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Enhancing Personal Health Record Security Through Blockchain-Based Authentication

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Abstract: Authentication plays a crucial role in ensuring the security and privacy of sensitive information in various domains, including healthcare. In traditional Personal Health Record (PHR) systems, patients often lack control over their health records as these systems are managed by a central authority. This centralization renders PHRs susceptible to data breaches, unauthorized access, tampering, and misuse. Blockchain technology, due to its decentralized and immutable characteristics, presents a viable way to improve the security and privacy of PHR systems.

This paper explores the application of blockchain to develop a decentralized PHR web application. The proof of concept demonstrates how blockchain and smart contracts can be utilized to manage data access and permissions, empowering patients with control over their health records while ensuring security and transparency. Moreover, a comprehensive study was conducted to evaluate the system's performance, including the effectiveness of smart contracts for secure access control, the transaction flow in the blockchain network, and the robustness of the authentication mechanisms. The results highlight the feasibility and advantages of a blockchain-based approach in addressing critical challenges of traditional PHR systems.

Keywords: Blockchain, Personal Health Records (PHR), Hyperledger Fabric, Decentralized Systems, Data Security, Smart Contracts, Usability Evaluation, Healthcare Data Management, Access Control, Privacy.

I. INTRODUCTION

In recent years, the swift advancement of network information technology has profoundly influenced lifestyles and industries, altering the management and perception of tasks traditionally performed manually. The healthcare sector is no exception to this technological evolution, as it persistently seeks innovative approaches to enhance efficiency, security, and accessibility. A notable solution arising in the healthcare sector is the implementation of electronic health records (EHRs) [1]. EHRs provide a structured digital platform where patient data can be stored, updated, and shared among healthcare stakeholders. However, traditional paper-based medical records have several limitations [2], including susceptibility to damage, loss, and difficulty in managing and sharing the information. These issues highlight the need for a rapid shift towards paperless and electronic healthcare data systems.

Despite the adoption of EHRs in healthcare institutions, current implementations present challenges. These records are typically stored in centralized databases managed by individual institutions, limiting patients' ability to access and control their health data [3]. Patients require mechanisms to manage, track, and authorize access to their personal health records (PHRs) without relying on intermediaries. Unlike EHRs, PHRs aim to provide patients with a comprehensive and accurate medical history that they can manage online [4]. The sharing of PHRs offers the potential to improve medical diagnosis accuracy and foster advancements in healthcare research.

However, existing PHR solutions are predominantly hosted on centralized servers, creating concerns around transparency, privacy, trust, and security. In centralized systems, data ownership is often unclear, and access management depends on third-party entities, which reduces patient autonomy and control. These limitations underscore the importance of developing a more robust, secure, and decentralized framework for PHR management.

Blockchain technology has gained attention in recent years as a solution to the challenges associated with centralized PHR systems. Its decentralized architecture, coupled with features such as immutability, transparency, and tamper-proof mechanisms, makes it a promising tool for safeguarding sensitive medical data. Blockchain offers a secure and distributed environment where patients can retain ownership and control over their health records while enabling authorized stakeholders to access and manage data transparently. This study proposes a blockchain-based PHR system leveraging the Hyperledger Fabric framework, which provides a secure, decentralized, and scalable platform tailored to address the limitations of traditional PHR systems. By empowering patients with full control over their data and ensuring robust security measures, the proposed system aims to set a new standard for personal health record management.

II. LITERATURE REVIEW

A. Personal Health Records (PHRs)

Personal Health Records (PHRs) have gained significant attention in eHealth research over the past decade due to the growing interest in developing consumer-centric healthcare systems [5][6]. The term PHR was first introduced in the late 1970s and continues to be widely used in healthcare literature [7][8]. Although there is no universally agreed-upon definition, a PHR is generally considered an electronic record of an individual's health information that is controlled by the individual. This control enables users to manage, track, and participate in their healthcare effectively.

PHRs should not be confused with Electronic Health Records (EHRs). While EHRs are managed and maintained by healthcare providers, PHRs focus on empowering individuals to manage their health data. PHRs have the potential to provide individuals with a longitudinal health history, including information such as diagnoses, medications, and test results. These records are generally accessible over the Internet, providing flexibility for users to view their information from any location.

