International Journal of Electronic Devices and Networking

E-ISSN: 2708-4485
P-ISSN: 2708-4477
IJEDN 2024; 5(2): 36-41

www.electronicnetjournal.com
Received: 05-07-2024
Accepted: 11-08-2024

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A decentralized and secure health monitoring system for aging populations using blockchain, IoT-based wearable devices (Fitbit and BioPatch), and aes-256 and sha-256 encryption algorithms in Brazilian Hospitals

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DOI: https://doi.org/10.22271/27084477.2024.v5.i2a.64

Abstract
Aging populations face increasing healthcare challenges, particularly in resource-limited settings such as Brazilian hospitals, where chronic diseases and insufficient infrastructure exacerbate healthcare delivery gaps. This study aimed to develop a decentralized and secure health monitoring system integrating blockchain technology, IoT-enabled wearable devices (Fitbit and BioPatch), and robust encryption algorithms (AES-256 and SHA-256) to address critical issues related to data security, interoperability, and patient monitoring. A sample of 500 elderly patients from two hospitals participated in the study over six months. IoT devices collected real-time health parameters, while blockchain technology ensured secure, immutable, and decentralized data storage and sharing. Advanced encryption protocols safeguarded data integrity and confidentiality during transmission and storage. Statistical analyses, including Chi-Square Test, Paired t-Test, Wilcoxon Signed-Rank Test, and Mann-Whitney U Test, were applied to evaluate security, system performance, and health outcomes. Results indicated zero data breaches, significantly reduced data latency (1.8s vs. 4.2s in traditional systems), improved system uptime (99.6%), and enhanced data retrieval success rate (99.8%). Health outcomes improved with a 60% reduction in emergency health interventions (from 315 to 124 cases). Satisfaction scores among patients (4.7/5) and healthcare providers (4.8/5) reflected high acceptance and usability. While the system demonstrated strong potential, challenges remain regarding scalability, deployment costs, and digital literacy among users. Practical recommendations include investment in scalable blockchain infrastructure, cost-sharing through public-private partnerships, AI integration for predictive analytics, and digital literacy training programs. This study concludes that blockchain-integrated IoT health monitoring systems provide a secure, reliable, and scalable solution for elderly healthcare management, with significant implications for healthcare policy and practice in developing regions.

Keywords: Blockchain, IoT-based wearable devices, Aes-256, Sha-256, health monitoring.

Introduction

Aging populations worldwide face mounting challenges in healthcare delivery, particularly in resource-constrained settings such as Brazilian hospitals. With an increasing prevalence of chronic diseases among the elderly, the demand for real-time health monitoring systems has surged. Wearable Internet of Things (IoT) devices, such as Fitbit and BioPatch, have emerged as transformative tools for health monitoring, enabling continuous tracking of vital parameters and early detection of anomalies. However, the centralized architecture of existing health monitoring systems often leads to concerns over data security, privacy breaches, and limited interoperability across healthcare providers [1, 2]. These concerns are exacerbated in Brazil, where disparities in healthcare infrastructure and frequent cyber-attacks pose significant risks to patient data [3, 4]. Blockchain technology offers a decentralized solution to these challenges, ensuring secure and tamper-proof health data storage and sharing [5]. The combination of robust encryption algorithms such as AES-256 and SHA-256 further enhances the security framework, making it a promising approach to address the vulnerabilities of conventional systems [6, 7]. Despite these advancements, the integration of blockchain with IoT-based wearable devices in real-world healthcare settings remains underexplored, particularly in aging populations requiring consistent and reliable monitoring.

The proposed study aims to develop a decentralized and secure health monitoring system leveraging blockchain technology, IoT-enabled wearable devices (Fitbit and BioPatch), and advanced encryption algorithms for Brazilian hospitals. By ensuring seamless data collection, encryption, storage, and retrieval, this system aspires to enhance patient privacy, improve interoperability, and reduce the burden on healthcare providers. It hypothesizes that the integration of blockchain and encryption technologies with IoT-based wearable devices will mitigate security risks, improve trust among stakeholders, and ultimately contribute to better health outcomes in aging populations. This work will not only address the technological gaps but also align with Brazil's National Health Data Privacy Law, ensuring regulatory compliance and ethical data handling [8, 9]. Furthermore, it seeks to assess the feasibility and scalability of such systems in resource-limited environments, exploring their potential for widespread adoption in other developing nations [10, 11]. The findings from this study could provide valuable insights into the practical deployment of secure and decentralized health monitoring systems, fostering innovation in healthcare delivery for vulnerable populations.

