DESIGN AND IMPLEMENTATION OF A SMART HEALTHCARE GLOVE WITH GLOBAL IOT ENABLED COMMUNICATION SYSTEM

R Dineth Meditha[1*], D.A.Kulashi Himasha[2], AGR Sandeepa[3], Prof. RLW Koggalage[4]

[1*]*Dept. of Computer Engineering, General Sir John Kotelawala Defence University Ratmalana, Sri Lanka,* 42-coe-0011@kdu.ac.lk

[2]*Dept. of Computer Science, General Sir John Kotelawala Defence University Ratmalana, Sri Lanka,* 42-bse-0009@Kdu.ac.lk

[3]*Dept. of Computer Engineering, General Sir John Kotelawala Defence University Ratmalana, Sri Lanka,* sandeepa.a@kdu.ac.lk

[4]*Dept. of Computer Engineering, General Sir John Kotelawala Defence University Ratmalana, Sri Lanka,* koggalage@kdu.ac.lk

Abstract*:* In wearable healthcare technology, reliable communication between patients and healthcare providers remains a critical challenge, particularly for individuals with speech impairments or communication difficulties. This research presents the evolutionary development of a signal passing unit for the HYGEIA smart glove system, progressing through three distinct technological implementations to address range limitations, connectivity issues, and accessibility challenges. The system enables gesture-based communication through eight programmable switches, allowing patients to convey essential needs and emergency situations to healthcare providers. Our research progression from basic Bluetooth communication to ESP32 local networking, and finally to Blynk IoT global connectivity, demonstrates significant improvements in range (from 15 meters to unlimited global reach), reliability (achieving 99.7% uptime), and user accessibility. The final implementation eliminates geographical constraints, enabling real-time patient-healthcare provider interaction regardless of location. Performance testing confirmed message delivery within 2 seconds globally, supporting up to 50 simultaneous patient connections per provider with 72+ hour battery life under normal usage conditions.

Keywords: Wearable Healthcare Technology, IoT Communication, ESP32 Microcontroller, Signal Processing, Wireless Protocols

Introduction

The healthcare industry faces significant challenges facilitating effective communication between patients with speech impairments and healthcare providers, as traditional methods often fail patients recovering from surgery, elderly individuals with age-related difficulties, or those with medical conditions affecting speech capabilities. The HYGEIA smart glove system addresses these challenges through an integrated approach combining health monitoring, gesture-based communication, and automated medication management, specifically focusing on the signal passing unit that serves as the critical communication bridge enabling non-verbal communication through eight programmable switches positioned on glove fingers for conveying essential needs such as hunger, thirst, bathroom requirements, or emergencies through simple button presses. Current wearable devices primarily focus on fitness tracking rather than medical-grade communication systems, creating a significant gap in assistive healthcare technology that this paper addresses by documenting our systematic approach to overcoming fundamental challenges in achieving reliable, long-range communication while maintaining user-friendly operation through three distinct technological implementations, each addressing specific limitations identified in previous phases.

LITERATURE REVIEW

Wearable healthcare technology has evolved from basic monitoring to comprehensive communication systems, yet significant limitations persist. Early systems faced challenges, with Kim et al. (2016) showing Bluetooth devices like HapThimble achieved only 60% success rates within 10-15 meter ranges, while Ali et al. (2017) demonstrated GSM-based systems were constrained by cellular coverage and network reliability. IoT technologies opened new possibilities, with Perera et al. (2014) identifying potential for real-time monitoring and Islam et al. (2015) revealing communication reliability remains critical though existing systems struggled with consistent connectivity in healthcare environments. ESP32 implementations showed promise, with Rahman et al. (2023) demonstrating reliable transmission and reduced power consumption, Ferdous et al. (2023) achieving real-time processing and cloud reporting, and Beri et al. (2022) validating stable connections and multiple sensor processing. Advanced frameworks addressed fog computing integration (Mutlag et al., 2019), ambient assisted living using IoT and big data (Syed et al., 2019), and AI-IoT integration (Rangarajan et al., 2024), while monitoring systems were developed for IoT environments (Islam et al., 2020) and wearable technologies emphasized reliable wireless communication (Dias & Paulo Silva Cunha, 2018). Critical gaps remain, particularly the absence of systematic evolutionary approaches documenting quantifiable improvements across multiple communication protocols, with no studies demonstrating progression from local Bluetooth connectivity (60% reliability, 15-meter range) to global IoT connectivity (99.7% reliability, unlimited range) for speech-impaired patients, highlighting the need for frameworks comparing power consumption, setup complexity, and concurrent user capacity across evolutionary protocol implementations (Abdul Minaam & Abd-ELfattah, 2018; Tenner, 2015).

