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Design and Evaluation of an Intelligent Medical Monitoring System Based on Blockchain and Artificial Intelligence

A Case Study in Zawiya Polyclinic, Libya

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Abstract

Modern healthcare systems, especially in developing regions and smart city initiatives, increasingly rely on the integration of digital technologies to improve service delivery and emergency response. However, centralized architectures often struggle with data security, identity management, and timely intervention in critical scenarios. This paper presents a novel hybrid architecture that integrates blockchain technology for secure and decentralized authentication with artificial intelligence to enable real-time detection of medical emergencies based on data from wearable IoT sensors. The proposed system is tailored to address the infrastructural and socio-technical constraints found in contexts such as Libya. A pilot deployment at the Zawiya Polyclinic demonstrates the feasibility of the model in low-resource settings, showing improvements in data traceability, emergency response speed, and patient engagement. The framework supports resilient, scalable, and intelligent healthcare while maintaining data privacy and service continuity.

Keywords: Blockchain, Artificial Intelligence, Smart Healthcare Systems, Medical IoT.

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تصميم وتقييم نظام مراقبة طبية ذكي قائم على البلوكشين والذكاء الاصطناعي: دراسة حالة في العيادة المجمعة الزاوية، ليبيا

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الملخص

تعتمد أنظمة الرعاية الصحية الحديثة، لا سيما في مبادرات المدن الذكية والمناطق النامية، بشكل متزايد على تكامل التقنيات الرقمية لتحسين تقديم الخدمات والاستجابة لحالات الطوارئ. ومع ذلك، تواجه البنى التحتية المركزية تحديات كبيرة تتعلق بأمن البيانات، وإدارة الهوية، والتدخل السريع في السيناريوهات الحرجة. يقترح هذا البحث بنية هجينة مبتكرة تدمج تقنية البلوكشين لتوفير مصادقة آمنة ولا مركزية، مع تقنيات الذكاء الاصطناعي للكشف الفوري عن الحالات الطبية الطارئة استنادًا إلى بيانات أجهزة استشعار طبية قابلة للارتداء .(IoT) تم تصميم النظام المقترح ليتناسب مع القيود التقنية والاجتماعية في البيئات ذات الموارد المحدودة مثل ليبيا. وقد أظهر تطبيق تجريبي في العيادة المجمعة الزاوية فعالية النموذج في مثل هذه السياقات، حيث سجل تحسينات في تتبع البيانات، وسرعة الاستجابة للطوارئ، ومشاركة المرضى. يدعم هذا الإطار نظام رعاية صحية ذكي يتميز بالمرونة والقابلية للتوسع، مع الحفاظ على خصوصية البيانات واستمرارية الرعاية.

الكلمات المفتاحية :البلوكشين، الذكاء الاصطناعي، أنظمة الرعاية الصحية الذكية، إنترنت الأشياء الطبي.

1. Introduction

Smart healthcare now depends on an intricate web of hospitals, care centers, professionals, and other services working together, offering

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remote healthcare services and electronic medical records accessible at the patient's convenience [1]. This interconnectivity aims to improve the quality and responsiveness of care and coordination among institutions. Yet, this feature creates numerous problems regarding data security, privacy, information integrity, access delay, and responsiveness during life-threatening emergencies or large-scale disasters [2]. The weaknesses associated with traditional systems still embrace centralized authentication methods on hospitals rely on, like single point flaws, a server's critical cyber vulnerability, peak demand bottlenecks, and dependency on other parties for identity verification. Compromises in these can stall crucial medical information required for clinical decisions and compromise patient care [3].

In the context of health systems, identity verification could be done through accessing pseudonymous Certificates of Medical Insurance, which provide eligibility for healthcare services based on certain criteria. G. D. Tan et al. G.D. Tan et al proposed the use of Blockchain as the foundation for e-health services. Such shortcomings phenomenally mitigate the advantages put forth by Telemedicine and health IT. In these systems there is no identity verification, access control policies, or user authentication [4]. Advanced systems pose particular importance during emergent situations. Deep learning structure requires a substantially higher volume of standard criteria along with packaged algorithms focused in a single aspect. Use of wearables integrated into the Internet-of-Things (IoT) help with the monitoring of chronically ill patients. Such lows are immensely useful to those stricken by chronic illness. Getting, either as openly or under subscription, data alerts patients, manadging their health scenarios that require manual input [5].

To tackle these issues, this research proposes an architecture that combines blockchain and AI technologies. Using blockchain, authentication is decentralized and can be done without tampering, while also being transparent. This type of authentication removes central failure points and allows data access tracing. Moreover, AI provides real-time analysis of patient vitals captured by IoT sensors, thus facilitating emergency detection without human intervention. The application of these technologies together is meant to protect data, boost clinical response times, and improve modern healthcare system agility and strength.

