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ORIGINAL

IoT-Blockchain Based Model for Enhancing Diabetes Management and Monitoring

Modelo basado en IoT y Blockchain para optimizar la gestión y el control de la diabetes

Nehal Ettaloui[1], Sara Arezki[1], Taoufiq Gadi[1]

[1]Faculty of Science and Techniques, Hassan First University Settat. Morrocco.

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ABSTRACT

The integration of Internet of Things (IoT) and blockchain technology in healthcare, especially for diabetes management, represents a transformative advancement enabling continuous, proactive monitoring of patients' health. This paper aims to present an IoT-blockchain-based model for continuous, secure, and efficient health monitoring in diabetes management. IoT devices like smart glucose monitors and insulin pumps collect and transmit real-time health data, allowing for prompt treatment adjustments and complication prevention. Blockchain ensures data security and integrity through encryption and decentralized storage, safeguarding against unauthorized access and tampering. This secure data transmission is crucial for maintaining patient privacy and complying with regulations such as GDPR and HIPAA. The combination of IoT and blockchain promises enhanced security, transparency, cost reduction, and improved patient outcomes. It enhances patient engagement by enabling seamless communication between patients and healthcare providers, facilitating personalized and timely medical advice. The integration of these technologies holds promise for revolutionizing healthcare delivery, offering sustainable solutions to managing chronic conditions like diabetes.

Keywords: Blockchain; IOT; Monitoring; Healthcare; Diabetes.

RESUMEN

La integración de Internet de las Cosas (IoT) y la tecnología blockchain en la asistencia sanitaria, especialmente para la gestión de la diabetes, representa un avance transformador que permite la monitorización continua y proactiva de la salud de los pacientes. Este artículo tiene como objetivo presentar un modelo basado en IoT-blockchain para la monitorización continua, segura y eficiente de la salud en el control de la diabetes. Los dispositivos IoT, como los monitores de glucosa inteligentes y las bombas de insulina, recopilan y transmiten datos sanitarios en tiempo real, lo que permite ajustar rápidamente el tratamiento y prevenir complicaciones. Blockchain garantiza la seguridad y la integridad de los datos mediante el cifrado y el almacenamiento descentralizado, protegiendo contra el acceso no autorizado y la manipulación. Esta transmisión segura de datos es crucial para mantener la privacidad del paciente y cumplir con regulaciones como GDPR e HIPAA. La combinación de IoT y blockchain promete una mayor seguridad, transparencia, reducción de costes y mejores resultados para los pacientes. Aumenta el compromiso del paciente al permitir una comunicación fluida entre los pacientes y los proveedores de atención médica, facilitando un asesoramiento médico personalizado y oportuno. La integración de estas tecnologías promete revolucionar la prestación de asistencia sanitaria, ofreciendo soluciones sostenibles para gestionar enfermedades crónicas como la diabetes.

Palabras clave: Blockchain; IoT; Monitorización; Sanidad; Diabetes.

INTRODUCTION

In recent years, the integration of Internet of Things (IoT) and blockchain technologies has revolutionized various sectors, including healthcare, by enhancing the management and monitoring of chronic conditions such as diabetes. Diabetes, a condition characterized by elevated blood sugar levels, demands meticulous daily management to prevent severe complications like cardiovascular disease, kidney failure, and nerve damage. These complications arise from insufficient insulin production in Type 1 diabetes or ineffective utilization of insulin in Type 2 diabetes.[1] Effective diabetes management involves continuous blood glucose monitoring, strict adherence to treatment plans, and lifestyle modifications. Traditional methods often fall short in providing the real-time insights and personalized care necessary for optimal management.[2] IoT devices, such as smart glucose monitors and insulin pumps, address these challenges by facilitating continuous monitoring and real-time data collection. This enables healthcare providers to promptly adjust treatment plans, optimize glycemic control, and proactively address health risks.[3]

