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An ErgoStroke Home Healthcare Management System with Gesture-Based Communication and Vital Sign Tracking for Stroke Patients

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ABSTRACT

Providing optimal care for homebound stroke patients remains a significant challenge due to limited mobility and substantial communication barriers. This project presents the enhanced ErgoStroke system, an ergonomic, wearable healthcare solution designed to facilitate patient-caregiver communication and real-time health monitoring. The system utilises customised finger gloves integrated with biomedical sensors to track vital signs, including oxygen saturation, heart rate, and body temperature. A primary innovation of this redesign is the implementation of a dual-mode feedback mechanism: a speaker module provides auditory confirmation of recognised gestures, while an LCD screen ensures visual request identification in quiet environments. Data management is facilitated through an ESP32-based web dashboard developed with Bootstrap, enabling caregivers to visualise real-time data and review historical health trends. Usability testing conducted with a stroke patient demonstrated high system accuracy, ease of use, and a marked improvement in caregiver response times. However, technical evaluations identified hardware instabilities related to portable jumper cables and ESP32 port conflicts. To ensure consistent performance and commercial viability, the study recommends the development of a dedicated Printed Circuit Board (PCB). Ultimately, ErgoStroke offers a comprehensive and reliable solution that empowers patients, reduces caregiver burden, and enhances the quality of long-term home-based healthcare.

1.0 Introduction

Caregivers and stroke patients face numerous challenges in healthcare management, including communication difficulties, usability issues with medical devices, and the need for effective technology-based interventions. Parental caregivers struggle with communicating health information to child patients, acknowledging different perceptions of illness, and understanding unexpressed emotions. (Seo et al., 2021). Home care medical devices present usability challenges, particularly in device-user interfaces, highlighting the importance of involving end-users in design processes. (Tase et al., 2022). Technology-based interventions for caregiver's face obstacles related to equity, privacy, and inclusive design. (Lindeman et al., 2020). Research gaps include the need for standardized methods to collect user feedback on device usability and the development of systems that allow caregivers to provide input and direct healthcare professionals' attention to specific issues (Foong et al., 2020; Tase et al., 2022). Addressing these challenges and gaps could lead to more effective, user-friendly healthcare solutions for both caregivers and patients.

To bridge the communication and monitoring gaps in home-based stroke care, this research focuses on an enhanced version of the ErgoStroke system, specifically designed for paralyzed stroke patients who receive infrequent medical consultations at home. Building upon the earlier Automated Stroke Paralysis Healthcare System, which faced limitations such as discomfort from full-hand gloves, inaccurate vital sign monitoring, and a lack of data storage, the redesigned ErgoStroke system introduces significant improvements in usability, accuracy, and functionality. The new design features tailored finger gloves for greater comfort and integrates advanced sensors to accurately monitor oxygen levels, heart rate, and temperature in real time. A speaker module has been added to provide auditory feedback, supporting multimodal communication for patients with limited expressive abilities. Detected patient requests are also visually displayed on an LCD, ensuring a clear understanding in different caregiving environments. Furthermore, a real-time web-based dashboard, developed using ESP32 and Bootstrap, enables the monitoring, visualization, and storage of health data, providing caregivers and healthcare professionals with access to historical records for better medical decision-making. To evaluate the system's practical viability, a real-world usability test involving an actual stroke patient was conducted, assessing comfort, system responsiveness, and overall user experience. These enhancements collectively aim to improve patient-caregiver interaction, enhance real-time health tracking, and support better outcomes for paralyzed stroke patients in long-term home care.

2.0 Literature Review

Recent advances in healthcare technology have increasingly emphasized the development of automated and wearable systems to support stroke rehabilitation and home-based care. These systems integrate Internet of Things (IoT) technologies, wireless communication, and sensor-based monitoring to assist stroke paralysis patients by tracking vital signs (Yusoff et al., 2024) and movement patterns. Such systems have proven essential for improving patient outcomes, reducing caregiver burden, and enabling timely medical care. (Chen & Sawan, 2021; Saloni et al., 2022; Eshrak et al., 202). Variouss studies have proposed the use of wearable devices for continuous health monitoring and patient communication. For instance, tilt-based input systems and motion sensors allow patients with limited mobility to communicate through functional body parts, facilitating timely caregiving and emergency response. (Eshrak et al., 2023; Padmaja K. V & Hemanth Kumar, 2021). Additionally, wrist- and limb-based accelerometers have been employed to monitor physical activity levels, assess hemiparesis severity, and evaluate rehabilitation progress. Signal processing and coherence-based techniques have shown strong correlations with clinical assessments and have proven effective for quantifying stroke recovery in time and frequency domains. (Ou et al., 2020; Datta et al., 2020).

Home-based rehabilitation systems increasingly include adaptive exercises and real-time feedback, which improve patient engagement and guide clinical decision-making. (Craig et al., 2020). Smart home technologies, such as the Howz system, offer increased reassurance and safety for stroke survivors living independently. (Rogerson et al., 2020). In parallel, portable EEG systems like HealthSOS have demonstrated substantial accuracy in real-time stroke classification, while mobile health applications support automated symptom detection and emergency alerting. (Bat-Erdene & Saver, 2021; Hussain & Park, 2020). Beyond motion tracking, wearable devices are now essential tools in broader healthcare contexts, including elderly care, chronic disease management, and preventive medicine. (Casselman et al., 2017; Pardamean et al., 2020). These devices can monitor heart rate, oxygen saturation, and body temperature, transmitting real-time data to caregivers via cloud-based or GSM communication platforms. (Almarzouki et al., 2021;

Kate et al., 2022). Moreover, IoT-enabled wearable orthotic systems to have emerged as cost-effective home therapy solutions, offering customizable settings and real-time performance feedback. (Megalingam et al., 2023).