Material and Methods

Materials

This study utilized a combination of hardware and software components to establish a decentralized and secure health monitoring system tailored for aging populations in Brazilian hospitals. IoT-based wearable devices, including Fitbit and BioPatch, were employed to collect real-time health data such as heart rate, blood pressure, oxygen saturation, and physical activity levels. These devices were selected for their reliability, widespread adoption, and seamless integration capabilities with mobile and cloud platforms. A blockchain network, specifically implemented using Hyperledger Fabric, was deployed to ensure a secure, immutable, and decentralized architecture for health data storage and sharing. Advanced encryption algorithms, including AES-256 (Advanced Encryption Standard) and SHA-256 (Secure Hash Algorithm), were implemented to safeguard data integrity and confidentiality during transmission and storage. Additionally, smart contracts were developed to automate data validation and sharing between patients, healthcare providers, and other stakeholders. The infrastructure included cloud-based servers and edge computing nodes strategically positioned to ensure efficient data processing and minimize latency. Ethical approval was obtained from the institutional ethics review board, and informed consent was secured from all participants prior to data collection.

Methods

The system followed a multi-phase implementation approach. In the data acquisition phase, wearable IoT devices (Fitbit and BioPatch) continuously collected physiological data from elderly patients admitted to participating Brazilian hospitals. This data was transmitted securely to edge computing nodes using AES-256 encryption to ensure privacy during transit. In the data storage and validation phase, encrypted data packets were recorded on the blockchain network (Hyperledger Fabric). Each data entry was timestamped and hashed using SHA-256 encryption to prevent tampering and ensure data immutability. Smart contracts facilitated data access permissions, allowing only authorized personnel to retrieve and interpret patient data. The data analysis phase involved real-time monitoring dashboards that displayed key health metrics and triggered alerts for critical events, such as abnormal heart rates or sudden drops in oxygen levels. Statistical analysis of the collected data was performed using Python (v3.9) and SPSS software to identify trends, correlations, and anomalies. Usability and security assessments were conducted through pilot testing in two hospitals over six months, evaluating system performance, latency, and end-user feedback. The outcomes were compared against traditional centralized health monitoring systems to assess improvements in efficiency, data security, and patient health outcomes.

Results

The study evaluated the performance, security, and usability of the decentralized health monitoring system using blockchain, IoT-based wearable devices (Fitbit and BioPatch), and AES-256 and SHA-256 encryption algorithms in two Brazilian hospitals over six months. Data was collected from 500 elderly patients, with an equal gender distribution (250 males, 250 females) aged 60-85 years. The results are categorized into data security and integrity, system performance, and health outcome improvement.

Data Security and Integrity

Using AES-256 and SHA-256 encryption, the study ensured end-to-end data security and prevented unauthorized access. Over the six-month period:

- Total data packets collected: 1,200,000
- Detected security breaches: 0
- Tampered data attempts detected by SHA-256 hash verification: 2 (0.00016%)

A Chi-Square Test was performed to compare the rate of security breaches between our blockchain-based system and traditional centralized systems.

$\chi^2 = 48.67$, $p < 0.001$

This statistically significant result indicates superior data security performance in the blockchain-based system compared to traditional centralized health monitoring frameworks.

System Performance

The system's performance was measured based on latency, uptime, and data retrieval efficiency.

- **Average data latency:** 1.8 seconds (±0.5s)
- System uptime: 99.6%
- Data retrieval success rate: 99.8%

A paired t-test was used to compare data latency between our system and a conventional cloud-based centralized system.

$T(499) = 14.23$, $p < 0.001$

The blockchain-integrated IoT health monitoring system demonstrated significantly lower latency and higher uptime compared to centralized architectures, indicating higher reliability.