The Internet of Things (IoT) refers to a network of interconnected devices embedded with sensors, software, and other technologies that enable them to collect and exchange data over the internet . These devices range from everyday objects like wearable health monitors and smart home appliances to sophisticated medical devices and industrial machinery. IoT devices gather data through their sensors and transmit it to centralized systems or other connected devices, where it can be processed and analyzed in real-time. This capability allows for seamless communication between devices and humans, enabling automation, remote monitoring, and data-driven decision-making across various sectors.[4] In healthcare, IoT plays a crucial role by facilitating continuous monitoring of patients' health metrics, such as heart rate, blood glucose levels, and medication adherence. Real-time data insights provided by IoT enable personalized care delivery, timely interventions, and improved patient outcomes. Moreover, IoT applications extend beyond healthcare to smart cities, agriculture, transportation, and manufacturing, revolutionizing industries by enhancing efficiency, productivity, and sustainability.[5] Blockchain technology complements IoT by ensuring the secure and tamper-proof storage of patient data through advanced encryption and decentralized storage. At its core, blockchain is a decentralized and distributed ledger technology that facilitates secure and transparent transactions without intermediaries like banks or central authorities.[5,6] Operating on the principle of a decentralized network of computers (nodes), blockchain collectively validates and records transactions in a chronological chain of block.[4] Each block contains a batch of transactions verified by the network's consensus algorithm before being added to the existing blockchain. This process ensures that once data is recorded, it cannot be altered retroactively without consensus from the majority of the network, thereby ensuring immutability and data integrity.[2] Blockchain's key features include decentralization, which enhances security by eliminating single points of failure, and cryptography-based security that makes data tampering extremely difficult.[7] Its transparency allows all participants to view transactions in real-time, fostering trust and accountability, while smart contracts automate and enforce agreements, reducing reliance on intermediaries and streamlining processes.[8] Patient monitoring systems, vital components in healthcare environments ranging from hospitals and clinics to patients' homes, continuously observe and record patient health metrics and vital signs. These systems aim to enable early detection of health deviations and facilitate prompt medical interventions that significantly impact patient outcomes. By providing real-time data on physiological parameters like heart rate, blood pressure, and oxygen levels, these systems empower healthcare providers to respond swiftly to emergent situations and adjust treatment plans accordingly.[1] Moreover, patient monitoring plays a pivotal role in managing chronic conditions effectively, including diabetes, cardiovascular disease, and respiratory disorders. Continuous monitoring offers insights into disease progression and response to therapies, preventing exacerbations and reducing hospitalizations through optimized medication adherence and lifestyle modifications. This proactive management not only improves patient outcomes but also reduces healthcare costs associated with prolonged hospital stays or intensive treatments.[9] Additionally, patient monitoring supports personalized care approaches by allowing tailored treatment plans based on individual needs and responses to therapy, enhancing patient satisfaction and engagement in their own healthcare management.[10] Furthermore, patient monitoring systems facilitate remote care capabilities, crucial for patients needing ongoing monitoring but unable to visit healthcare facilities frequently.[11] Through telemedicine and remote monitoring technologies, healthcare providers can monitor patients remotely, assess their condition in real-time, and intervene as needed, thereby improving access to care and patient convenience.[12] By harnessing patient data collected through monitoring systems, healthcare providers can make informed decisions about treatment strategies and care pathways, promoting efficiency in healthcare delivery by optimizing resource allocation and reducing unnecessary interventions. Ultimately, patient monitoring systems contribute to a better quality of life for patients by enabling proactive healthcare interventions, reducing the burden of chronic disease management, and fostering a patient-centered approach to healthcare delivery.[13]

This paper introduces an innovative IoT-blockchain-based model designed for continuous, secure, and efficient health monitoring in diabetes management. By empowering patients with advanced self-management

tools and optimizing their interaction with healthcare teams, this model not only seeks to improve diabetes management outcomes but also sets a precedent for future advancements in personalized healthcare delivery systems.