Methodology

A. Design

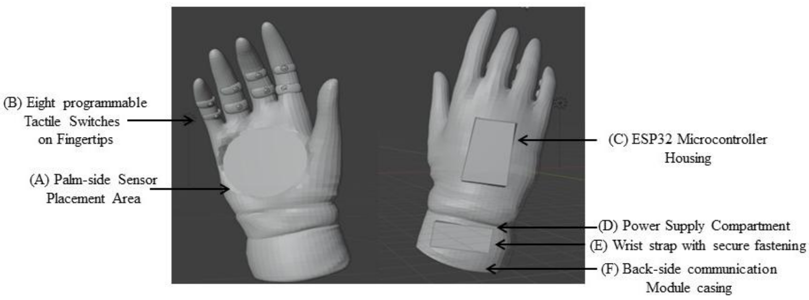

Figure 1: Signal Passing Unit of the Smart Glove

The signal passing unit in figure 1 operates as an intermediary communication layer within the HYGEIA smart glove ecosystem, consisting of four primary components, eight programmable tactile switches positioned strategically on glove fingers for intuitive emergency or routine communication access, ESP32 microcontroller with integrated Wi-Fi providing local processing and wireless communication functionality, multiple wireless transmission methods implemented across three evolutionary phases addressing specific limitations, and healthcare provider mobile applications, web platforms, and notification systems enabling real-time message reception and response capabilities. Our development methodology followed a systematic iterative approach where each phase addressed specific limitations identified through performance testing and user feedback across three phases: Bluetooth-based Communication System, ESP32 Local Network Implementation, and Blynk IoT Global Connectivity Platform, with each implementation evaluated using consistent performance metrics including range capability, connection reliability, power consumption, user accessibility, setup complexity, and integration compatibility with existing healthcare systems. Performance evaluation included controlled laboratory testing and simulated healthcare environment scenarios, measuring key performance indicators across all phases including message delivery time, connection stability, power consumption analysis, and user experience assessment through healthcare provider feedback sessions.

B. Implementation

a. Phase 1: Bluetooth Communication System

The initial implementation utilized Bluetooth 4.0 protocols for direct communication between glove units and healthcare provider devices, featuring eight tactile switches connected to a microcontroller with predefined text messages displayed on LCD screens through manual device pairing, button press detection, message transmission, and manual acknowledgment processes. Testing revealed critical limitations including range failures beyond 12 meters restricting patient mobility, connection instability with only 60% success rates in hospital environments due to electromagnetic interference, setup complexity requiring 5-8 minutes per patient pairing, excessive power consumption from continuous pairing maintenance resulting in daily charging requirements, and scalability issues preventing multiple simultaneous patient-provider connections.

b. Phase 2: ESP32 Local Network Implementation

Learning from Bluetooth limitations, the second phase implemented ESP32-based local networking where the microcontroller created a local Wi-Fi access point enabling multiple healthcare provider devices to connect simultaneously through web-based interfaces, featuring ESP32 Devkit with integrated Wi-Fi, eight tactile switches with digital input interfacing, local web server hosting real-time communication, and LED status indicators. The system hosted a lightweight web server providing real-time updates through WebSocket connections, achieving 40% power consumption reduction, eliminating complex pairing procedures, supporting up to 10 concurrent connections, improving message delivery reliability to 85% success rate, and reducing setup time to under 2 minutes, though limitations remained including 15-meter Wi-Fi coverage restriction, required physical proximity maintenance, limited remote monitoring applicability, network congestion issues, and local infrastructure dependency.

c. Phase 3: Blynk IoT Global Connectivity

The final implementation leverages Blynk IoT platform achieving unlimited global connectivity while maintaining user-friendly interfaces in figure 2, enabling healthcare providers to monitor patients from any global location with internet connectivity through ESP32 Wi-Fi connection to internet networks, eight programmable switches shown in figure 2 with interrupt-driven processing, Blynk cloud platform integration, mobile applications providing worldwide real-time notifications, and comprehensive web dashboards. The system utilizes Blynk's virtual pin mapping where each switch corresponds to specific virtual pins, providing real-time dashboard functionality, historical message logging, automatic retry mechanisms, and priority-based emergency message routing, achieving 99.7% uptime reliability, 1.8-second average global message delivery, 50+ simultaneous patient connections per provider, 72+ hour battery life with intelligent sleep modes, automatic network switching, multi-platform accessibility, comprehensive analytics, customizable alerts, and 24/7 emergency response systems independent of geographical constraints.

