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Investigation on Collaborative Innovation Application of Blockchain and Artificial Intelligence in Healthcare

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Investigation on Collaborative Innovation Application of Blockchain and Artificial Intelligence in Healthcare

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Abstract. In order to establish a more secure and private healthcare system, this paper focuses on the synergistic application of blockchain and Artificial Intelligence (AI) technologies to explore their innovative solutions in the fields of healthcare data management and drug supply chain. Blockchain enables tamper-proof storage and secure sharing of healthcare data through decentralized ledgers, consensus mechanisms (e.g., proof-of-work, proof-of-equity), and smart contracts, such as anti-counterfeiting tracking of pharmaceutical packaging and secure data sharing solutions based on two-dimensional chaos mapping (2DCM-DS), while AI supports personalized healthcare services with its data analytics capabilities, and the combination of the two yields significant synergistic effects: The MedRec system empowers patients to control their own data through blockchain smart contracts, and combined with AI analysis, patient satisfaction has increased by 40%; in the field of cardiovascular healthcare, blockchain solves the problem of "data scarcity" for AI training, and through cross-institutional data sharing and AI algorithms to analyze ECG and other data, it improving personalized diagnosis and disease prediction. The paper combed six application scenarios, including drug supply chain security, cardiovascular data ecology, medical data management, public health, mental health analysis, and medical image security, confirming that the fusion of blockchain and AI can effectively improve the security of the healthcare system, the efficiency of data sharing, and the accuracy of diagnosis. However, current technologies face challenges like complexity, weak privacy, poor interpretability, and high energy use. Future efforts should enhance lightweight blockchain, privacy computing, and interpretable AI for sustainability.

INTRODUCTION

Healthcare refers to the maintenance or improvement of people's diseases, injuries, and other physical and mental disorders through prevention, diagnosis, and treatment. It is the core element of maintaining people's well-being and plays an indispensable role in reducing population mortality and improving public health. The current medical system has become increasingly powerful, but it still faces many challenges, such as transaction security issues. Then, to solve this problem, the technologies of blockchain and Artificial Intelligence (AI) are gradually being considered for use in healthcare to build a healthcare system with greater privacy and security since AI can process huge amounts of medical data and discover patterns from it to propose personalized healthcare services accordingly.

Derived from Satoshi Nakamoto's 2008 Bitcoin protocol [1], blockchain has evolved as a technology to address healthcare challenges through its core innovations: consensus mechanisms such as Proof of Work (PoW) and Proof of Stake (PoS), smart contracts (Ether, Hyperledger Fabric), and decentralized ledgers. Currently, blockchain is closely linked to the healthcare system and maintains the security of the system at all times. Blockchain technology is used in pharmaceutical packaging to prevent counterfeiting and tracking. For example, packaging companies can use blockchain tags on pharmaceutical packaging to record information about the packaging process and share it with interested parties via the blockchain network [2]. In addressing the privacy and security issues in medical data sharing, a secure medical data sharing scheme (2DCM-DS) based on two-dimensional chaotic mapping and blockchain is proposed [3], which can be applied to data sharing scenarios between health insurance companies to ensure that patients' medical information is adequately protected during the sharing process.

On the other hand, blockchain has also been combined with artificial intelligence to address healthcare system

security. MedRec system, a blockchain-based medical data management system. It utilizes the blockchain's features of decentralization, non-tampering, and smart contracts to provide patients with full control over their medical data. Combined with AI analysis, it realizes accurate referrals and increases patient satisfaction by 40% [4]. Blockchain and AI also have synergistic applications in cardiovascular medicine, where blockchain can solve the "data starvation" problem required for AI training [5]. Through the decentralized ledger to achieve cross-institutional data sharing, combined with AI algorithms to analyze Electrocardiogram (ECG), imaging, and other data, to improve personalized diagnosis and disease prediction ability. The non-tampering nature of the blockchain ensures that the data source is credible, providing high-quality training data for AI models. Given the growing significance of blockchain and AI in healthcare, many researchers have explored this field in recent years, leading to great advancements. Therefore, it is essential to provide a comprehensive overview of these developments to better understand their impact and future potential.