Several platforms and services have attempted to address the need for effective PHR management:

1) Google Health [9]: A web-based platform allowing patients to retrieve, edit, and share their medical information. However, the system was discontinued, and its reliance on centralized management posed challenges in terms of transparency and user control.
2) Apple Health App [10]: Combines health data from multiple sources into a single platform, enabling users to track their activity, vitals, and medical records.
3) Microsoft HealthVault [11]: A platform designed for storing and sharing medical records. Despite its initial promise, the service was shut down in November 2019.
4) My Doclopedia PHR [12]: A free, web-based solution for recording and sharing health history. While simple and accessible, it lacks critical features such as transparency, traceability, and robust security.

These existing solutions highlight common challenges, such as centralized data storage, limited user control, and vulnerabilities to privacy breaches. To address these issues, the ideal PHR system should incorporate features like transparency, immutability, auditability, and enhanced security mechanisms.

B. Blockchain Technology

A blockchain is fundamentally a decentralized database or public ledger that records all transactions or digital events completed and shared among participating entities. Every transaction in the public ledger is validated by the agreement of a majority of the system's members. Once inputted, information is irrevocable. The blockchain maintains an immutable and verifiable record of every transaction ever conducted. The notion originates from Santoshi Nakamoto's 2008 Bitcoin cryptocurrency [13]. The transactions on Bitcoin's blockchain signify financial exchanges: transferring designated quantities of Bitcoin between accounts. Any anyone can ascertain the ownership of a specific Bitcoin by employing suitable software tools to analyse the transactions recorded on the public blockchain.

Blockchain technology is based on three fundamental principles[14]. Initially, data is recorded in a public, immutable transaction ledger accessible to everybody. Due to the immutable nature of transactions, a comprehensive and incontrovertible record of all transactions is perpetually maintained. Secondly, blockchains are deployed within a decentralized network of computing nodes, rendering them resilient to failures and attacks. Decentralization signifies that no single entity has or governs.

The blockchain. Third, the metadata pertaining to each transaction is accessible to all users on the system; however, this does not imply that the data contained within the blockchain is comprehensible. Blockchain depends on pseudo-anonymity (substituting names with identifiers) and public key infrastructure (PKI), enabling the encryption of blockchain data in a manner that is prohibitively costly to breach. Each of these core principles is applicable for implementing blockchain technology in health data.

These attributes render it an appealing remedy for overcoming the constraints of conventional PHR systems. A blockchain is fundamentally a decentralized ledger that documents transactions in a verifiable and immutable fashion. Every transaction undergoes validation through a consensus mechanism prior to its inclusion on the blockchain, thereby safeguarding the integrity of the data.

Key components of blockchain technology include:

1) Cryptographic Hash Functions: These are used to secure data by generating unique outputs for any given input. Even minor changes to the input result in entirely different hash values, ensuring data integrity.

2) Asymmetric Key Cryptography: A public-private key system that secures blockchain transactions. Users digitally sign transactions with their private keys, while others verify the signatures using public keys [15].
3) Consensus Mechanisms: Blockchain networks use consensus protocols like Proof-of-Work (PoW) or Proof-of-Stake (PoS) to validate transactions. While effective, some mechanisms like PoW are resource-intensive and can lead to inefficiencies in platforms such as Ethereum.

The decentralized architecture of blockchain guarantees that no one entity possesses authority over the system, hence augmenting trust and diminishing reliance on intermediaries. Furthermore, blockchain's capacity to generate indelible and traceable records renders it an effective instrument for managing sensitive data such as health records.

C. Existing Blockchain-Based PHR Solutions

In recent years, blockchain-based methods and systems have been proposed to enhance the acquisition, storage, and management of patient medical data:

1) MedRec[16]: An Ethereum-based system using smart contracts to manage data authorization, permissions, and sharing between stakeholders.
2) MediBloc[17]: A commercial product leveraging public blockchain for storing metadata while actual data resides on the InterPlanetary File System (IPFS). Smart contracts handle access control.
3) Zheng et al.'s Scheme [18]: A blockchain-based PHR sharing solution using public blockchain and cloud storage to ensure safe and efficient data sharing.
4) Madine et al.'s Framework [19]: This system employs decentralized storage via IPFS and Ethereum smart contracts to provide secure data sharing. Features like proxy re-encryption and reputation-based oracles enhance security.