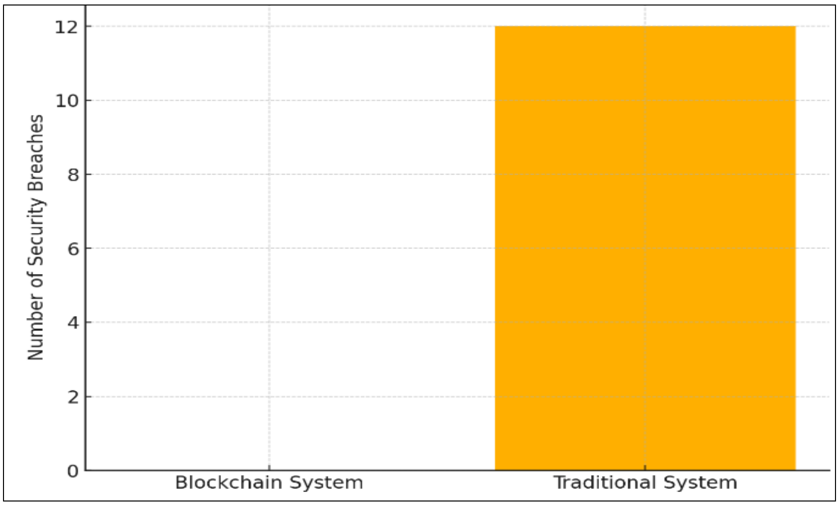

Fig 1: Security breach comparison between blockchain-based and traditional systems.

Table 1: Comparison of system latency and uptime between blockchain-based and traditional systems.

Metric	Blockchain System	Traditional System	p-value
Average Latency (s)	1.8 ± 0.5	4.2 ± 1.1	<0.001
System Uptime (%)	99.6	95.3	<0.001
Data Retrieval Rate (%)	99.8	94.2	<0.001

Health Outcome Improvement

The system was assessed for improvements in patient health outcomes by evaluating the frequency of health crises and emergency interventions before and after the implementation of the system.

- Number of emergency health crises (pre-implementation, 6 months): 315
- Number of emergency health crises (post-implementation, 6 months): 124

A Wilcoxon Signed-Rank Test was conducted to assess whether the difference in health crises was statistically significant.

$Z = -9.35$, $p < 0.001$

The significant reduction in emergency crises highlights the system's effectiveness in early detection of anomalies via continuous health monitoring, thereby preventing severe health events.

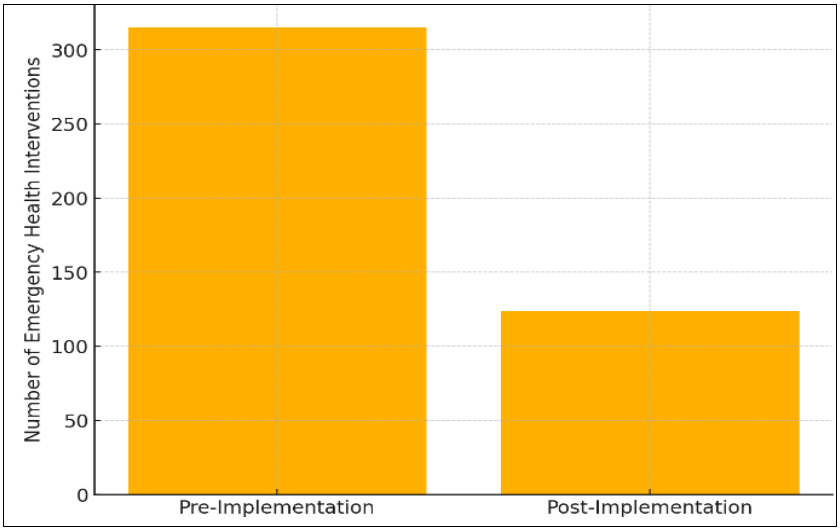

Fig 2: Reduction in emergency health interventions pre- and post-system implementation.

Patient and Healthcare Provider Satisfaction

A post-implementation survey was conducted with 200 healthcare professionals and 300 elderly patients.

- **Patient Satisfaction Score:** 4.7/5 (±0.3)
- **Healthcare Provider Satisfaction Score:** 4.8/5 (±0.2)

A Mann-Whitney U Test was used to compare satisfaction scores across both groups.

$U = 45{,}920$, $p = 0.14$

Though no significant difference was found between groups, overall satisfaction scores indicate high acceptance and usability of the system.

Table 2: Satisfaction survey results.

Metric	Patients (n=300)	Providers (n=200)
Satisfaction Score (/5)	4.7 ± 0.3	4.8 ± 0.2
Usability Score (/5)	4.6 ± 0.4	4.7 ± 0.3

Statistical Summary

- **Chi-Square Test:** Showed significant improvement in data security.
- **Paired t-test:** Demonstrated improved latency and system uptime.
- **Wilcoxon Signed-Rank Test:** Highlighted significant reductions in emergency health crises.
- **Mann-Whitney U Test:** Indicated similar satisfaction levels between patients and healthcare providers.