Despite this progress, several implementation challenges persist. Concerns regarding data privacy, regulatory compliance, and usability remain significant obstacles to widespread adoption. (Lauer-Schmaltz et al., 2023). Importantly, informal caregivers, often lacking medical training, face difficulties in interpreting sensor data or responding to alerts, limiting their effectiveness in at-home care settings. (Lauer-Schmaltz et al., 2023). To address this, researchers have proposed smart dashboards that integrate sensor data, electronic health records, and clinical guidelines using computational reasoning and interactive tools like chatbots. These dashboards can enhance communication and decision-making, but still face challenges related to interface design, data visualization, and recommendation interpretation. (Kökciyan et al., 2019; Lauer-Schmaltz et al., 2023) Wearable rehabilitation technologies, such as glove-type sensors, finger-assist exoskeletons, and virtual reality-based systems, have shown promise in improving upper limb motor recovery and encouraging therapy adherence. (Ou et al., 2020; Park et al., 2021) Studies further support that remote rehabilitation via wearable devices significantly enhances patient mobility, engagement, and self-management compared to conventional therapy. (Bu et al., 2023; Toh et al., 2023). Comprehensive reviews highlight that wearable systems integrating machine learning and artificial intelligence hold considerable potential for optimizing stroke recovery outcomes. (Lingampally et al., 2024).

Despite these advancements, a critical gap persists in the development of ergonomic, fully integrated wearable healthcare systems specifically designed for stroke paralysis patients and their caregivers. Many current systems focus exclusively on either clinical-grade monitoring or rehabilitation functionality, but few offer a comprehensive, user-centred approach that combines medical accuracy, daily usability, and real-time support. For instance, existing glove-type designs have been associated with physical discomfort and fatigue during prolonged use, which undermines their practicality for long-term rehabilitation. (Eshrak et al., 2023). Additionally, inaccuracies in vital sign monitoring limit the reliability of remote health data used in clinical decision-making. (Saloni et al., 2022). A further limitation is the lack of integrated platforms for storing and visualizing patient health histories, which restricts retrospective analysis and coordinated care. (Azodo et al., 2020). Moreover, the design of many current systems does not adequately consider the needs and capabilities of informal caregivers, who often lack tools to interpret technical health data or interact meaningfully with digital health systems. (Lauer-Schmaltz et al., 2023).

To address the limitations of existing healthcare solutions, the current project proposes the design and development of an ergonomic wearable automated healthcare system specifically tailored for stroke paralysis patients. The system features custom-designed finger gloves made from soft, ergonomic materials to ensure maximum comfort during prolonged use. It also includes upgraded biosensors capable of accurately monitoring vital parameters such as oxygen saturation, heart rate, and body temperature in real time. Additionally, a customizable web-based dashboard, developed using the ESP32 microcontroller and the Bootstrap framework, allows for real-time data visualization, remote data storage, and retrospective analysis to support ongoing patient care and clinical decision-making. By integrating accurate sensing, ergonomic design, and user-friendly caregiver interfaces, the proposed system aims to fill a critical gap in current wearable health solutions and deliver improved home-based care for stroke patients. This innovation not only supports clinical outcomes but also empowers caregivers with actionable insights, ultimately enhancing the quality of life for both patients and their support networks.

3.0 Methodology

3.1 System Overview

The proposed system integrates an ESP32 microcontroller and a web-based dashboard to monitor stroke paralysis patients efficiently. It gathers physiological data through various sensors and offers real-time viewing together with historical record management, as shown in Fig.1 (A). The proposed system aims to monitor and manage healthcare data for stroke paralysis patients by merging an ESP32 microcontroller with a web-based dashboard. The system architecture consists of two main components: sensor-based data acquisition and an interactive caregiver interface. As illustrated in Fig.1, the ESP32 microcontroller processes inputs from a flex sensor, a MAX30102 pulse oximeter, and a non-contact temperature sensor. These sensors track essential health parameters, which are processed and transmitted for further analysis. The collected physiological data is then transmitted to a database for storage and analysis while simultaneously being displayed on an LCD for real-time monitoring.

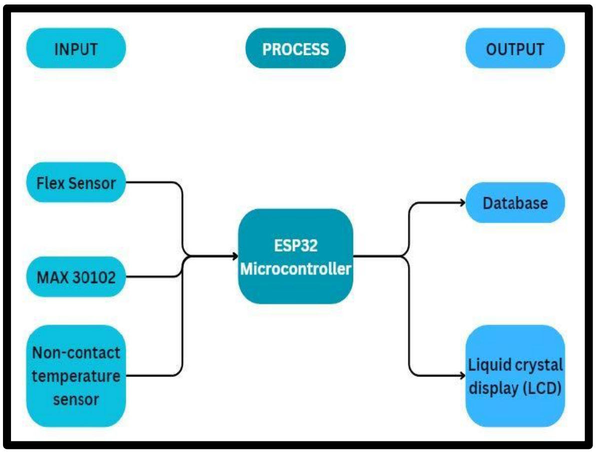


Fig. 1 (a). Block Diagram of ErgoStroke Home Healthcare Management System (Hardware)

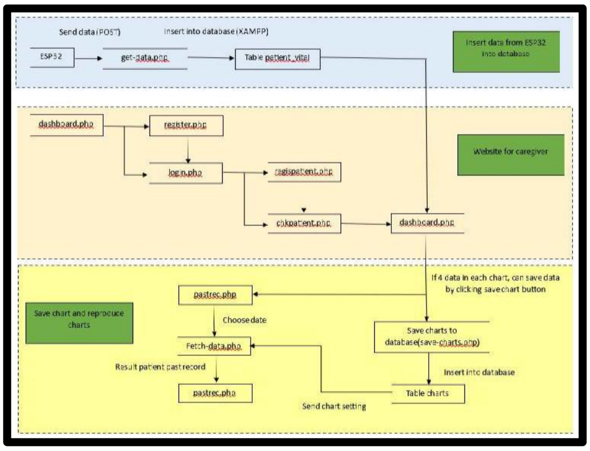


Fig. 1 (b). Block Diagram of ErgoStroke Home Healthcare Management System (Dashboard)

To enhance accessibility for caregivers, a web-based dashboard has been developed, as illustrated in Fig. 1 (B). The dashboard enables caregivers to register patients, view real-time health data, and generate historical records for further analysis. The system utilizes PHP scripts for data insertion, retrieval, and display, facilitating effective management of patient records. This system guarantees ongoing surveillance and enables prompt intervention for stroke paralysis patients.

