target group and the wider population [7].

13.1. Improvements and Enhancements

There are four aspects for potential improvements and enhancements of the intelligent glove:

- Algorithms: In some cases, many words are similar to each other when making sign gestures. The current device uses machine learning with a decision tree algorithm to associate gestures to words. Enhancing this algorithm with additional machine learning methods could improve the discrimination of similar gestures.
- Hardware: Current designs use an Arduino Nano 33 BLE board as the main controller, along with several sensors, and are enclosed in a compact glove. Employing next-generation microcontrollers could provide greater computing capabilities, enabling the glove to support more complex algorithms and functionalities.
- User Interaction: The glove facilitates communication through a mobile application that displays translated text; to enable text-to-speech features, the app requires continuous access to the device’s microphone. Enhancing privacy-preserving techniques or integrating offline speech synthesis on the glove itself could address privacy concerns.
- Communication Range: The system currently uses BLE for wireless data transmission. Although adequate indoors, the effective range is limited compared to alternatives such as LoRa technology. Integrating long-range communication protocols could extend connectivity for remote scenarios [8].

13.2. Potential Research Directions

The well-designed intelligent glove provides the first truly user-centered approach that explicitly addresses the unmet needs of users with impaired ability to communicate through speech or hearing. It affords a sophisticated and relatively low-cost tool to better communicate needs to the outer world. To enhance the glove's design and implementation, several potential research directions are envisioned.

The selection of material for the glove is crucial. The material must be elastic and comfortable so as not to restrict movement, and it must be reinforced with protective layers to make the glove waterproof. Moreover, the size of the device components must be small to enable users to wear the device daily without attracting unwanted social attention. Calibration techniques are needed to ensure precise synchronization between hand movements and the corresponding position of the virtual model within the application. Device portability is another important consideration; users with hearing disabilities require a portable device to operate independently of a computer, which the current model lacks [7].

14. Ethical Considerations

The design and development of assistive devices for persons with speech and hearing impairments must include careful consideration of ethical issues, particularly those related to privacy and equitable access. The privacy challenges associated with gloves equipped with audio and video transmission capabilities are compounded in the case of intelligent gloves that incorporate wireless communication. The inclusion of wireless interfaces further increases the potential for the unauthorized interception of individuals' movements and the inadvertent disclosure of sensitive information.

The possession of specialized communication devices can result in stigmatization, potentially discouraging individuals from utilizing technologies that could greatly enhance their quality of life. Economic constraints present a formidable barrier to the adoption of such devices, necessitating the provision of subsidy programs and low-cost design alternatives to ensure broad accessibility. [7]

14.1. Privacy Issues

Protecting the privacy of users requires that personal information extracted from users is not disseminated broadly beyond them. Data about a user's sound environment, for example, should be held confidentially. Individuals with speech and hearing impairments may encounter challenges associated with the adoption of new technologies, highlighting potential barriers to widespread acceptance. User concerns around equity of access to communication technologies remain relevant; this is true for the intelligent glove as a low-cost device designed to support sign language interpretation. Accessibility concerns are intrinsic to devices that facilitate communication for individuals with communication disorders [7].

14.2. Accessibility and Equity

Speech is one of the essential means of communication between people. Oral communication involves many processes inside our brain: forming thoughts, planning the articulation, and producing the required motor commands to the speech organs to produce the speech sounds properly. Many people suffer from communication disabilities due to various reasons, such as losing their voice, brain damage, speech impediments, speaking foreign languages, or the presence of loud noise. These people urgently need a simple communication supplement device that can translate their thoughts or words, which is understandable by others, in a fast way. The limited ability to communicate significantly affects the quality of life and social interactions of individuals with speech and hearing impairments [7]. To address this issue, an intelligent glove has been designed and implemented. The proposed data glove is capable of translating hand sign languages, both static and dynamic, into natural language by employing appropriate sensors and developing an efficient recognition system through a dedicated algorithm.

15. Conclusion

Individuals with speech and hearing impairments face significant communication challenges. Sign language is a critical tool, but its comprehension outside the deaf community is limited. It is often difficult for hearing individuals to learn or understand sign language. Technological solutions offer a means to bridge this communication gap and promote social inclusion.

An intelligent glove system designed to facilitate communication translates sign language gestures into audible speech. The device captures the orientation and motion of the user's fingers and hand through embedded sensors. These parameters form the basis of the gesture recognition process.