While these systems demonstrate the feasibility of using blockchain for PHR management, they also reveal challenges such as performance inefficiencies, scalability issues, and high transaction costs associated with certain consensus mechanisms like PoW.

D. Gaps Addressed by the Proposed System

The current project addresses key limitations in existing solutions by leveraging the Hyperledger Fabric framework. Unlike Ethereum-based platforms, which are limited by PoW inefficiencies and high transaction costs, Hyperledger Fabric offers a permissioned blockchain environment that is more suited for healthcare use cases. Key features of the proposed system include:
Decentralization: Ensuring patient control over health records without reliance on centralized servers.

1) Transparency and Traceability: All transactions are logged on the blockchain, providing a verifiable history of data access and modifications.
2) Access Control: Patients can grant or revoke access to their health data, empowering them with full control over sensitive information.
3) Scalability: The system's modular architecture and pluggable consensus mechanisms make it adaptable to large-scale healthcare applications.

By focusing on practical implementation and addressing real-world challenges, this project lays the groundwork for a secure, decentralized, and patient-centric PHR management system.

III. PROPOSED SYSTEM

A. System Architecture

The proposed system leverages the capabilities of the Hyperledger Fabric framework to create a decentralized and secure Personal Health Record (PHR) management platform. The system is designed to empower patients with control over their medical data while maintaining the transparency and security required for sensitive health records.
Key Components of the System:

1) *Blockchain Infrastructure:*

- Peers: Nodes that maintain copies of the distributed ledger and execute smart contracts (chaincode). These peers are responsible for validating and committing transactions to the blockchain.
- Ordering Service: Responsible for packaging transactions into blocks and ensuring the correct sequence of transactions across the network.
- Ledger: A tamper-proof record of all transactions, including health data access logs, stored in a decentralized manner.

- Chaincode (Smart Contracts): Implements the business logic for the system, such as granting and revoking access permissions to patient data.

2) User Roles:
- Patients: The owners of personal health records who can view, update, and manage access permissions to their data.
- Doctors: Authorized users who can access patient medical data for diagnosis or treatment after permissions are granted.
- Administrators: Responsible for registering new users (patients and doctors) and managing the system infrastructure.

3) Data Flow:
- Patients create, update, and store their medical data on the blockchain via a web-based interface.
- Doctors request access to specific patient data, which is granted or revoked by the patient through smart contracts.
- All transactions (e.g., granting access, updating medical data) are recorded immutably on the blockchain for transparency and auditability.

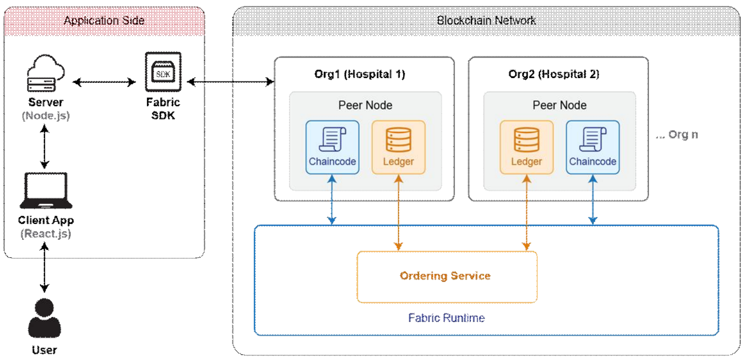

Figure 1 System Architecture

As shown in Figure 1, the proposed system integrates user roles, blockchain infrastructure, and data flow to create a decentralized and secure PHR management platform. The interaction between the application side and blockchain network ensures transparency and control over sensitive health records."

B. Authentication Flow

The proposed system implements secure authentication and access control mechanisms using blockchain technology and smart contracts. By decentralizing data storage and permissions management, the system eliminates reliance on third-party intermediaries, ensuring patients maintain full control over their personal health records. Each operation, such as user registration, access management, and medical record updates, is validated and immutably recorded on the blockchain, ensuring transparency, security, and data integrity.