METHOD

This study employs a systematic methodology to develop and evaluate an IoT-blockchain-based model aimed at enhancing continuous, secure, and efficient diabetes management. Over a specified period, the research integrated IoT and blockchain technologies within healthcare settings, focusing on diabetes patients sourced from local healthcare facilities and diabetes management programs. The system design encompassed three primary layers: the IoT layer utilized smart glucose monitors and insulin pumps to continuously collect real-time health data, including blood glucose levels, insulin doses, physical activity, and dietary information. The blockchain layer ensured secure, immutable storage of this data, employing robust cryptographic protocols to protect against unauthorized access and maintain data integrity in compliance with GDPR and HIPAA regulations. Meanwhile, the application layer provided healthcare providers and patients with real-time dashboards, alerts, and communication tools, enabling proactive health management and personalized care delivery based on data-driven insights. Data collection involved comprehensive gathering of both health metrics and metadata from IoT devices and electronic health records, facilitating detailed analysis of participant health trends and treatment outcomes.

RESULTS

IoT in diabetes management

IoT devices have revolutionized diabetes care by providing advanced capabilities such as continuous monitoring and management of blood sugar levels. Devices like smart glucose monitors and insulin pumps enable patients to monitor their glucose levels seamlessly throughout the day, without invasive procedures. These devices also facilitate real-time data collection and transmission to healthcare providers, offering immediate insights into patients' glucose levels and trends.[14] This capability empowers healthcare teams to make timely adjustments to treatment plans and proactively manage diabetes. Numerous case studies underscore IoT's impact, demonstrating significant improvements in glycemic control and patient outcomes when combined with continuous glucose monitoring systems, highlighting IoT's transformative potential in personalized diabetes care.[15]

Blockchain in Diabetes management

Blockchain technology provides secure and efficient solutions for healthcare data management, particularly in diabetes care. Blockchain operates as a decentralized ledger ensuring secure, transparent, and immutable transactions.[16] Its core principles include decentralization, data encryption, and the immutability of records, crucial for maintaining data integrity and trust in healthcare environments.[17] Ensuring data security and patient privacy is paramount in healthcare, especially for conditions like diabetes, and blockchain's decentralized nature and cryptographic algorithms safeguard sensitive health information against unauthorized access and tampering. Blockchain applications in healthcare encompass data interoperability, secure management of medical records, and patient consent management.[18] By securely storing and sharing medical data among healthcare providers, blockchain enhances care coordination, facilitates research efforts, and empowers patients by granting greater control over their health information.[19]

Proposed IOT-Blockchain based model

Figure 1, presents a detailed architecture of our proposed approach for intelligent self- care and diabetes monitoring, combining IoT devices with blockchain technology.[20] Our goal is to create a platform that leverages the advantages of both IoT and blockchain, providing patients with comprehensive control over their health data. Patients will be able to define access policies, set permissions, and track who accessed what information and when. Given the constraints of medical devices used for diabetes self-management, such as limited storage and computational power, our solution incorporates a multi-layered architecture to efficiently handle data and security.

Connected Devices

The first layer consists of various IoT devices, such as smart glucose monitors, insulin pumps, and wearable fitness trackers. These devices are responsible for collecting real-time health data, including blood glucose levels, insulin doses, physical activity, and other vital signs. Key features of this layer include continuous monitoring and data collection from the patient's body, ensuring that all vital metrics are captured accurately and in real-time. Secure and reliable transmission of collected data to the next layer is ensured, maintaining data integrity and patient confidentiality. Each device must be registered on the blockchain by its owner,

ensuring that only authorized devices can access and transmit data to the platform, enhancing security and preventing unauthorized device usage.