3.2 Design of Ergonomic Wearable Device

The Fig. 2 in the methodology section depicts the structured approach to designing an ergonomic wearable device (ErgoStroke) utilizing Inventor Pro. It graphically illustrates the sequential steps involved in the development process, commencing with conceptual design and culminating in final simulation and testing. The workflow begins with preliminary sketches and parametric modelling, during which the essential shape and structure of the device are developed. The subsequent phase is assembly, which guarantees the correct integration of individual components to create a functional unit. Furthermore, the figure underscores the significance of ergonomic study, accentuating user comfort, fit, and flexibility to human motion. The final stages include simulation and performance testing, during which structural integrity, material characteristics, and mechanical stress are evaluated to refine the design before production. This process guarantees that the wearable device satisfies both functional and ergonomic criteria, yielding an efficient and user-friendly product.

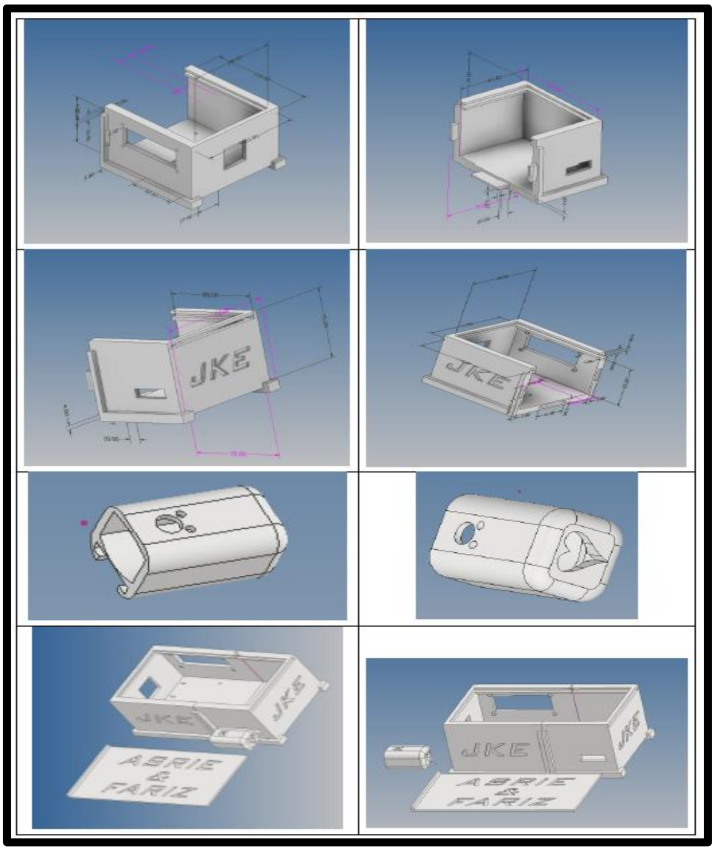


Fig 2. Ergonomic Wearable Device Design Using Inventor Pro

3.3 Device Operation Workflow

The device operation workflow integrates biomedical sensors and flex bend pressure sensors to continuously monitor vital signs such as heart rate, oxygen saturation, and temperature, which are displayed in real time on an LCD screen. Designed specifically for patients with stroke-induced paralysis, the system allows effortless engagement through minimal movement. Flex bend sensors detect 90° finger flexions, each associated with a specific patient request, enabling intuitive communication. Real-time data acquisition ensures immediate response and facilitates data retention for later analysis. Rigorous testing confirmed the system's precision in accurately identifying patient needs based on sensor input.

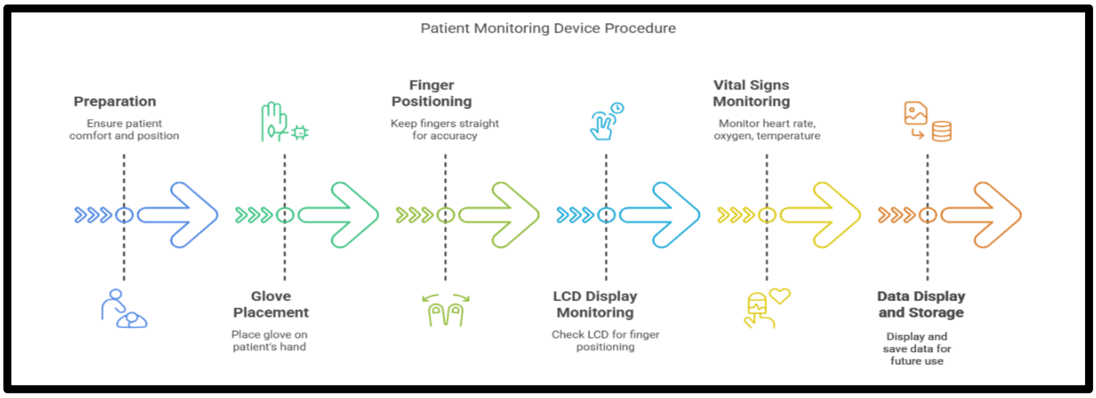


Fig.3. Workflow ErgoStroke Device Function

The ErgoStroke Dashboard Home Healthcare Management System for Stroke Patients offers a comprehensive and user-friendly solution for managing and visualizing patient health data. The system employs PHP and XAMPP to handle data processing and storage, as illustrated in Fig. 4. Patient vitals collected by the ESP32 are transmitted via HTTP POST requests to a designated API, which logs the information into the patient vital table for subsequent access and analysis. An interactive web-based dashboard, also shown in Fig. 4, is designed for caregivers to register, log in, and manage patient records efficiently. This interface ensures convenient and uninterrupted access to patient data, enhancing real-time monitoring and decision-making. Caregivers begin by registering with the required credentials, ensuring secure and confidential data handling. Once registered, they can enter and update patient information, which is stored in a structured and accessible format. The system's secure login mechanism ensures that only authorized personnel can access sensitive patient details.