Key Processes

1) Patient Registration Administrators create new patient accounts via the system, as illustrated in Figure 2. This process involves assigning each patient a unique cryptographic identity (public/private key pair) that enables secure and authenticated access to the blockchain network. Once the patient registration process is completed, the blockchain immutably logs the transaction, ensuring traceability.
2) Doctor Registration A similar process is followed for registering doctors, as shown in Figure 3. Administrators assign cryptographic identities to doctors, enabling them to interact with the blockchain. Permissions for doctors are restricted to accessing patient records only after explicit authorization from the patient.
3) Adding Medical Data Doctors can update a patient's medical details, a process demonstrated in Figure 4. Using the client application, the doctor submits the new data, which is validated by the blockchain via the Fabric SDK and recorded immutably through a smart contract. This ensures that medical updates remain tamper-proof and traceable.
4) Access Control via Smart Contracts Patients manage access to their records via smart contracts, allowing them to grant or revoke access to specific doctors:

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- Granting Access: As depicted in Figure 5, patients can grant a doctor access to their health records by interacting with the blockchain through the client application. The transaction is validated and logged on the blockchain, ensuring transparency and accountability.
- Revoking Access: As shown in Figure 6, patients can revoke access permissions previously granted to a doctor. The smart contract securely updates the permissions on the blockchain, ensuring that unauthorized access is prevented.

5) Data Integrity and Immutability All operations, including medical updates, access permissions, and user registrations, are cryptographically hashed and immutably stored on the blockchain. This guarantees data integrity and ensures that an unalterable audit trail is maintained.

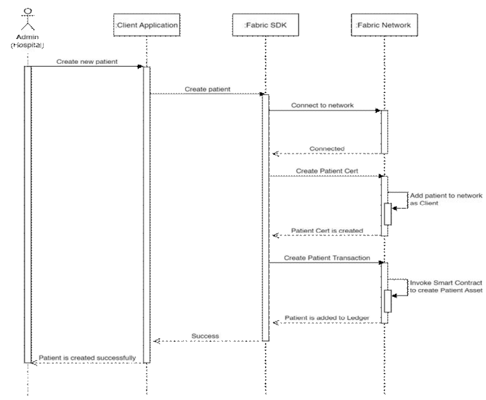

Figure 2 Sequence Diagram (Creating New Patient)

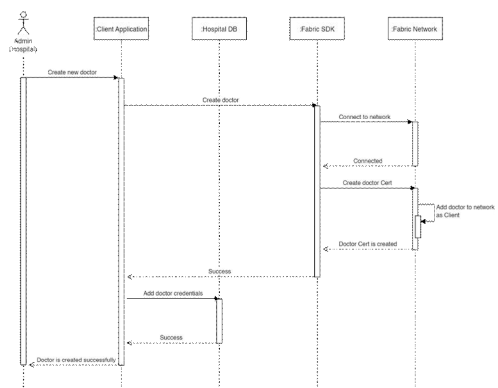

Figure 3 Sequence Diagram (Creating New Doctor)

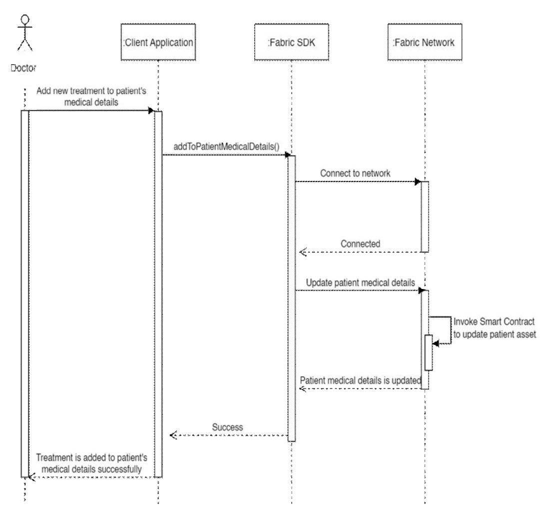

Figure 4 Sequence Diagram Admin (Add new Treatment)

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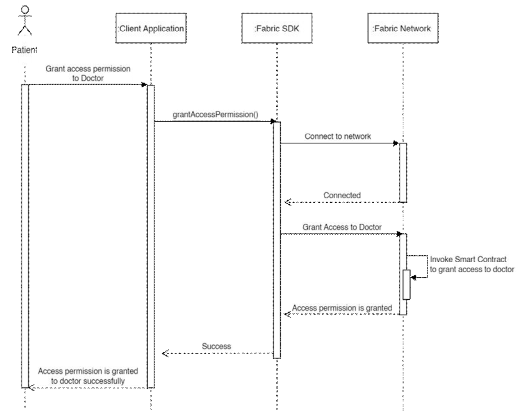