The other sections of this review are as follows, first, the paper will focus on how others have combined AI and blockchain to solve some of the challenges in healthcare, and a specific description of their work will be given in Section 2, followed by a discussion of the limitations of the current approaches and future perspectives in Section 3. Finally, Section 4 will summarize the entire paper and present conclusions based on the previously discussed research.

METHOD

Preliminaries of Blockchain and AI

Blockchain technology, which originated with Bitcoin, is a decentralized ledger technology that is tamper-proof through distributed storage and consensus mechanisms. Its components include blocks that store data (e.g., medical records), timestamps, and cryptographic hashes to form a tamper-proof blockchain; consensus algorithms (e.g., PoW/PoS) for transaction validation; and smart contracts for automated rule enforcement. In addition, the core workflow of blockchain is: firstly, users or systems submit transaction requests to the blockchain network; then nodes in the network verify the legitimacy of the transactions through consensus algorithms; the verified transactions are packaged into new blocks, which are confirmed through mechanisms such as proof of workload or proof of interest, and then the new blocks are added to the main chain, and distributed synchronization is achieved throughout the blockchain system through the peer-to-peer network that ensures data consistency across all nodes. In healthcare, it enables decentralized data sharing and provides fraud-proof audit trails for AI analytics.

Artificial intelligence is primarily based on a data-driven learning model with algorithms to decipher patterns in healthcare data. Its essence lies in using labeled datasets to train models that enable various clinical applications, such as accurate predictions, diagnostic support, and personalized treatment recommendations. The framework of AI consists of three main components, which are the data layer, algorithm layer, and application layer. In addition, the core workflow of AI is: firstly, collect multi-source medical data such as patients' electronic health records and IoT sensor data through the blockchain network, and complete data cleaning, labeling and encryption pre-processing; subsequently, based on the hash value stored in the blockchain to validate the data integrity, and utilize federated learning to train the disease prediction model on the encrypted data; after the completion of the model training, the model will be called up through a smart contract to perform performance evaluation of historical data in the chain; finally, the validated model will be deployed to a Decentralized Application (dApp) to realize real-time services such as remote medical diagnosis and epidemic warning. Each step is closely integrated with blockchain, and the two build a credible and efficient collaborative ecosystem through technical complementarity.

Pharmaceutical Supply Chain

Haji et al. proposed a framework for integrating blockchain and artificial intelligence into pharmaceutical supply chain security, using machine learning to analyze transaction data on the chain and optimize security protocols [2]. Specifically, their approach consists of three key steps: in the first step, anomaly detection through machine learning. The researchers applied supervised learning algorithms to historical transaction data to train models to identify patterns that indicate the circulation of counterfeit medicines or irregular distribution routes. In the second step, a predictive model for risk mitigation is constructed. By combining blockchain-recorded transaction history with external data, such as market demand trends, Haji et al. developed predictive models for predicting supply chain vulnerabilities. In the third step, integrate with smart contracts in real time. The framework combines AI-generated insights with blockchain smart contracts to automate responses. For example, when an AI model identifies a high-risk transaction,

the smart contract automatically triggers a transaction hold, notifies relevant stakeholders, and initiates a blockchain audit of the relevant parties.

Cardiovascular Medicine

Krittanawong et al. proposed that the fusion of blockchain and AI can build a patient-centered cardiovascular data ecosystem [5]: through blockchain smart contracts to realize the decentralized depository and rights management of multi-source data (e.g., electrocardiograms, genetic tests, and wearable devices), the patient can independently authorize hospitals, pharmaceutical companies, or research institutes to access the data, and AI can train a model based on federated learning on encrypted data. AI trains models based on federated learning on encrypted data to realize precise diagnosis of arrhythmia, with an accuracy rate up to the level of experts.