Furthermore, the dashboard features graphical data visualization and robust record management capabilities. It provides a visual representation of patient health records, enabling caregivers to track recovery trends over time. Users can select specific dates, retrieve historical charts, and input new data seamlessly, supporting effective monitoring of patient conditions and caregiver interventions. To enhance communication and system interactivity, a compact speaker module was integrated into the ErgoStroke device. The speaker emits pre-programmed voice alerts based on the patient's finger gestures, corresponding to needs such as food, water, hygiene, or repositioning. Each detected gesture is confirmed by an audible cue (e.g., "Water requested"), helping caregivers understand patient intent without needing to observe the dashboard. This feature enhances usability in dynamic home environments and supports visually impaired users.

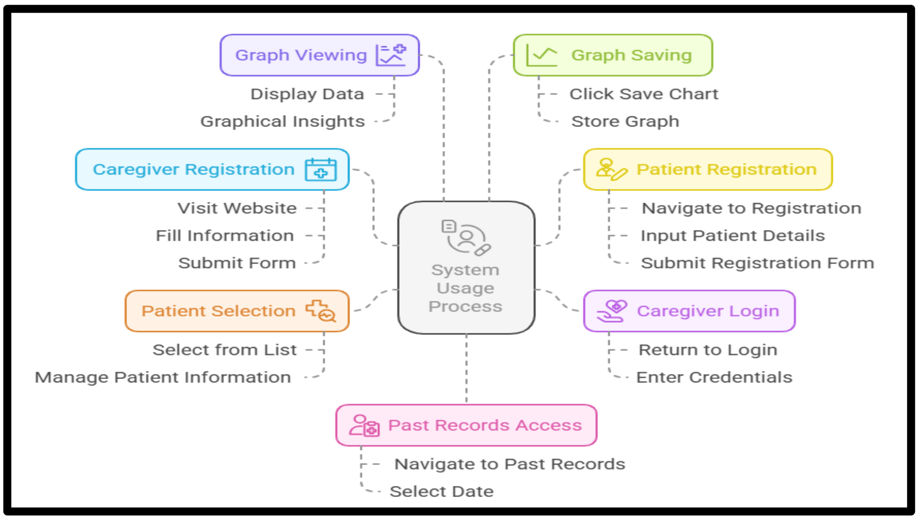


Fig. 4. System Workflow of the Dashboard ErgoStroke Home Healthcare Management System

3.4 Participants and Procedures:

A pilot usability test was conducted involving a **61-year-old male stroke survivor with right-side hemiplegia**. The test session lasted **30 minutes** and was carried out under caregiver supervision in a home environment. The patient used the **redesigned ErgoStroke prototype**, which included a set of finger gloves embedded with flex bend sensors and biomedical sensors, along with auditory (speaker) and visual (LCD) feedback modules. The procedures involved the patient performing predefined finger gestures to represent basic needs—such as requesting food, water, hygiene, or repositioning. Vital signs (temperature, oxygen saturation, heart rate) were continuously monitored and displayed on an LCD and the web-based dashboard. Structured interviews were conducted with both the patient and caregiver to obtain feedback on system comfort, gesture recognition, speaker comprehension, and response time. System logs were also analysed to validate detection speed and response accuracy.

4.0 Results and Discussion

This section will concentrate on the presentation of system testing results, specifically addressing the evaluation of the prototype design, including ergonomic gloves, sensor accuracy, and a real-time monitoring dashboard. Assessing the efficacy of the redesigned components and their impact on system performance.

4.1 Prototype Design Testing

Previous Prototype | Current Prototype

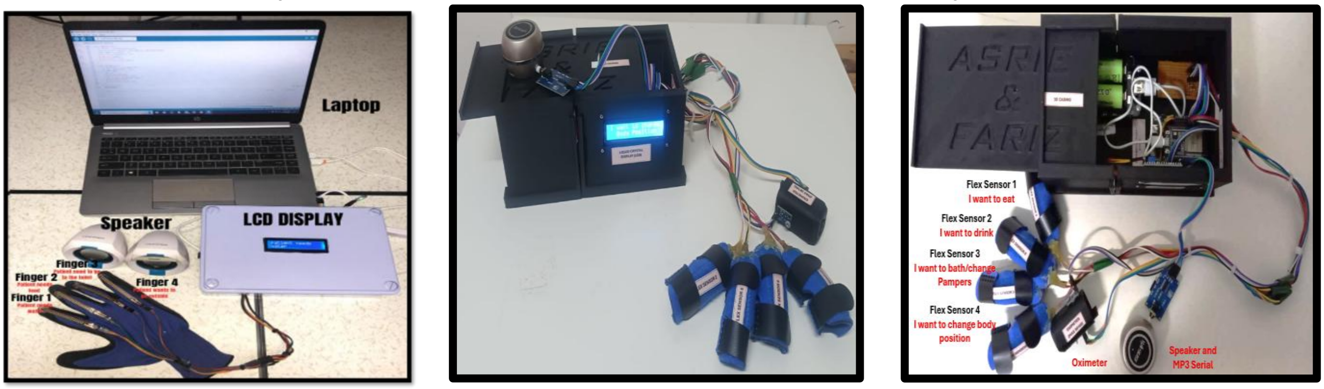


Fig. 5. ErgoStroke Device Prototype

Table 1. Prototype Design and Testing Redesigned Finger Gloves Comparing with the Previous Design