Figure 5 Grant Access to Doctor

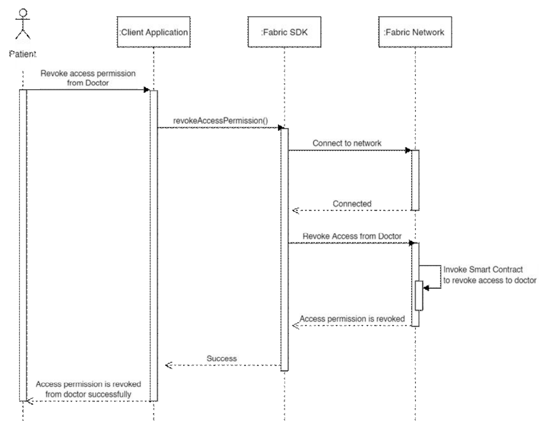

Figure 6 Revoke Access to Doctor

IV. IMPLEMENTATION

A. Hyperledger Fabric Network

The implementation of the proposed system leverages the Hyperledger Fabric v2.x blockchain platform [20] to establish a permissioned and secure network for managing Personal Health Records (PHRs). The network configuration and chaincode development are tailored to support the secure and decentralized management of health records.

1) Network Configuration

a) Organizations:

- The network is divided into multiple organizations, representing different stakeholders (e.g., patients, doctors, and administrators).
- Each organization has its own peers that maintain copies of the ledger.

b) Peers:

- Each organization runs peers that validate transactions, execute chaincode (smart contracts), and maintain the distributed ledger.

c) Channels:

- Channels are used to isolate and control communication between different participants in the network. A single channel connects all participants to allow data sharing while maintaining security and privacy.

d) Ordering Service:

- The ordering service packages transactions into blocks and ensures that all peers maintain a consistent copy of the ledger.

2) Chaincode Development

The chaincode (smart contracts) developed for the system defines the business logic for managing PHRs. Key functionalities include:

a) Updating Medical Data:

- Doctors or authorized users can append new medical records to a patient's health record. These updates are recorded immutably on the blockchain.

b) Granting/Revealing Access Permissions:

- Patients interact with the chaincode to grant or revoke access to their health records for specific doctors.

c) Access Validation:

- The chaincode validates all access requests to ensure that only authorized users can view or modify a patient's data.

3) Transaction Flow

The transaction flow follows the Hyperledger Fabric's Execute-Order-Validate model:

a) Proposal (Execute):

- A transaction proposal (e.g., updating medical data or granting access) is sent to endorsing peers, which simulate the transaction and provide endorsements.

b) Ordering and Packaging:

- Endorsed transactions are sent to the ordering service, which packages them into blocks in the correct order.

c) Validation and Commitment:

- All peers validate the transactions in the block (checking endorsements and ensuring no conflicts) before committing them to the ledger.

A transaction flow as shown in Figure 7, showing the proposal phase where transactions are endorsed, ordering phase where transactions are packaged into blocks and validation and commitment phase where transactions are finalized on the blockchain.

Figure 7 Transaction Flow

B. User Interfaces

The web-based system provides multiple interfaces to support the operations of patients, doctors, and administrators. These interfaces are designed for usability, ensuring that users can interact with the system efficiently and securely.

1) Key Interfaces and Functionalities:

a) Registration Interface:

- Admins register patients and doctors into the system by creating unique cryptographic identities for each user. This ensures secure access to the blockchain network, as shown in Figure 8.

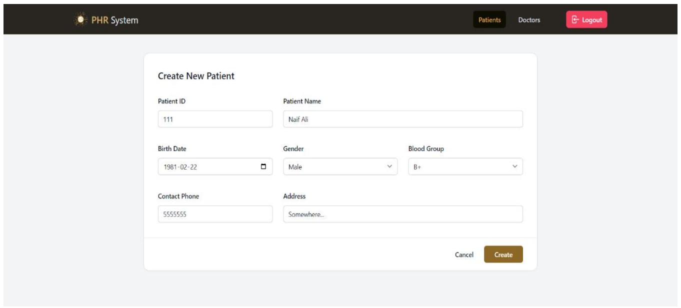

Figure 8 Registration Interface

b) Medical Data Entry Interface:

- Doctors can add new medical records for patients through this interface. The system uses smart contracts to record and validate these updates on the blockchain, as shown in Figure 9.