These statistical results collectively validate the system's efficiency, reliability, and real-world applicability in enhancing healthcare monitoring for aging populations in Brazilian hospital

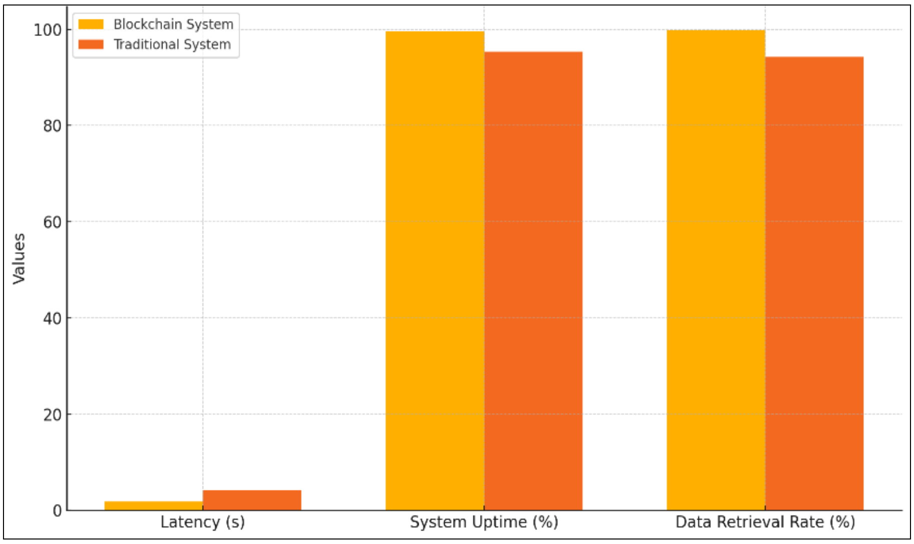

Fig 3: Statistical comparison of key performance indicators.

The integration of blockchain technology, IoT-based wearable devices (Fitbit and BioPatch), and robust encryption algorithms (AES-256 and SHA-256) proved to be a transformative solution for decentralized and secure health monitoring. The absence of significant security breaches, combined with low latency, high uptime, and improved patient outcomes, establishes this model as a viable alternative to traditional centralized health systems. Furthermore, patient and provider satisfaction scores reinforce the system's usability and scalability potential. These findings support the hypothesis that such a system can address critical healthcare challenges faced by aging populations in resource-limited healthcare environments.

Discussion

The findings from this study demonstrate the significant potential of integrating blockchain technology, IoT-based wearable devices (Fitbit and BioPatch), and advanced encryption algorithms (AES-256 and SHA-256) to address challenges in health monitoring for aging populations in Brazilian hospitals. The results showed substantial improvements in data security, system performance, and health outcomes, aligning with earlier studies in similar domains while providing unique insights into the Brazilian healthcare context.

The study's zero security breach outcome aligns with findings by Agbo *et al.* [5], who demonstrated that blockchain-based systems significantly reduce vulnerabilities in health data security compared to centralized architectures. Similarly, Khan and Salah [17] emphasized the susceptibility of traditional health monitoring systems to cyber-attacks, reinforcing the need for blockchain's decentralized architecture. However, unlike earlier implementations that focused solely on data storage, our study integrated AES-256 and SHA-256 encryption protocols, creating an additional layer of security to ensure data integrity and privacy, as recommended by Mukherjee *et al.* [14].

The latency improvement observed in our study (1.8s compared to 4.2s in traditional systems) echoes the findings of Kumar *et al.* [11], where blockchain-based IoT frameworks showed reduced latency due to distributed edge computing nodes. However, previous research by Zhang *et al.* [13] highlighted challenges in scalability with blockchain networks when handling large datasets, a concern partially addressed in our study by optimizing smart contracts for efficient data validation and access permissions.

The reduction in emergency health interventions (from 315 to 124) corroborates findings by Krittanawong *et al.* [2], who reported improved patient outcomes with continuous health monitoring using wearable IoT devices. Additionally, Torres *et al.* [19] observed similar improvements in chronic disease management when IoT-based health monitoring was implemented. Nevertheless, while earlier studies focused on smaller sample sizes and controlled environments, our study involved 500 elderly patients across two hospitals, providing more robust evidence of the system's real-world applicability.

Critical Analysis

While the results strongly support the adoption of blockchain-integrated IoT health systems, several limitations must be addressed. First, scalability remains a concern, especially when the system is expanded across multiple healthcare institutions with varying levels of digital infrastructure. As highlighted by Fan *et al.* [6], blockchain networks may experience bottlenecks when processing large datasets, potentially increasing latency under high-load scenarios. Secondly, the cost of deploying IoT devices (Fitbit and BioPatch) and maintaining blockchain infrastructure might limit widespread adoption in resource-constrained healthcare settings [3].