Healthcare Data Management

Ekblaw et al. present MedRec, a blockchain-based healthcare data management system that aims to address data silos and patient permission gaps in traditional electronic medical records [4]. The system enables decentralized storage by securing medical data hashes on the blockchain and cross-institutional interoperability through modular API integration with legacy systems such as EPIC. Core features of the system include smart contract-based access control, where patients can define fine-grained data permissions (e.g., granting hospitals access to specific ECG records), and AI-driven automation through Natural Language Processing (NLP) parsing of EHR text to generate structured data for blockchain storage. On the medical research side, MedRec incentivizes data sharing through a “mining” mechanism that rewards researchers for using aggregated, anonymized datasets (e.g., 50,000+ heart failure records) while enforcing usage restrictions through smart contracts. Artificial intelligence algorithms analyze on-chain transaction patterns to detect anomalies such as high-frequency rare disease data requests and optimize security protocols. The system also uses federated learning to train models on encrypted data, for example, using multi-agency CT scans to improve lung cancer detection accuracy to 92%.

Public Health

Kumar et al. proposed that the synergistic technology of AI and blockchain can solve the problems of privacy leakage, and inefficient decision-making in public health [7]. The study builds a three-layer public health ecosystem: the data layer stores medical data hashes via blockchain and combines smart contracts to achieve fine-grained permission management, ensuring patient autonomy in controlling data access; the intelligence layer utilizes AI to perform federated learning on encrypted data; and the application layer develops decentralized apps to support telemedicine, drug traceability, and outbreak alerts.

Mental Health Analytics and Privacy Protection

The combination of artificial intelligence and blockchain in mental health addresses key challenges in data privacy and personalized care. Shinde et al. proposed a framework that combines NLP with blockchain for analyzing patient feedback and clinical notes while protecting sensitive information [8]. The system utilizes smart contracts to grant fine-grained access to anonymized datasets, enabling researchers to train models on aggregated data without revealing their personal identity. In a pilot study, this approach improved the accuracy of depression risk prediction by 25 percent compared to traditional methods. In addition, the blockchain's immutable ledger ensures data integrity and prevents adversarial attacks that could compromise the reliability of AI models.

Medical Imaging Security

Blockchain technology enhances the security and interoperability of medical imaging workflows, as highlighted in a 2020 study by Rapu [9]. By storing radiological images (e.g., CT scans, MRIs) on a decentralized ledger, healthcare providers can securely share data across institutions while maintaining records of patient consent. Artificial intelligence algorithms trained on these blockchain-stored images can detect abnormalities such as subtle tumors or fractures with up to 95% accuracy, comparable to radiologists.

DISCUSSION

Limitations and Challenges

Technical complexity and scalability are problematic. The integration of AI and blockchain in healthcare faces significant technical barriers. For example, the real-time machine learning analytics framework proposed by Haji et al. in the pharmaceutical supply chain relies on blockchain transaction data [2], but consensus mechanisms for decentralized ledgers (e.g., PoW) are computationally expensive, leading to delays in data processing. This delay may weaken the timeliness of counterfeit drug detection, especially during peak demand periods that may leave fraudulent transactions undetected in a timely manner. Similarly, Krittanawong et al.'s federated learning model for cardiovascular disease prediction requires secure data sharing across organizations [5], but encryption overhead and decentralized storage limit the speed of model training and reduce diagnostic efficiency.

Data privacy and anonymization are at risk, although blockchain provides cryptographic protection. For example, Ekblaw et al.'s MedRec system manages patient data access through smart contracts [4], but the transparency of the blockchain ledger could expose sensitive information due to flaws in the anonymization technology. The aggregated cardiovascular dataset used in Krittanawong et al.'s study could compromise patient identities through re-identification attacks, violating General Data Protection Regulation (GDPR) and Health Insurance Portability and Accountability Act (HIPAA) regulations [5]. Shinde et al.'s mental health analytics framework relies on NLP to parse clinical records, which may retain identifiable details despite anonymization, leading to privacy breaches.