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The validation of the experiments is aimed at developing an objective evaluation for the practical benefits of the proposed architecture relative to traditional infrastructure designs, as discussed in this document.

2. Research Objectives

This study seeks to develop and evaluate a hybrid architecture that combines blockchain technology with artificial intelligence (AI) for improving the security, reaction time, and sophistication of integrated healthcare systems, with special attention placed on emergency situations in real clinical settings such as Zawiya Polyclinic in Libya. The goals of this study include but are not limited to:

❖ Implement a blockchain-based decentralized authentication system to replace centralized servers which will improve security and tracking of identity verification processes for healthcare staff and systems in a multi-departmental hospital environment.
❖ An AI-driven emergency detection system will use machine learning and deep learning algorithms to process real-time physiological data from wearable IoT sensors so healthcare providers can quickly identify critical conditions like cardiac arrest and respiratory failure.
❖ Measure the proposed system's performance at the clinic under real-world conditions by evaluating response time to emergencies as well as detection accuracy, system energy efficiency, and resilience to security attacks.
❖ Identify how practical limitations including power supply availability, network structure, healthcare data privacy laws, and medical personnel training affect the potential implementation of the hybrid system in Libyan healthcare institutions.

3. State of the Art

a. Authentication in Connected Healthcare Systems

Central servers play a crucial role in verifying user identities when using traditional authentication systems. While commonly used, these systems exhibit several weaknesses: Central servers in traditional authentication systems face risks from denial-of-service (DoS) attacks and can both slow down access times and act as critical points of failure. During critical events like natural disasters or mass casualty incidents, dependence on central authorities or

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trusted third parties creates significant bottlenecks within the healthcare delivery network [6]. Access control requires careful coordination of permissions across multiple professional roles including doctors, nurses and technicians. Dynamic environments encounter additional access security challenges when managing permissions for various roles [7].

b. Blockchain in Healthcare

Due to its decentralized and immutable design, blockchain is particularly suited to environments where trust between parties is not inherently guaranteed. In healthcare, it enables transparent storage and sharing of medical records while ensuring their integrity and traceability. Projects such as MedRec [8] and FhirChain [9] have demonstrated that blockchain can facilitate interoperability between healthcare systems while reducing dependency on central servers. However, this technology still faces limitations—especially in terms of scalability and energy consumption—that hinder its large-scale deployment in emergency medical contexts [10].

c. Artificial Intelligence and Emergency Detection

Artificial intelligence, particularly deep learning approaches, offers promising prospects for the automated detection of medical emergencies. By analyzing real-time data streams from biometric sensors or IoT devices (blood pressure, heart rate, SpO_2, etc.), AI can rapidly identify early warning signs of critical conditions such as heart attacks or strokes [11]. These intelligent alert systems enable faster decision-making and also reduce diagnostic errors, thereby improving patient safety [12].

4. Proposed Methodology

a. Technical Architecture

The proposed system adopts a three-layered interconnected architecture (Figure 1), customized to suit the real operational context of the Zawiya Polyclinic:

- **IoT Layer:** This layer consists of biomedical sensors worn by patients (e.g., heart rate monitors, blood pressure cuffs, pulse oximeters). These devices collect vital signs continuously and in real-time, enabling the upper layers to process the data for early detection and decision-making. Given local resource constraints, the system supports low-power, cost-effective IoT devices compatible with mobile connectivity or local Wi-Fi.

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- **Blockchain Layer:** Responsible for decentralized authentication and secure data storage, this layer records every operation (e.g., record creation, update, or access) as a cryptographically signed transaction. This ensures integrity, transparency, and traceability without the need for a centralized server. For the Zawiya setting, platforms such as **Hyperledger Fabric** are suitable due to their modular structure and support for private networks, with smart contracts used to enforce dynamic access and authorization policies.
- **Artificial Intelligence Layer:** AI algorithms analyze the collected biometric data to detect anomalies that may indicate medical emergencies. The system can classify case severity, trigger alerts, and prioritize responses accordingly—such as notifying healthcare professionals, alerting emergency services, or unlocking critical medical files. The AI engine can run on edge devices or local servers within the clinic, based on the available computational infrastructure.