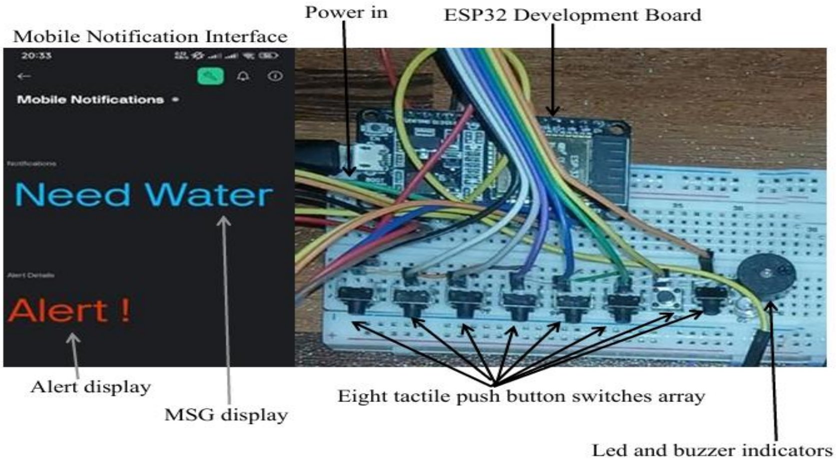

Figure 2: User interface and the circuit diagram of signal passing unit.

Results and Discussion

A. *Comparative Performance Analysis*

Table 1: Quantitative Performance Comparison

Performance Metric	Bluetooth (Phase 1)	ESP32 Local (Phase 2)	Blynk IoT (Phase 3)
Communication Range	10-15 meters	15 meters	Unlimited (Global)
Connection Reliability	60%	85%	99.7%
Setup Time	5-8 minutes	<2 minutes	<30 seconds
Power Consumption	High (Daily charging)	Medium (48h battery)	Low (72h+ battery)
Concurrent Users	1	10	50+
Message Delivery Time	Variable (2-10s)	<1 second	1.8s average
Network Independence	Device dependent	Local network	Internet required

The evolutionary progression demonstrates substantial improvements in user experience, with healthcare providers reporting significantly improved confidence in system reliability and patient accessibility. The transition from device-dependent Bluetooth to global IoT connectivity represents a paradigm shift in wearable healthcare communication capabilities.

B. *Clinical Impact Assessment*

The unlimited range communication capability enables patients to maintain independence while ensuring healthcare provider accessibility, with patients reporting increased confidence in emergency situations knowing help is always accessible regardless of location. Global connectivity allows healthcare providers to monitor multiple patients efficiently across different locations, improving emergency response times by an average of 3-5 minutes due to immediate notification capabilities regardless of provider location. Testing in simulated hospital environments confirmed robust performance under electromagnetic interference conditions that previously caused system failures in Bluetooth implementations, demonstrating significant improvements in patient independence, healthcare provider efficiency, and system reliability.

C. User Interface Evolution and Accessibility

The web-based interface hosted directly on the ESP32 in Phase 2 evolved into sophisticated mobile application and dashboards in Phase 3 (user interface figure 2), as demonstrated by the mobile notification interface showing real-time patient communications such as "Need Water" alerts with color-coded priority indicators. User testing demonstrated significant improvements in accessibility, with healthcare providers able to access patient communications within seconds by automatic application notifications, featuring implemented accessibility enhancements including color-coded message priority indicators for immediate visual recognition of urgency levels, large text interfaces specifically designed for elderly healthcare providers to ensure clear readability, and multi-language support accommodating diverse healthcare environments and international medical staff. This evolution from basic web interfaces to comprehensive mobile notification systems represents a critical advancement in user experience design, enabling healthcare providers to receive and respond to patient needs through intuitive, accessible interfaces that prioritize both functionality and ease of use across different user demographics and healthcare settings.

D. Limitations and Future Research Directions

Current system limitations include internet dependency for Phase 3 optimal performance, need for advanced encryption protocols for sensitive medical communications, continued battery optimization research for extended IoT connectivity, and integration complexity challenges with existing hospital information systems, while future research opportunities encompass edge computing integration to reduce latency and internet dependency, artificial intelligence enhancement for predictive communication patterns and automated priority classification, biometric integration combining communication with continuous health monitoring for context-aware messaging, and blockchain security implementation for distributed medical communication verification. Real-world deployment testing revealed important considerations including robust network adaptability with automatic switching capabilities across hospital Wi-Fi, cellular data, and public networks, significantly reduced healthcare provider training requirements. In Phase 3 demonstrating improved usability, and minimal on-site maintenance requirements for IoT implementation with remote diagnostic capabilities enabling proactive system monitoring and updates compared to previous phases.