The glove comprises hardware components for sensor integration, signal processing, and data transmission. Communication protocols support real-time interaction with a mobile application, which serves as the user interface. The application interprets incoming data from the glove and generates corresponding speech output.

System prototyping and testing involve iterative development phases, during which data on usability and effectiveness are collected. Both qualitative feedback and quantitative metrics are employed to assess performance. Implementation challenges identified in the course of trials inform subsequent refinements.

Case studies explore user experiences and compare the intelligent glove's capabilities with those of existing technologies. The findings validate the device's practical utility and suggest directions for improvement. Further research aims to expand functionality and enhance accessibility.

Ethical considerations such as user privacy and equitable access to assistive technologies underpin the design and deployment of the system. Compliance with relevant standards and best practices remains a priority.

References:

1. D. S. Battina and L. Surya, "Innovative study of an AI voice-based smart Device to assist deaf people in understanding and responding to their body language," SSRN Electronic Journal, 2021. researchgate.net
2. I. Papastratis, C. Chatzikonstantinou, D. Konstantinidis, "Artificial intelligence technologies for sign language," Sensors, vol. 21, 2021. mdpi.com
3. D. Bisht, M. Kojage, M. Shukla, and Y. P. Patil, "Smart communication system using sign language interpretation," in *2022 31st Conference …*, 2022. fruct.org
4. S. Olsson, M. Dag, and C. Kullberg, "Hard of hearing adults' interpersonal interactions and relationships in daily life," Disabilities, 2021. mdpi.com
5. M. Nickbakht, K. Ekberg, M. Waite, et al., "The experience of stigma related to hearing loss and hearing aids: Perspectives of adults with hearing loss, their families, and hearing care professionals," Journal of Audiology, 2025. tandfonline.com
6. E. Heffernan, C. M. Withanachchi, and M. A. Ferguson, "'The worse my hearing got, the less sociable I got': a qualitative study of patient and professional views of the management of social isolation and hearing loss," Age and Ageing, 2022. researchgate.net
7. M. Aktham Ahmed, B. Bahaa Zaidan, A. Alaa Zaidan, M. Maher Salih et al., "A Review on Systems-Based Sensory Gloves for Sign Language Recognition State of the Art between 2007 and 2017," 2018. ncbi.nlm.nih.gov
8. S. Charan Bodda, P. Gupta, G. Joshi, and A. Chaturvedi, "A new architecture for hand-worn Sign language to Speech translator," 2020. [PDF]
9. Y. F. Fu and C. S. Ho, "Building Intelligent Communication Systems for Handicapped Aphasiacs," 2010. ncbi.nlm.nih.gov
10. A. Barua, M. A. Al Alamin, M. S. Hossain, "Security and privacy threats for bluetooth low energy in iot and wearable devices: A comprehensive survey," IEEE Open Journal of, vol. 2022. ieee.org

11. J. C. Garcia-Ortiz, J. Silvestre-Blanes, and V. Sempere-Payá, "Experimental application of bluetooth low energy connectionless in smart cities," Electronics, 2021. mdpi.com
12. I. Natgunanathan, N. Fernando, S. W. Loke, "Bluetooth low energy mesh: Applications, considerations and current state-of-the-art," Sensors, 2023. mdpi.com
13. S. Nanayakkara, R. Shilkrot, K. Peen Yeo, and P. Maes, "EyeRing: A Finger-Worn Input Device for Seamless Interactions with Our Surroundings," 2013. [PDF]
14. J. M. (José Mauricio) Ochoa and D. (Derek) Kamper, "Desarrollo de un guante ortótico para proveer asistencia en la extensión de los dedos a pacientes que han sufrido derrame cerebral," 2009. [PDF]
15. A. Nelson, S. McCombe Waller, R. Robucci, C. Patel et al., "Evaluating touchless capacitive gesture recognition as an assistive device for upper extremity mobility impairment," 2018. ncbi.nlm.nih.gov
16. J. Enrique Calacuayo Rojas, S. Denisse Martínez Sosa, and A. García Barrientos, "DISEÑO Y CONSTRUCCIÓN DE UN GUANTE TRADUCTOR DE LENGUAJE DE SEÑAS A MENSAJES DE AYUDA (DESIGN AND CONSTRUCTION OF A GLOVE TRANSLATOR FROM SIGN LANGUAGE TO MESSAGES FOR HELP)," 2019. [PDF]