Prototype Design Comparison			
Aspect	**Previous Prototype Design (Blue Glove with Laptop)**	**Current Prototype Design (Ergonomic Wearables with Black Box)**	**Remarks**
Design	Glove-based, open setup connected to a laptop. Wires are exposed. Suitable for early-stage testing.	Enclosed a black box with connected ergonomic wearable (flex sensors). Components are well-arranged and portable.	The current prototype is more refined, durable, and ready for real-world use.
Power Supply	Powered via laptop USB connection. Requires continuous connection to function.	Uses internal DC power or rechargeable battery. Operate independently without needing a computer.	The current prototype supports patient mobility and ease of setup.
Patient Monitoring	4 flex sensors on glove fingers to detect physical movement. No vital sign integration.	4 flex sensors in ergonomic wearable form plus an oximeter for monitoring basic health status.	The current version provides both functional input and health monitoring.
User Feedback System	LCD shows text output; speakers use laptop for audio.	LCD and MP3 speaker module deliver independent visual and voice messages to caregivers.	The current prototype gives reliable and standalone feedback without relying on a laptop.
Communication	Communication relies on laptops for both display and sound output.	Pre-recorded audio messages and visual cues are delivered through built-in modules.	The current system enables fast, direct caregiver alerts.
Ergonomics	Gloves may cause discomfort and limit finger motion during extended wear.	Ergonomic wearable sensors fit comfortably on fingers with minimal restriction. Compact unit reduces bedside clutter.	The current design is more patient-centered and long-term wearable.
Intended Use	Designed for stroke patients to express basic needs; suitable for lab testing or demonstration.	Designed for stroke survivors (e.g., right-side hemiplegia) to express specific needs (e.g., eat, drink, reposition).	The current version is practical for daily use in homes or healthcare facilities.
Test Results on Redesigned Finger Gloves			
Test Parameter	**Previous Prototype Design (Full Glove with Laptop)**	**Current Prototype Design (Ergonomic Wearable with Black Box)**	**Remarks**
Comfort & Fit	Tight gloves may cause discomfort and sweating.	Soft finger-mounted straps improve breathability and comfort.	The current design is more suitable for long-term use.
Sensor Accuracy	Flex sensors integrated into glove fabric may shift slightly.	Sensors directly fixed on fingers give more stable and accurate readings.	Improved sensor precision in current design.
Ease of Wear	Requires help to wear properly; limited adjustability.	Simple and adjustable finger straps; easier for caregiver or patient to manage.	Easier and faster to put on in current design.
Durability	Fabric gloves may wear out or stretch over time.	Wearable parts are modular and replaceable; made from more durable materials.	The current design is more robust and maintenance friendly.
Signal Stability	Sensor output may vary due to glove fabric movement or slack.	Stable signal due to firm sensor placement and direct contact.	Better signal consistency in current prototype.
Power Consumption	Relies on laptop USB; higher power demand.	Uses efficient microcontroller with lower power consumption.	More energy-efficient in current design.
User Independence	Patients need assistance to wear and operate system.	Design allows more independence or minimal caregiver support.	Promotes autonomy for stroke patients.

4.1.1 Test Results of Sensor Accuracy Testing

The automated healthcare system for stroke paralysis integrates flex bend pressure sensors and biomedical monitoring to aid patients with restricted movement. The system detects finger motion and tracks vital signs, including heart rate and oxygen saturation, in real time.

Table 2. Results of ErgoStroke Sensor Accuracy

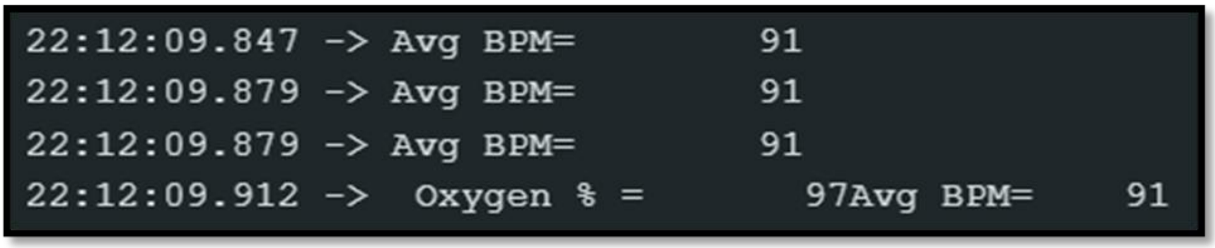
Table 2(a). Flex Bend Sensor Output for 4 Finger Movement

Position **Status**	**Index Finger (Food)**	**Middle Finger (Water)**	**Ring Finger (Bath/Change Pampers)**	**Little Finger (Change Body Position)**
Sensitivity reading (Detected 90^o)	YES	YES	YES	YES
Sensitivity (Time)	1 Second	1 Second	1 Second	1 Second

Table 2(b). Biomedical Sensors for Patient Health Monitoring

Status	**Temperature Reading**	**Oxygen Reading**	**Heart Rate Reading**
Detected Value	35^oC~37^oC	95 ~ 99	>60<100
Response Time	Immediate	40~50 Second	40~50 Second

Table 2(c). Serial Monitor Output for Result of Biomedical Sensors Output



```
22:12:09.847 -> Avg BPM=      91
22:12:09.879 -> Avg BPM=      91
22:12:09.879 -> Avg BPM=      91
22:12:09.912 ->  Oxygen % =      97Avg BPM=    91
```

Table 2(a) depicts the operation of a Flex Bend Pressure Sensor (Modification Design), which is used to interpret the movements of four different fingers for communication purposes in patients with limited mobility. According to the 4 Finger Movement system shown in Figure 5, indicates that the motion of each finger is related to a certain patient need:

i. **Index Finger (Food)** – Indicates the patient wants to eat.

ii. **Middle Finger (Water)** – Indicates the patient wants to drink.

iii. **Ring Finger (Bath)** – Indicates the patient wants to bathe or change Pampers.

iv. **Little Finger (Go Outside)** – Indicates the patient wants to change body position.