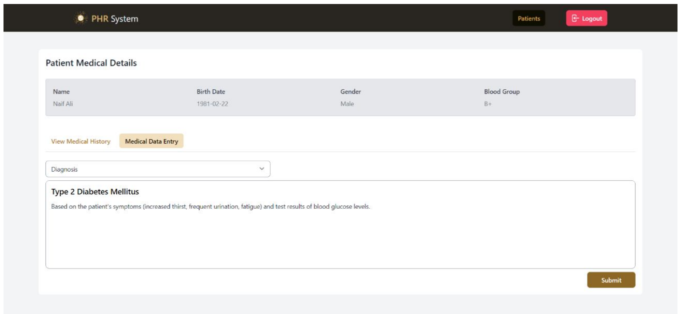

Figure 9 Medical Data Entry Interface

c) Access Control Interface:

- Patients have complete control over their medical data. This interface allows patients to grant or revoke access permissions for specific doctors, as shown in Figure 10. The system ensures that these permissions are securely managed via smart contracts.

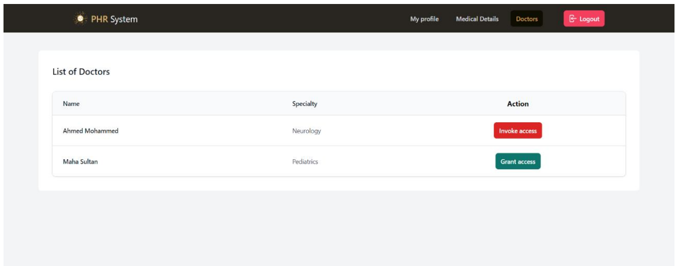

Figure 10 Access Control Interface

d) Medical Details View Interface:

- Doctors can view the medical history of patients who have granted them access. As shown in Figure 11, this interface retrieves and displays data stored on the blockchain ledger, ensuring transparency and integrity.

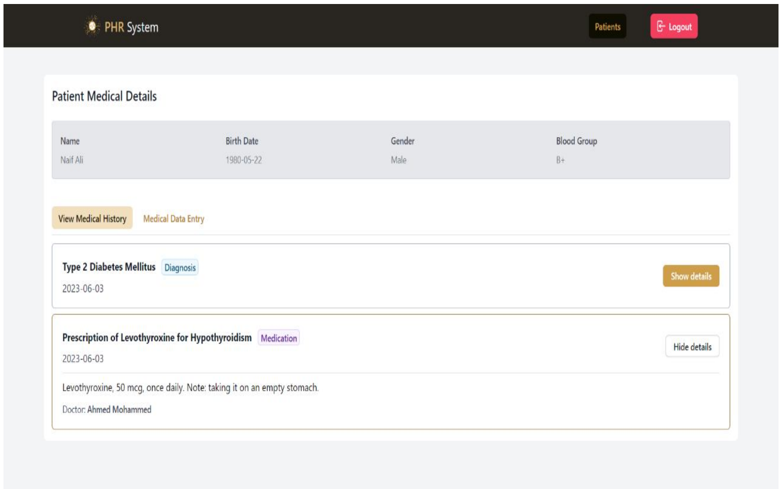

Figure 11 Medical Details View Interface

V. RESULTS AND DISCUSSION

This section evaluates the outcomes of the blockchain-based Personal Health Record (PHR) system, focusing on usability, awareness, adoption potential, and challenges based on participant feedback and survey data.

A. Results

1) Demographics of Participants:

The survey included 200 participants from various roles (patients, doctors, and administrators), representing a balanced distribution across gender and age groups. The demographic characteristics, summarized in Table 1, show a diverse participant base, with 60% of respondents identifying as patients, followed by 25% as doctors and 15% as administrators.

TABLE 1 DEMOGRAPHIC CHARACTERISTICS OF PARTICIPANTS (N = 200)

Demographic	Category	Count (N)	Percentage (%)
Gender	Male	140	70%
	Female	60	50%
Age	20–30	80	40%
	31–40	90	45%
	41+	30	15%
Role	Patient	120	60%
	Doctor	50	25%
	Administrator	30	15%

2) Awareness and Trust in Blockchain Technology

Participants demonstrated moderate to high levels of awareness and trust in blockchain technology. The survey results, summarized in Table 2, reveal that most participants had heard of blockchain technology (mean score: 4.1), and a significant portion trusted its ability to secure sensitive health information (mean score: 4.0).