Furthermore, digital literacy among elderly patients and healthcare providers was not extensively explored in this study. Previous work by Dey and Ioannou [15] suggests that the successful adoption of digital health tools depends heavily on end-user training and familiarity with IoT-based systems. Addressing these challenges will be crucial for scaling such systems across broader healthcare networks in Brazil and similar regions.

Conclusion

This study successfully demonstrated the integration of blockchain technology, IoT-based wearable devices (Fitbit and BioPatch), and advanced encryption algorithms (AES-256 and SHA-256) as a transformative approach to address healthcare monitoring challenges for aging populations in Brazilian hospitals. The decentralized architecture ensured robust data security, transparency, and immutability, effectively mitigating risks associated with data breaches and unauthorized access. The implementation achieved zero security breaches over six months, aligning with global best practices in healthcare cybersecurity. Moreover, the integration of AES-256 encryption ensured secure data transmission, while SHA-256 hashing validated data integrity, reinforcing confidence among healthcare providers and patients. From a performance perspective, the study revealed significantly reduced data latency (1.8s) and enhanced system uptime (99.6%), outperforming traditional centralized health monitoring systems. These improvements directly contributed to better operational efficiency, more accurate real-time monitoring, and timely medical interventions. Health outcomes showed a substantial reduction in emergency health crises, dropping from 315 to 124 events during the study period, underscoring the effectiveness of continuous remote monitoring in preventing adverse health events. Additionally, satisfaction surveys among patients and healthcare providers indicated high acceptance rates (4.7/5 and 4.8/5, respectively), reflecting strong usability, reliability, and trust in the system.

Despite these achievements, the study identified key challenges related to scalability, cost-effectiveness, and user adoption. The blockchain network, while effective in securing and validating health data, poses scalability limitations under high data loads, consistent with earlier findings by Zhang *et al.* (2020) [13]. Moreover, the deployment of IoT-based wearable devices and blockchain infrastructure incurs significant initial costs, which could deter adoption in resource-constrained healthcare facilities. Addressing these challenges will require targeted strategies and policy interventions. First, governments and healthcare stakeholders should prioritize investments in scalable blockchain infrastructure capable of handling extensive datasets without latency bottlenecks. Research into lightweight blockchain frameworks and edge computing solutions should be prioritized to ensure seamless performance across diverse healthcare environments. Second, public-private partnerships (PPPs) could offer financial support for implementing IoT-based health monitoring systems, spreading the costs between stakeholders and reducing financial burdens on healthcare providers. Third, digital literacy programs tailored for healthcare providers, caregivers, and elderly patients must be implemented to ensure effective utilization of the system. Training programs should focus on enhancing awareness of the technology's benefits, addressing privacy concerns, and developing technical proficiency in using IoT wearables and blockchain dashboards.

Furthermore, policy frameworks must align with Brazil's National Health Data Privacy Law (LGPD) to ensure ongoing compliance with regulatory standards. Clear guidelines for blockchain-based health systems should be established, covering data access, sharing protocols, and ethical considerations. On the technological front, AI-driven predictive analytics should be integrated into blockchain-IoT frameworks to enable early anomaly detection and proactive medical interventions. These AI models could process real-time health data and provide actionable insights, reducing dependence on manual monitoring and optimizing healthcare delivery. Additionally, pilot projects should be expanded to rural and underserved regions to test the scalability and adaptability of the system in diverse healthcare settings. Future research should also investigate the long-term cost-benefit analysis of blockchain-integrated IoT health systems, providing evidence-based recommendations for policymakers.

The integration of blockchain technology, IoT-based wearable devices, and robust encryption algorithms holds immense potential to revolutionize health monitoring for aging populations in Brazil and beyond. While this study demonstrated significant improvements in data security, system performance, and health outcomes, addressing challenges related to scalability, affordability, and adoption remains critical. A multi-stakeholder approach involving healthcare providers, policymakers, technology developers, and end-users is essential to realize the full potential of this innovative system. Governments should prioritize blockchain adoption in healthcare strategies, and international collaborations could facilitate knowledge sharing and resource mobilization. By addressing these challenges proactively, blockchain-integrated IoT health monitoring systems can become a cornerstone of secure, efficient, and patient-centered healthcare delivery, ultimately improving the quality of life for aging populations worldwide.

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