Table 2(a) sensitivity analysis verifies that the system detects a 90° finger bend for all four fingers, eliciting a positive response ("YES"). The response time for detecting each movement is consistently 1 second across all finger inputs, ensuring a rapid and uniform recognition process. This design ensures an intuitive, efficient, and user-friendly interface for patients, enabling them to convey vital needs successfully with less exertion. The consistent sensitivity response across all fingers enhances reliability, rendering the system a desirable, helpful device in home-based and healthcare environments.

Table 2(b) presents the observational outcomes of biomedical sensors that assess essential vital signs, including temperature, oxygen saturation, and heart rate. These parameters are crucial for monitoring the health conditions of patients, especially those with restricted mobility or chronic illnesses. Figure 8 indicates that the detected vital sign readings demonstrate that the temperature is within the normal human body temperature range of 35°C to 37°C, with an instantaneous response time, facilitating real-time monitoring. The oxygen saturation (SpO_2) values are within a healthy range of 95% to 99%, necessitating a 50-second response time for detection. The heart rate is within normal physiological ranges, ranging from 60 and 100 beats per minute (BPM), consistent with a typical resting heart rate for humans, and has a detection response time of 40 seconds. The measurements demonstrate that the patient is stable, with oxygen levels and heart rate within normal ranges, ensuring patient safety and stability throughout sensor activation.

According to the serial monitor output in Table 2(c), an average heart rate monitoring (BPM) of 91 was observed, with repeated readings consistently sustaining this value over a short period. This consistency signifies a steady and dependable heart rate measurement system. The lack of substantial variations indicates that the monitoring system accurately and reliably measures the user's heart rate. The monitored oxygen saturation level (SpO_2) was 97%, falling within the healthy range of 95%-99%. The system accurately records real-time oxygen levels alongside BPM values, facilitating thorough monitoring of the patient's health. The differences in response times indicate that while temperature readings are instant, oxygen and heart rate measurements require a short delay before an accurate reading is obtained. These results suggest that the system effectively captures essential health indicators, contributing to real-time remote health monitoring for patients who require continuous observation.

4.2 Dashboard of ErgoStroke Home Healthcare Management System

The dashboard depicted in Fig. 6 effectively visualizes patient vitals, facilitating real-time health monitoring by displaying vital indicators in an accessible manner. The system's capacity to monitor, archive, and represent health data renders it a vital resource for hospitals, clinics, and telemedicine applications.

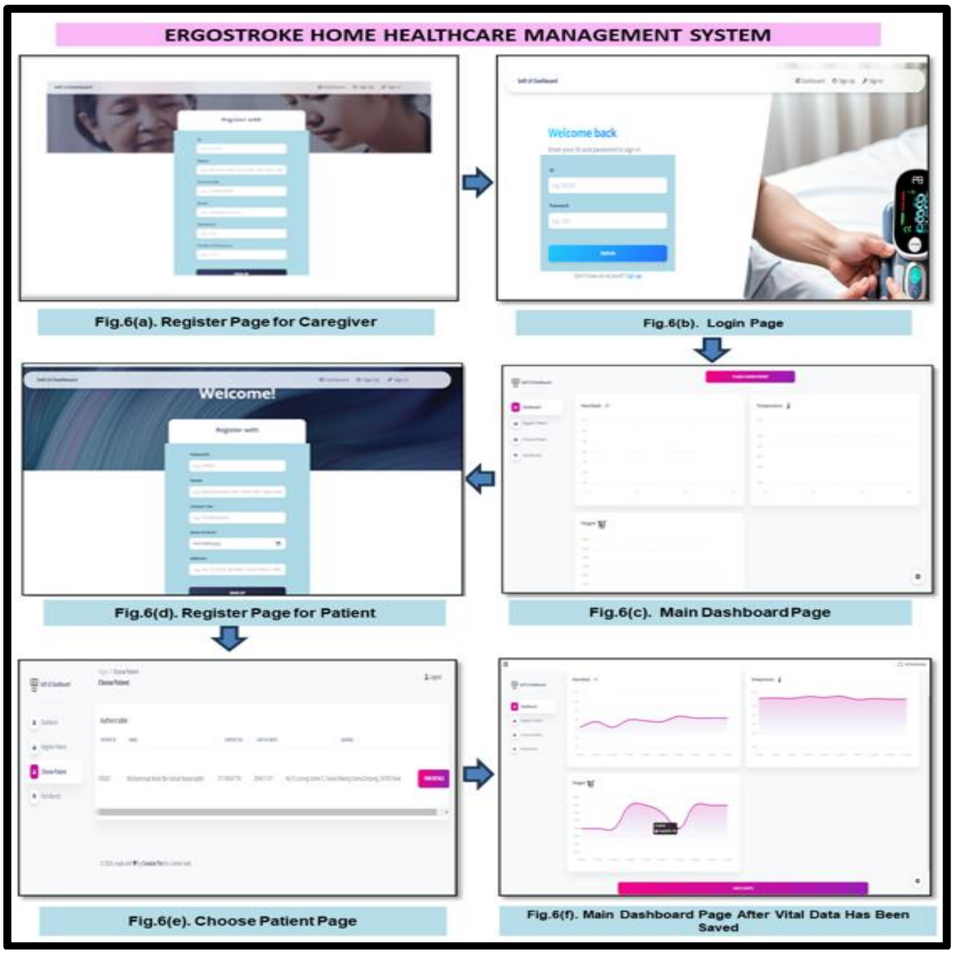


Fig.6(a-f). Dashboard of ErgoStroke Home Healthcare Management System

4.2.1 System Testing Results

Fig. 7(a) illustrates a phpMyAdmin interface presenting the outcomes of a MySQL database query for the caregiver table. The query SELECT * FROM caregiver retrieves all records from the table, listing caregivers' details. The displayed columns include Caregiver_ID, Name, Contact_No, Email, and Password. It ensures secure storage, easy retrieval, and management of caregiver data for patient monitoring. The implementation of hashed passwords highlights a focus on security, whereas unique IDs streamline caregiver identification. Fig. 7(b) presents the patient registration table, which stores the details of patients receiving medical monitoring. It stores vital patient information, allowing caregivers and healthcare professionals to access and monitor patient details efficiently. Fig. 7(c) illustrates a phpMyAdmin interface presenting real-time patient vital data stored in the "patient vital" table within the "hospital" database. The table records patient ID, heartbeat, temperature, oxygen levels, and timestamps, which are received from IoT medical sensors connected to an ESP32-based healthcare monitoring system. Fig.7(d) represents a Dashboard of the ErgoStroke Home Healthcare Management System designed for monitoring patient vitals, including oxygen levels, temperature, and heartbeat. The interface has a **soft UI design**, facilitating a seamless user experience with intuitive navigation. The dashboard comprises essential functionalities, including:

i. **Dashboard View:** Displays real-time graphical trends of patient health data.

ii. **Register Patient:** Allows new patient registration.

iii. **Choose Patient:** Selects a patient for monitoring.

iv. **Past Record:** Provides historical health data access.

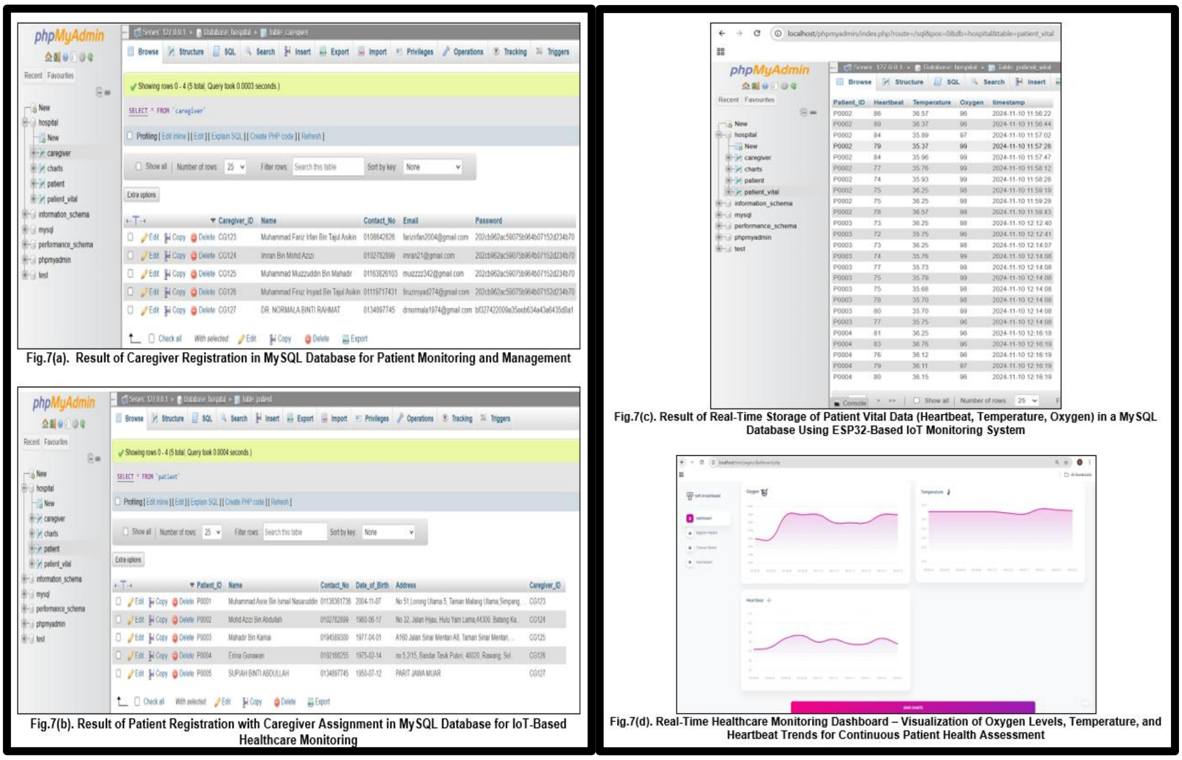


Fig.7(a). Result of Caregiver Registration in MySQL Database for Patient Monitoring and Management

Fig.7(b). Result of Patient Registration with Caregiver Assignment in MySQL Database for IoT-Based Healthcare Monitoring

Fig.7(c). Result of Real-Time Storage of Patient Vital Data (Heartbeat, Temperature, Oxygen) in a MySQL Database Using ESP32-Based IoT Monitoring System

Fig.7(d). Real-Time Healthcare Monitoring Dashboard – Visualization of Oxygen Levels, Temperature, and Heartbeat Trends for Continuous Patient Health Assessment

Fig. 7(a-d). Results of the Dashboard of the ErgoStroke Home Healthcare Management System Workflow

The graphs illustrate real-time data trends for oxygen saturation (SpO_2), body temperature, and heartbeat rate, assisting healthcare providers in tracking changes over time. It's illustrated that the result analysis indicates that the Oxygen Saturation (SpO_2) Trend fluctuates between 94% and 99%, signifying normal but slightly varying oxygen saturation levels. A notable rise is observed around 09:38:46, succeeded by a phase of stability. The Temperature Trend status is constant, fluctuating between 34°F and 37°F, which is within the normal body temperature range. The minimal fluctuation suggests a steady physiological condition. The Heartbeat Trend fluctuates between 60 bpm and 110 bpm, with a consistent rise pose 09:38:46, indicating a possible physiological reaction or activity. The system demonstrates high performance and data integrity through real-time data logging, guaranteeing ongoing and current monitoring of patient vitals. The consistent sensor readings, without extreme fluctuations, confirm the accuracy and reliability of the sensors in tracking stable patient health. Furthermore, the ESP32 adeptly communicates data to the MySQL database, signifying a seamless and dependable communication flow between IoT sensors and the storage system. These results confirm the system's efficacy in providing accurate, consistent, and real-time health monitoring for patients.