TABLE 2 BLOCKCHAIN-RELATED SURVEY RESPONSES (N = 200)

Category	Question	Mean	Mode
Understanding of Blockchain	I have heard of blockchain.	4.1	5
	Blockchain protects my health information securely.	4.0	4
Trust in Blockchain	Blockchain transmits data securely.	4.1	4

3) Usability of the System

The usability of the blockchain-based PHR system was evaluated through questions focused on navigation, access control, and overall user confidence. The results, summarized in Table 3, indicate a positive user experience, with participants giving an average System Usability Score (SUS) of 74.2.

Participants particularly valued the ease of navigation (mean score: 4.0) and the ability to grant/revoke access permissions (mean score: 4.2). Additionally, confidence in the system's security was rated highly, with a mean score of 4.1.

TABLE 3 USABILITY-RELATED SURVEY RESPONSES AND SUS SCORES (N = 200)

Question	Mean	Mode
The system is easy to navigate.	4.0	4
I can grant/revoke access easily.	4.2	4
I feel confident in the system's data security.	4.1	4

4) Willingness to Adopt the System

The survey also evaluated participants' willingness to adopt the system and replace traditional centralized methods for managing health records. The findings, summarized in Table 4, show high adoption potential, with 80% of participants indicating their readiness to use the system for managing their personal health data. Participants also expressed confidence in blockchain's ability to replace existing centralized systems (mean score: 4.0).

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TABLE 4 WILLINGNESS TO ADOPT THE SYSTEM (N = 200)

Question	Mean	Mode
I am willing to use this system for PHRs.	4.3	4
Blockchain can replace traditional methods.	4.0	4

5) Correlation Across Survey Questions

The heatmap, shown in Figure 3, illustrates the correlations between Blockchain Awareness, Usability, and Willingness to Adopt the System. Strong correlations are observed between usability features (e.g., ease of navigation, access control) and participants' willingness to adopt the system. This emphasizes the importance of user-friendly design in driving system acceptance.

Additionally, the heatmap reveals moderate positive correlations between blockchain awareness (e.g., trust in blockchain security) and usability, suggesting that familiarity with blockchain principles positively influences user acceptance of the system.

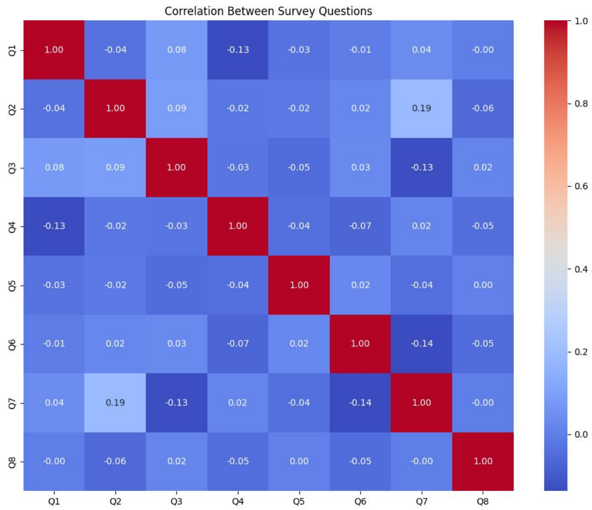

Figure 12 Correlation Between Usability and Willingness

B. Discussion

1) Achievements

The results demonstrate that the blockchain-based PHR system effectively addresses key challenges in health data management:

- Decentralization: The system eliminates reliance on centralized servers, empowering patients with full control over their health records. Participants appreciated the system's transparency and ownership features.
- Security and Transparency: Blockchain’s tamper-proof record-keeping fosters trust among users, as supported by positive feedback in Table 2.
- User-Centric Features: Features such as granting/revoking access permissions were highly rated, aligning with the project’s goal to empower users. As shown in Figure 2, usability ratings confirm the system’s intuitive design.