Insufficient model interpretability and clinical acceptance. The "black box" nature of AI models combined with blockchain raises liability concerns. For example, Haji et al.'s gradient boosting decision tree for supply chain anomaly detection lacks transparency, making it difficult for human operators to validate AI decisions. krittanawong et al.'s federated learning model achieves expert-level accuracy in arrhythmia diagnosis, but fails to provide clinicians with an explainable reasoning process, reducing trust in AI recommendations. This opacity is particularly acute in high-risk scenarios such as emergency triage. As a result, clinicians are wary of adopting such systems. 2023 research suggests that 45% of physicians view AI - blockchain tools as a barrier to adoption due to liability issues [9].

A final concern is energy consumption and environmental sustainability. The energy-intensive consensus mechanism of blockchain conflicts with the computational demands of AI. For example, the carbon footprint of training a single AI model on a proof-of-work blockchain network is 10 times that of traditional cloud training [8]. This environmental cost is particularly acute for large-scale applications like public health outbreak prediction systems, which process millions of IoT sensor data points per day.

Future Prospects

To address the technical complexity and scalability issues, lightweight blockchain and edge computing integration can be investigated in the future, i.e., the use of PoS or Delegated Proof of Stake (DPoS) consensus mechanisms combined with edge computing to process medical data in real time and reduce cloud latency. For example, in the pharmaceutical supply chain, verifying transactions and training AI models through edge nodes reduces response time to within 5 seconds [2].

Privacy protection and compliance are increasing. To address the risk of data privacy and anonymization, a fusion of privacy computing technologies combining Homomorphic Encryption (HE) and Secure Multi-Party Computing (MPC) has been adopted to allow AI analysis of encrypted data on the blockchain. For example, the European Union's "Privacy Enhanced Blockchain" project enables compliant sharing of genetic data with a 40% lower error rate through HE technology.

Aiming at the challenges of insufficient interpretability and low clinical acceptance of current AI models, future research should focus on the multi-dimensional path of "technology empowerment + knowledge fusion + human-computer collaboration" to promote the transition of AI from "black-box decision-making" to "transparent reasoning" [10]. Future research needs to focus on the multi-dimensional path of "technology enablement + knowledge integration + human-machine collaboration" to promote the transformation of AI from "black box decision-making" to "transparent reasoning." Specifically, interpretable tools such as LIME and SHAP can be used to transform AI decisions into clinically understandable feature analysis and help doctors verify model logic. In addition, knowledge-driven expert systems can be constructed by combining clinical guidelines and rule engines to generate transparent reasoning chains in the form of "if-then," balancing the advantages of data-driven and knowledge-driven. Finally, interactive

visualization platforms are developed to dynamically display feature importance and support physician parameter tuning to facilitate collaborative human-computer decision-making.

Currently, AI and blockchain technologies are facing serious energy consumption and environmental challenges (e.g., high energy consumption of PoW consensus mechanisms and significant carbon emissions of large-scale AI models), and future research needs to focus on the synergistic development of green blockchain infrastructures and low-energy-consumption AI models. For example, developing lightweight neural networks (e.g., MobileNet) and combining them with model pruning and quantization techniques can reduce training energy consumption by more than 60% while maintaining performance [11]. In addition, it is necessary to integrate the supply of renewable energy with the optimization of whole-life-cycle energy efficiency, balancing technological innovation with environmental responsibility, and providing green solutions for global digital transformation.

CONCLUSION

This paper synthesized a collaborative blockchain-AI framework to address challenges in healthcare, including secure data sharing through joint learning, detection of counterfeit medicines through real-time analytics, and patient-centered management using smart contracts to improve privacy protection and operational efficiency. This paper compiles six applications of blockchain and AI technology in healthcare, namely: pharmaceutical supply chain, cardiovascular medicine, healthcare data management, public health, AI for mental health analytics and privacy protection, and artificial intelligence-driven medical imaging security. The analysis shows that blockchain and AI integration significantly improve the efficiency of anti-counterfeiting in the pharmaceutical supply chain, accelerate the speed of medical data sharing, and improve diagnostic accuracy and patient satisfaction, but it still faces the limitations of high energy consumption and privacy protection technology. In the future, bottlenecks need to be broken through lightweight blockchain architecture, homomorphic cryptography, and interpretable AI tools while exploring synergies between green energy and global policies and promoting the development of international standards for healthcare blockchain.

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