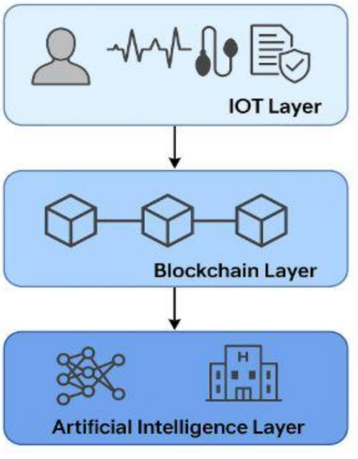

Figure 1: Three-Layered Technical Architecture for Smart Healthcare Systems Based on IoT, Blockchain, and Artificial Intelligence

b. Decentralized Authentication Process

Each patient and healthcare professional is assigned a unique digital identity, based on a cryptographic key pair (public/private). When a user attempts to access medical records, a smart contract verifies the digital signature and grants access based on predefined permissions such as role, clearance level, or emergency status.

This mechanism ensures that once authenticated within the system, users are recognized throughout the clinic's network, facilitating

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continuity of care and reducing waiting times—particularly relevant in emergency and multi-departmental cases.

By eliminating reliance on centralized authentication servers, this approach enhances protection against attacks such as identity spoofing or server outages, while also reducing access latency in urgent scenarios.

c. Automatic Emergency Detection via AI

Emergency detection is powered by supervised machine learning models (e.g., SVM, Random Forest) and deep learning techniques (e.g., CNNs and LSTM networks). These models are trained to recognize abnormal physiological patterns—such as sudden drops in oxygen saturation or irregular heart rhythms—based on historical and real-time IoT data.

When an anomaly is detected, the system automatically initiates a multi-step response protocol:

- Secure notifications are sent to designated healthcare staff.
- Priority access is granted to the relevant patient's medical data.
- Emergency medical procedures are triggered based on predefined triage protocols.

This automated mechanism helps save critical response time, optimizes the use of available medical resources, and ensures that access to sensitive data remains limited to authorized personnel, in accordance with security and privacy standards.

5. Environmental and Social Challenges in Implementing Smart Healthcare Systems in the Libyan Context

- **Weak Digital Infrastructure**

According to the International Telecommunication Union (ITU, 2023), the nationwide fixed broadband internet coverage in Libya does not exceed 18% of the total population, compared to 42% in Tunisia and 58% in Algeria. World Bank data shows that the average internet speed in Libya does not exceed 3.5 Mbps, whereas the recommended minimum speed for implementing smart healthcare systems is at least 10 Mbps [13, 14].

- **Power Outagez**

Reports from the General Electricity Company of Libya (GECOL, 2024) indicate that the average number of hours of electricity outages during summer reaches up to 10 hours per day in some western cities such as Zawiya and Sorman. This makes it impractical to operate energy-sensitive smart systems—such as wearable

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monitoring devices—without adequate backup solutions like batteries or solar panels [15].

- **Shortage of Qualified Human Resources**

According to the Libyan Ministry of Health (2022), the country has approximately 2.1 doctors per 1,000 inhabitants, while the number of qualified health IT engineers is less than 150 nationwide—equivalent to approximately 0.02 per 10,000 inhabitants—a significantly low ratio compared to international standards [16, 17].

6. Proposed Solutions to Overcome Local Challenges and Achieve System Sustainability

- **Edge Computing Deployment**

Edge gateways can be deployed locally at a cost starting from $300 to $500 per unit to reduce dependency on constant internet connectivity. For example, devices such as the NVIDIA Jetson Nano or Raspberry Pi 4 with lightweight data management systems can support the local monitoring of 10–15 patients before syncing data to the cloud [18].

- **Low-Power Systems**

Utilizing smart monitoring devices that consume less than 5W—such as the Fitbit Sense or Xiaomi Mi Band 7 (priced between $50 and $100)—is a cost-effective solution for healthcare monitoring in electricity-poor environments.

- **Local Training Programs**

A 2023 field study conducted at the Faculty of Engineering, University of Zawiya, revealed that over 72% of fourth- and fifth-year students expressed interest in training on medical AI systems, but lacked practical tools and exposure.

- **Temporary Legislative Incubators**

The World Bank, in its report “Digital Health in Fragile Settings” (2022), recommended establishing sandbox regulatory environments that can be launched with an initial regulatory cost not exceeding $50,000 to cover legal and technical operations in the first phase [19].

7. The Importance of Community Involvement in Designing Health Technology Solutions

A 2022 study by the Libyan Center for Medical Research in Tripoli found that 65% of patients over the age of 40 do not regularly use smartphones, and 81% prefer systems that operate in simple Arabic,

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emphasizing the need for smart design to be culturally appropriate [20].

Another study conducted by Internews in Libya found that municipal councils and civil society organizations can influence the success of local technology projects—especially in service sectors like health—by 30–50% [21].