VI. CONCLUSIONS

This paper presents a blockchain-based Personal Health Record (PHR) system designed to address the challenges of security, privacy, and user control inherent in traditional centralized systems. By leveraging Hyperledger Fabric, the system ensures decentralization, data integrity, and transparent access management. Patients are empowered to control their health records through smart contracts, enabling secure and auditable interactions. A study evaluating the system demonstrated high usability, user confidence in data security, and a willingness to adopt blockchain for managing personal health records. This work provides a scalable and secure foundation for decentralized healthcare systems, with future opportunities for expanding interoperability and enhancing system performance.

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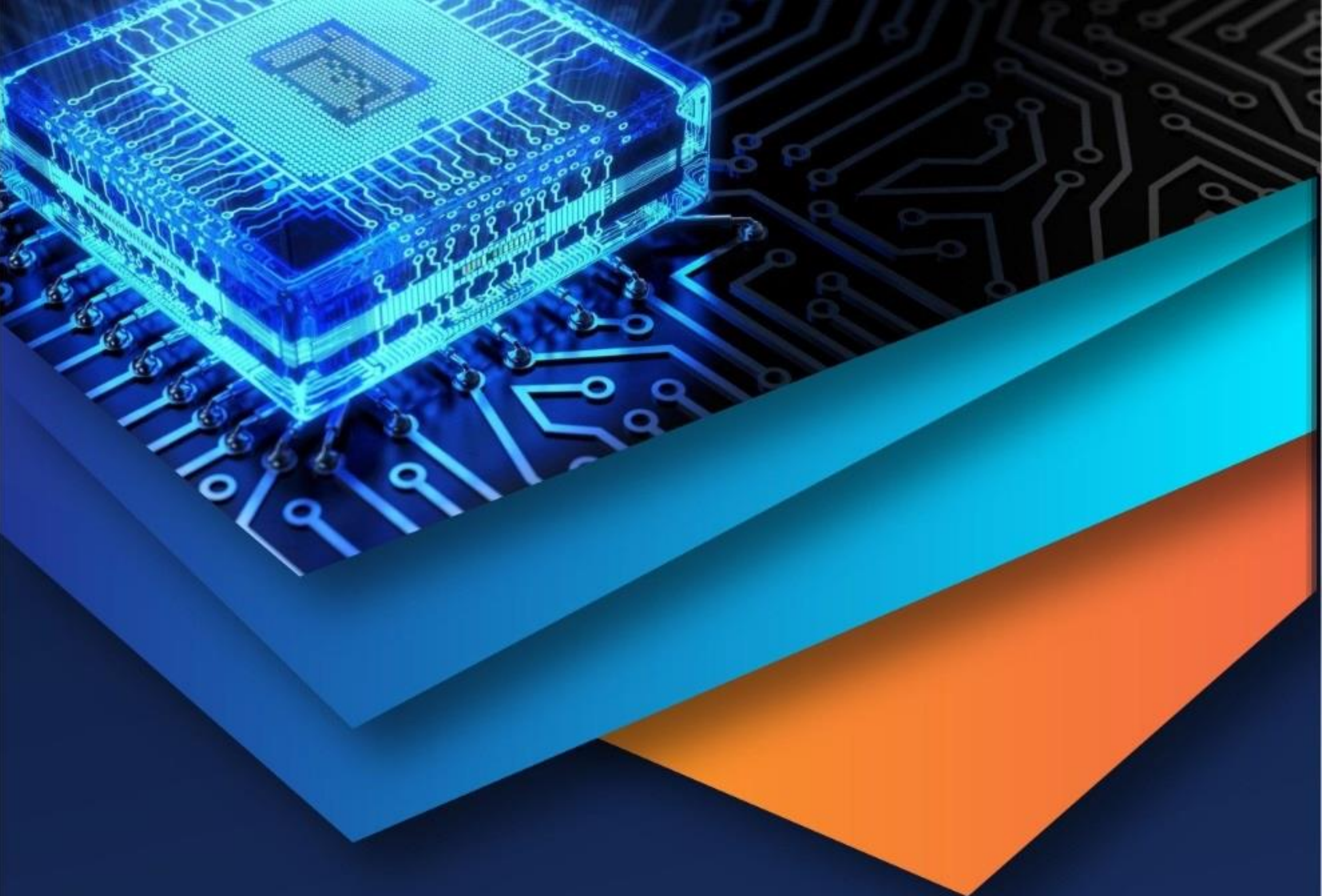

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