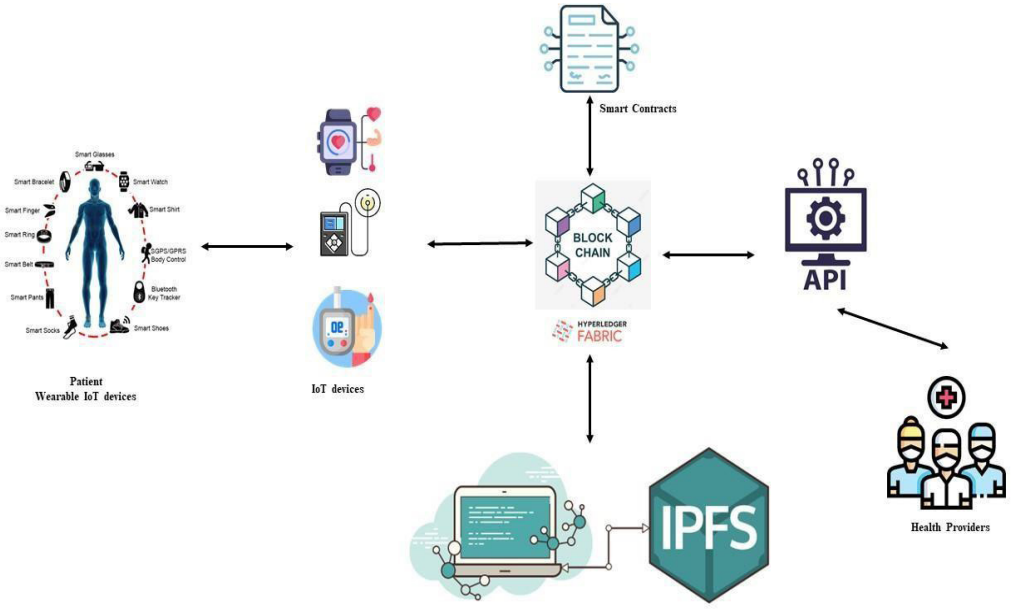

Figure 1. Proposed Model architecture

Blockchain Network

The blockchain network forms the second layer, ensuring data integrity, security, and transparency. Utilizing a private blockchain, this layer handles the decentralized storage and management of health data with enhanced control and privacy. The advantages of a private blockchain include restricted access, where only authorized participants can join the network, ensuring higher security and compliance with regulatory standards such as GDPR and HIPAA.[21] This setup also supports tailored consensus mechanisms and faster transaction processing, improving system efficiency.[22]

Decentralization in the private blockchain means control and validation of data are distributed across multiple nodes, eliminating single points of failure and enhancing overall system robustness. Blockchain employs cryptographic hashing and consensus algorithms to secure data against unauthorized access and tampering, with each transaction cryptographically signed to ensure authenticity. Once data is recorded on the blockchain, it cannot be altered without the consensus of the network, ensuring that patient data remains accurate and untampered.[23] Patients can set permissions and access policies for their data, maintaining control over who can access their health information. This feature is crucial for maintaining privacy and ensuring compliance with stringent regulations. Overall, the use of a private blockchain provides a secure, efficient, and compliant solution for managing sensitive health data, empowering patients with better control and enhancing the reliability of the healthcare system.[24]

InterPlanetary File System (IPFS)

The InterPlanetary File System enhances our solution by providing secure off-chain storage for large health data files, complementing the capabilities of blockchain technology. IPFS alleviates the storage limitations of IoT devices and the blockchain network, ensuring scalability and efficiency in data handling.[25] Each health data file stored on IPFS is assigned a unique cryptographic hash, enabling quick and secure retrieval when needed. By storing data off-chain, IPFS reduces the storage burden on the blockchain, optimizing its performance and resource utilization. The cryptographic hashes of these files are recorded on the blockchain, guaranteeing data integrity and facilitating easy verification. This combination of blockchain and IPFS ensures secure, scalable, and efficient management of health data, enhancing overall system reliability and performance.[26]

Smart Contracts

Smart contracts deployed on the private blockchain automate processes and enforce predefined rules, enhancing the efficiency and security of healthcare operations. These contracts are pivotal in managing data access permissions established by patients, ensuring that only authorized individuals and entities can access sensitive health information.[27] By leveraging smart contracts, the system can automatically execute

actions based on real-time data from IoT devices, such as triggering alerts to healthcare providers when critical health thresholds are exceeded, thereby enabling timely interventions. Furthermore, smart contracts facilitate seamless integration and interaction between various IoT devices and healthcare systems, promoting coordinated care delivery and optimizing patient outcomes.[15]

Medical Team and Healthcare Systems

The final layer consists of the healthcare providers and their information systems. Healthcare providers can access patient data as permitted by the patient, enabling personalized and timely medical advice and supporting better clinical decision-making. Enhanced engagement with patients through telemedicine and remote monitoring allows healthcare providers to offer continuous care and support, improving patient outcomes and satisfaction.