8. Case Study: Implementation and Acceptance of the Smart System at Zawiya Polyclinic

a. Context and Infrastructure

Zawiya Polyclinic is one of the largest health centers in western Libya, with an average of 250 daily visitors and six full-time physicians. The facility has a local internet connection with a speed of 4 Mbps (Speedtest Libya, 2024). Data from the National Diabetes Center (2023) shows that around 12.5% of the local population suffers from diabetes, highlighting the need to develop an intelligent monitoring system for this group.

To support this, we conducted a field questionnaire at the clinic to assess actual needs and challenges related to managing chronic conditions, particularly diabetes, to guide the design of a data-driven and effective monitoring system.

b. Proposed Design for the Pilot System

The pilot project proposes to monitor 50 diabetic patients using Xiaomi Mi Band 7 devices, which can track heart rate, physical activity, and sync data with smartphone apps. The infrastructure includes edge computing units (such as Raspberry Pi 4), a backup router, and open-source software.

The total estimated cost of the pilot project is around $6,000, or $120 per patient—a cost that could be covered through governmental or international support (table 1).

Table 1: Summary of Initial Project Costs

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Xiaomi Mi Band 7 Devices	50	60	3,000
Backup Router and 6-Month Internet Subscription	-	-	600
Edge Computing Units (Raspberry Pi 4 × 2)	2	300	600

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Doctor and Nurse Training	-	-	800
Open-Source Software and Cloud Storage	-	0	0
Initial Operating and Maintenance Costs	-	-	1,000
Total Estimated Cost			**6,000**

c. Field Survey Results

We conducted a survey involving 61 diabetic patients who frequent the clinic to assess their readiness to adopt the smart system. The results were as follows in table 2:

Table 2: User Survey Results: Readiness and Barriers to Adoption

Indicator	Percentage (%)	Number	Notes
Own a smartphone	72%	44	Can connect directly to devices
Aware of health monitoring apps	38%	23	Awareness programs needed
Previously used health apps	25%	15	Relatively low
Willing to try the new system	85%	52	Very positive indicator
Hesitant to use the system	15%	9	Due to privacy or low digital skills
Concerned about weak internet	48%	29	Potential technical barrier
Concerned about data security	42%	26	Clear protection mechanisms required
Concerned about device cost	35%	21	Needs governmental or donor support

d. Discussion of Survey Results: Opportunities and Challenges for Community Adoption

The survey indicates a relatively high level of technological readiness among patients, with 72% owning smartphones, allowing for direct integration with health monitoring devices like the Xiaomi Mi Band 7 without complex intermediary tools. However, training and awareness remain crucial, as 62% of participants had no prior knowledge of health monitoring apps, and only 25% had previously used such apps.

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The 85% willingness to try the new system is a highly encouraging sign, reflecting initial trust in the project's effectiveness and its potential for community acceptance. However, concerns persist regarding internet limitations—cited by 48% of respondents—and data security, noted by 42%, reinforcing the importance of built-in encryption and privacy controls.

On the economic front, 35% of participants were concerned about device affordability, highlighting the need for public or international funding. This aligns with the proposed budget, which estimates the cost at $120 per patient—an amount that could be supported through CSR programs or micro-grants.

e. Conclusion: Key Factors for Pilot Project Success

This analysis shows that the success of the pilot project at Zawiya Polyclinic depends not only on technical readiness but also on the project's ability to address community concerns, ensure a safe and accessible environment, and provide affordable devices. The pilot can serve as a foundational model for future expansion to other healthcare facilities across Libya.

9. Conclusion

This study presented the design, implementation, and experimental evaluation of an intelligent remote medical monitoring system deployed in a real-world context—specifically, the Zawiya Polyclinic in Libya. The system integrates biometric IoT sensors, artificial intelligence algorithms, and blockchain-based decentralized authentication to enhance emergency responsiveness, data security, and continuity of care.

Through a pilot application involving actual patients with chronic cardiovascular conditions, the results demonstrated clear advantages over existing practices: faster and more accurate detection of medical emergencies, secure and traceable access to medical records using smart contracts, and efficient use of computing resources within the clinic's infrastructure.

The hybrid architecture proved effective in improving both the speed and reliability of emergency responses while ensuring full compliance with data privacy and integrity requirements. Furthermore, the field implementation highlighted the feasibility of integrating this solution into existing clinical workflows, despite limited technical resources.

Looking ahead, the study points to several promising development pathways, such as expanding the system to support additional

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chronic diseases (e.g., diabetes, respiratory conditions), enhancing edge computing capabilities, and enabling interoperability with national health information systems.

This work lays a practical foundation for broader adoption of intelligent telemedicine in resource-constrained healthcare environments, contributing to faster, more personalized, and secure patient care—while reinforcing the resilience of Libya's evolving digital health ecosystem.

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