4.3 Usability Testing with Stroke Patient and Caregiver

A pilot usability test was conducted involving a 61-year-old male stroke survivor with right-side hemiplegia. The patient used the redesigned ErgoStroke prototype during a 30-minute session under caregiver supervision. Parameters assessed included ease of glove wearing, accuracy of finger gesture detection, comprehension of auditory alerts, comfort level, and caregiver response time. Subjective feedback was collected through structured interviews with both the patient and caregiver, and system logs were analysed to validate detection and response metrics. The findings confirmed the system’s ergonomic comfort, intuitive gesture-based controls, and effective communication through speaker prompts.

4.3.1 Patient and Caregiver Feedback from Pilot Test:

During the structured interview, the following **questions** were asked to both the **patient** and the **caregiver**, and their corresponding **responses** were recorded:

a) How comfortable was the glove device during use?

   i. *Patient response:* "Very comfortable. The finger gloves are soft and don’t hurt during movement."

   ii. *Caregiver response:* "No signs of discomfort or need for adjustment during the test."

b) Was the system able to recognize your gestures accurately?

   i. *Patient response:* "Yes, every time I bent my finger, it responded correctly."

   ii. *Caregiver response:* "The system was very responsive and accurately identified each command."

c) Could you understand the speaker's alerts clearly?

   i. *Patient response:* "Yes, the speaker's voice was clear and helpful."

   ii. *Caregiver response:* "The voice prompts were loud and clear even from a distance."

d) Was it easy for you to interact with the system?

   i. *Patient response:* "Yes, it didn’t need a lot of effort to use."

   ii. *Caregiver response:* "Simple and intuitive. Very helpful in understanding the patient's needs."

e) Did the system help in reducing your response time?

   i. *Caregiver response:* "Yes, the alerts—both visual and auditory—let me react faster."

4.4 Consequences of Findings

The deployment of the flex bend pressure sensor system significantly improves stroke patient care by facilitating effective communication between patients and caregivers. Stroke patients with paralysis frequently encounter difficulties in articulating their fundamental needs, resulting in frustration and discomfort. This system enables them to convey fundamental requests, such as food, water, bathing, or changing Pampers, and change body position, through basic finger movements, thereby enhancing their quality of life. The revised sensor design identifies movements within one second, compared to the five to seven seconds needed by the original model. This expedited response time guarantees that caregivers can deliver prompt assistance, minimizing delays that may result in patient distress or medical complications. This observation aligns with the research by Eshrak et al. (2023) and Padmaja K. V & Hemanth Kumar (2021), which highlights how automated healthcare systems for paralyzed patients can significantly improve mobility and communication by utilizing any remaining motor functions. The current ErgoStroke prototype further enhances patient care by transitioning from a laptop-dependent configuration to a compact, ergonomic wearable device. It integrates flex sensors, a pulse oximeter, and a temperature sensor for real-time health monitoring and gesture-based communication. Additionally, the implementation of a web-based Dashboard Home Healthcare System allows for seamless data collection, storage, visualization, and caregiver-patient interaction. This is consistent with Lauer-Schmaltz et al. (2023), who emphasized the benefits of intuitive digital dashboards for both professional and informal caregivers.

System observations during the pilot test also confirmed the device's ergonomic comfort and ease of use. The patient experienced no discomfort, and the interface was found to be intuitive. The speaker module and LCD improved communication clarity and boosted user confidence and caregiver response time. However, several limitations were identified. The flex sensors, despite their improved response speed, occasionally failed to detect weak finger movements in patients with severe paralysis, which could lead to miscommunication or delays. Moreover, environmental conditions such as humidity and temperature were found to marginally affect sensor accuracy (Yusoff et al., 2024), highlighting the need for further calibration and refinement. In addition to sensor-related issues, technical limitations were also observed. Output instability caused by portable jumper cables and LCD display conflicts due to shared ESP32 ports compromised overall system performance. To overcome these challenges, it is strongly recommended that future versions of the system adopt a custom-designed printed circuit board (PCB) to ensure more stable connections and reliable hardware integration.

The real-time vital sign monitoring capabilities, including temperature, oxygen saturation, and heart rate (Yusoff et al., 2024), greatly enhance ongoing health surveillance. This data, displayed on the dashboard, enables caregivers to quickly identify abnormalities and initiate timely interventions, potentially preventing risks such as hypoxia or fever. As noted by Eshrak et al. (2023), remote patient monitoring systems are increasingly essential for proactive care. The current ErgoStroke system streamlines workflow efficiency by eliminating the need for external computing devices, processing data directly within the wearable device, and displaying outputs in real time on an LCD and a centralized dashboard. Ultimately, the ergonomic design and integration of real-time health data contribute to faster caregiver response, improved decision-making, and more proactive patient care. Despite the observed limitations, the findings confirm that ErgoStroke significantly improves the quality of life for stroke patients while easing the burden on caregivers.

5.0 Conclusion

The enhanced ErgoStroke system, equipped with an auditory speaker and validated through real-user testing, demonstrates notable improvements in communication, usability, and caregiver responsiveness for stroke patients. By accurately monitoring vital signs and detecting finger movements with high sensitivity and minimal latency, it bridges communication gaps and ensures real-time health surveillance, particularly benefiting patients with severe mobility and speech impairments. The inclusion of a speaker enables immediate feedback, enhancing patient confidence and reducing caregiver response time, while usability testing confirms the system's practicality in real-world settings. Future enhancements will focus on increasing sensor sensitivity, integrating IoT for remote monitoring, and incorporating machine learning for predictive insights. Additionally, exploring alternative communication methods such as voice recognition and eye-tracking, along with advanced wearable sensors, will further personalize care and expand accessibility. Although the current prototype may incur higher costs due to advanced design and material selection, ErgoStroke remains an inclusive, adaptable, and reliable solution with strong potential to improve home-based stroke rehabilitation and patient outcomes.

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Author Contributions

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Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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