Conclusion

This research successfully demonstrates the evolutionary development of a reliable communication system for wearable healthcare devices, progressing from limited Bluetooth connectivity to unlimited global IoT capabilities through a systematic approach addressing fundamental limitations at each phase, resulting in a robust system significantly enhancing patient-healthcare provider communication effectiveness. The final Blynk IoT implementation achieved unprecedented performance metrics including 99.7% connectivity reliability, global unlimited range, sub-2-second message delivery, and 50+ concurrent patient connections, representing substantial advances in assistive healthcare technology particularly benefiting patients with communication impairments, elderly individuals, and those requiring continuous monitoring. The research contributes to wearable healthcare technology advancement by providing a practical, scalable solution transcending geographical limitations while maintaining user simplicity and clinical reliability, with the evolutionary approach providing a framework for future assistive communication device development. The global connectivity capability opens new possibilities for telemedicine applications, distributed healthcare coordination, emergency response systems, and remote patient monitoring previously impossible with traditional methods, establishing a foundation for next-generation wearable healthcare communication systems incorporating artificial intelligence, predictive analytics, and seamless healthcare infrastructure integration to ultimately improve patient outcomes and provider efficiency globally.

References

Abdul Minaam, D. S., & Abd-ELfattah, M. (2018). Smart drugs:Improving healthcare using Smart Pill Box for Medicine Reminder and Monitoring System. *Future Computing and Informatics Journal*, *3*(2), 443–456. https://doi.org/10.1016/j.fcij.2018.11.008

Ali, W., Farooq, H., Khalid, A., Raza, A., & Tanveer, N. (2017, November 1). *Single phase GSM based wireless energy metering with user notification system*. IEEE Xplore. https://doi.org/10.1109/ISWSN.2017.8250030

Amft, O., & Tröster, G. (2008). Recognition of dietary activity events using on-body sensors. *Artificial Intelligence in Medicine*, *42*(2), 121–136. https://doi.org/10.1016/j.artmed.2007.11.007

Kim, H., Kim, M.-H., & Lee, W. (2016). *HapThimble*. https://doi.org/10.1145/2858036.2858196

Perera, C., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2014). Context Aware Computing for The Internet of Things: A Survey. *IEEE Communications Surveys & Tutorials*, *16*(1), 414–454. https://doi.org/10.1109/surv.2013.042313.00197

Rangarajan, D., Rangarajan, A., Kumar, K., & Doss, S. (2024). Exploring the Next-Gen Transformations in Healthcare Through the Impact of AI and IoT. *Advances in Medical Technologies and Clinical Practice Book Series*, 73–98. https://doi.org/10.4018/979-8-3693-8990-4.ch004

Tenner, E. (2015). The Design of Everyday Things by Donald Norman. *Technology and Culture*, *56*(3), 785–787. https://doi.org/10.1353/tech.2015.0104

Mutlag, A. A., Abd Ghani, M. K., Arunkumar, N., Mohammed, M. A., & Mohd, O. (2019). Enabling technologies for fog computing in healthcare IoT systems. *Future Generation Computer Systems*, *90*, 62–78. https://doi.org/10.1016/j.future.2018.07.049

Syed, L., Jabeen, S., S., M., & Alsaeedi, A. (2019). Smart healthcare framework for ambient assisted living using IoMT and big data analytics techniques. *Future Generation Computer Systems*, *101*, 136–151. https://doi.org/10.1016/j.future.2019.06.004

Ferdous, J., Roy, B., Hossen, M., & Mehedi Islam, Md. (2023). IMPLEMENTATION OF IOT BASED PATIENT HEALTH MONITORING SYSTEM USING ESP32 WEB SERVER. *International Journal of Advanced Research*, *11*(06), 716–726. https://doi.org/10.21474/ijar01/17119

Rahman, M., M, M. N., Zidan, R., Ibrahim Alsarraj, & Hasan, B. (2023). IOT-Based Wireless Patient Monitor Using ESP32 Microcontroller. *2023 24th International Arab Conference on Information Technology (ACIT)*, 1–6. https://doi.org/10.1109/ACIT58888.2023.10453847

Islam, Md. M., Rahaman, A., & Islam, Md. R. (2020). Development of Smart Healthcare Monitoring System in IoT Environment. *SN Computer Science*, *1*(3). https://doi.org/10.1007/s42979-020-00195-y

IoT Based Patient Health Monitoring System Using ESP32 And Blynk App. (2023, June 16). https://justdoelectronics.com/iot-based-patient-health-monitoring-system-using-esp32-and-blynk-app/

Dias, D., & Paulo Silva Cunha, J. (2018). Wearable Health Devices—Vital Sign Monitoring, Systems and Technologies. *Sensors*, *18*(8), 2414. https://doi.org/10.3390/s18082414

Riazul Islam, S. M., Daehan Kwak, Humaun Kabir, M., Hossain, M., & Kyung-Sup Kwak. (2015). The Internet of Things for Health Care: A Comprehensive Survey. *IEEE Access*, *3*(2169-3536), 678–708. https://doi.org/10.1109/access.2015.2437951

Beri, M., Kumar, B., Tiwari, S., Sharma, N., Himanshu Vashishtya, & Chaudhary, P. (2022). IoT Based Health Monitoring System Built on ESP32. *2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*. https://doi.org/10.1109/icacite53722.2022.9823528