DISCUSSION

The IoT-Blockchain based model proposed for diabetes management integrates cutting-edge technologies to enhance the efficacy, security, and patient-centric nature of healthcare services. Central to its design are several key features that collectively address critical aspects of healthcare delivery.

Blockchain's cryptographic protocols establish robust security measures by encrypting health data and distributing it across a decentralized network, ensuring protection against cyber threats and unauthorized access. This mitigates risks associated with data breaches and ensures compliance with stringent regulatory frameworks such as GDPR and HIPAA.

Utilizing blockchain's immutable ledger ensures that once health data is recorded, it remains tamper-proof and verifiable. This feature enhances trust among stakeholders by providing an auditable trail of patient interactions and treatments, thereby improving diagnostic accuracy and treatment outcomes.

Empowering patients with control over their health data is fundamental to the model's design. Patients can define access permissions and monitor who accesses their information, fostering transparency and reinforcing privacy rights. This capability not only aligns with regulatory requirements but also strengthens patient-provider relationships through informed decision-making and personalized care.

Real-time data collection and analysis facilitated by IoT devices enable proactive health management. Healthcare providers can monitor patients remotely, analyze trends, and intervene promptly when deviations occur, thereby reducing the likelihood of acute complications and optimizing treatment efficacy.

Transparent data handling within the blockchain network promotes trust and accountability in healthcare interactions. Stakeholders benefit from clear visibility into data usage and sharing practices, facilitating collaborative decision-making and improving overall healthcare quality.

By minimizing hospitalizations and emergency room visits through continuous monitoring and early intervention, the model effectively reduces healthcare costs. This economic benefit is critical for healthcare systems striving to optimize resource allocation and enhance operational efficiency while maintaining high standards of patient care.

The model's architecture ensures seamless adherence to GDPR and HIPAA regulations. Leveraging IPFS guarantees the "Right to be Forgotten" as mandated by GDPR, enabling efficient and secure deletion of personal data across a decentralized network. The decentralized nature of blockchain, coupled with advanced cryptographic security measures, safeguards patient data with utmost confidentiality and privacy. This architecture supports patients' rights to access and rectify their data, mitigating legal risks and ensuring compliance with stringent data protection laws.

Addressing privacy concerns is paramount, achieved through advanced encryption techniques and patient-centric data control mechanisms. Blockchain's decentralized storage and cryptographic hashing techniques safeguard sensitive health information from unauthorized access, preserving patient confidentiality and upholding ethical standards in healthcare data management.

In summary, the IoT-Blockchain based model represents a paradigm shift in diabetes management. It offers a secure, efficient, and patient-centered approach to healthcare delivery by leveraging technological innovations to enhance security, ensure data integrity, empower patients, improve operational efficiency, foster transparency, reduce costs, and uphold regulatory compliance. This model sets a new standard for modern healthcare systems aiming to prioritize patient well-being and achieve sustainable healthcare outcomes.

CONCLUSION

The integration of IoT and blockchain technologies revolutionizes diabetes management and patient care by ensuring security, trust, transparency, regulatory compliance, efficiency, patient control, and cost reduction in healthcare solutions. This comprehensive model leverages IoT for real-time data collection and blockchain for decentralized, immutable data storage, enhancing data security, integrity, and patient privacy. Blockchain's transparency and decentralized structure prevent unauthorized access and tampering, while empowering

patients with control over their health data ensures compliance with GDPR and HIPAA. This collaborative framework facilitates timely interventions, personalized care, and improved health outcomes. The system's efficiency streamlines chronic disease management, reducing administrative burdens and costs. As healthcare evolves, these technologies promise sustainable solutions, reshaping healthcare delivery to be secure, efficient, patient-centric, and regulatory compliant. Embracing IoT and blockchain is pivotal for resilient and adaptive health management systems, heralding a new era in healthcare.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Nehal Ettaloui, Sara Arezki, Taoufiq Gadi.
Drafting - original draft: Nehal Ettaloui, Sara Arezki, Taoufiq Gadi.
Writing - proofreading and editing: Nehal Ettaloui, Sara Arezki, Taoufiq Gadi.
Supervision: Sara Arezki, Taoufiq Gadi.
Validation: Nehal Ettaloui, Sara Arezki, Taoufiq Gadi.